Technische Universität München

Module Catalog

M.Sc. Earth Oriented Space Science and Technology

Civil, Geo and Environmental Engineering

Technische Universität München

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Technische Universität München

Module Catalog: General Information and Notes to the Reader

What is the module catalog?

One of the central components of the Bologna Process consists in the modularization of university curricula, that is, the transition of universities away from earlier seminar/lecture systems to a modular system in which thematically-related courses are bundled together into blocks, or modules.
This module catalog contains descriptions of all modules offered in the course of study.
Serving the goal of transparency in higher education, it provides students, potential students and other internal and external parties with information on the content of individual modules, the goals of academic qualification targeted in each module, as well as their qualitative and quantitative requirements.

Notes to the reader:

Updated Information

An updated module catalog reflecting the current status of module contents and requirements is published every semester. The date on which the module catalog was generated in TUMonline is printed in the footer.

Non-binding Information

Module descriptions serve to increase transparency and improve student orientation with respect to course offerings. They are not legally-binding. Individual modifications of described contents may occur in praxis. Legally-binding information on all questions concerning the study program and examinations can be found in the subject-specific academic and examination regulations (FPSO) of individual programs, as well as in the general academic and examination regulations of TUM (APSO).

Elective modules

Please note that generally not all elective modules offered within the study program are listed in the module catalog.

Index

Modules 1. - 2. Semester

Technische Universität München

Module Description

BGU31006: Signal Processing and Microwave Remote Sensing

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcome is verified by a written exam, which takes 75 minutes. A written exam is required in order to check if students are able to apply the main mathematical methods and algorithms of signal processing as well as the methods of system theory and do the required calculations under time pressure. By doing the calculations they verify that they have understood the concepts of system theory and signal processing and the relation between space/time and frequency domain. The exam also contains theoretical questions related to the methods and applications of synthetic aperture radar (SAR) and by answering those the student verify that they are able to explain the main concepts behind SAR.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Complex calculus, linear algebra, integrals, MATLAB programming skills are helpful.

Content:
Basics and advanced skills in the field of
- application of complex numbers in signal processing
- signals in time, space, and frequency domain (continuous and discrete)
- convolution of signals
- linear time-invariant systems
- random signals, signal reconstruction, and interpolation
- microwave remote sensing and synthetic aperture radar

Intended Learning Outcomes:
After the successful conclusion oft the module, the students are able
- to evaluate the applied mathematical models and algorithms
- to explain advanced theoretical basics of system theory and signal processing
- to analyze the potential of system theory and signal processing by different practice examples
- to evaluate the relation between space/time domain and frequency domain
- to apply methods of signal processing to basic datasets
- to explain basic methods and applications of synthetic aperture radar

Teaching and Learning Methods:
The module consists of one lecture and one lecture with integrated exercises. The contents of the lectures are taught by talks, presentations, and panel painting. Practical examples and discussions encourage the students to devote themselves to topical contents. The understanding of lecture theory is supported by theoretical exercises

and programming exercises.

Media:
- presentations in electronic form
- handout
- exercise sheets
- panel

Reading List:
- Bracewell, RN, The Fourier Transform and its Applications, McGraw Hill, New York, 1965
- Marko H, Methoden der Systemtheorie, Springer, 1982
- Hänsler E, Statistische Signale, Springer, 1997
- Gaskill JD, Linear Systems, Fourier Transforms, and Optics, John Wiley & Sons, 1976

Responsible for Module:
Marco Körner

Courses (Type of course, Weekly hours per semester), Instructor:
Introduction into Microwave and SAR Remote Sensing (lecture, 1 SWS)
Eineder M

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU31007: Estimation Theory and Machine Learning

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam of 60 min duration. A written exam is required to verify that the students are able to reproduce and to understand the basics of probability theory and the key features of different estimation methods, enabling them to select in practice the appropriate method for a certain practical problem. Based on selected case studies and practical problems, it is verified that the students are able to analyze and to solve fundamental estimation problems, that they are able to assess the feasibility of various estimation models, and that they are able to interpret the results within a limited time frame and without additional support material.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Complex calculus, signal processing, linear algebra, integrals, statistcis and probability theory, principles of photogrammetry and remote sensing

Content:
Basics and advanced skills in the field of
- basics of probability theory
- methods for detection, classification, and parameter estimation
- estimation methods in time- and frequency domain
- selection of proper estimation models
- examples for the application of estimation methods in practice
- design and extraction of features and abstract data representations
- feature transformations and further operations in feature space
- non-linear optimization
- unsupervised and supervised learning for regression and classification (generative and discriminative methods)
- neural networks and deep learning

Intended Learning Outcomes:
Upon successful completion of the module, the students are able
- to understand the basics of probability theory
- to analyze the potentials and limitations of different estimation methods
- to solve basic estimation problems and to evaluate therefore the applicability of estimation models
- to understand basic and advanced principles of machine learning
- to apply state-of-the-art machine learning concepts to real-world problems

Teaching and Learning Methods:
The module consists of a lecture and an exercise. The contents of the lecture are taught by talks, presentations, and panel painting. Practical examples and discussions encourage the students to devote themselves to topical contents. The understanding of lecture theory is supported by solving practice related problems. In the exercise (lab), numerical exercises on the topics covered by the lecture are performed using MATLAB and Python; for the most part, the lab is organized as homework with the requirement of preparing midterm reports on methodology and results.

Media:
- presentations in electronic form
- handout
- exercise sheets
- panel

Reading List:
- Papoulis, A., Probability, Random Variables, and Stochastic Processes, McGraw Hill, New York, 1977.
- Sivia, D.S., Data Analysis: A Bayesian Tutorial, Oxford Science, Publications, 1996.
- Hänsler, E, Statistische Signale, 2. Aufl., Springer, Heidelberg, 1997.
- Rodgers, C. D., Inverse methods for atmospheric sounding: Theory and practice, World Science, London, 2000.
- Gonzalez, R., Woods, R., Digital Image Processing, Pearson, 2007.
- Bishop, C., Pattern Recognition and Machine Learning, Springer,2006.
- Murphy, K., Machine Learning: A Probabilistic Perspective, MIT Press, 2012.
- Goodfellow, I., Bengio, Y., Courville, A., Deep Learning, MIT Press, 2016.

Responsible for Module:
Marco Körner

Courses (Type of course, Weekly hours per semester), Instructor:
Estimation Theory (lecture, 3 SWS)
Bamler R, Körner M

Lab Estimation Theory (exercise, 1 SWS)
Körner M [L], Körner M

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU45037: Introduction to Earth System Science

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified with a written exam of 120 min duration, which might also contain short mathematical problems to be solved. In the written exam, the students should verify, by answering theoretical and numerical questions, that they are able to understand the basic components of system Earth and its main geodynamic processes in the Earth interior, at the surface, and the global energy budget. A written exam is required in order to check if students are able to apply the Earth system concepts to practical problems as well as to perform corresponding numerical analyses. By means of numerical tasks and problems, it is verified that students are able to apply the mathematical and physical concepts for the solution of practical problems. By means of selected tasks, the students are able to interpret geophysical, geodetic and geodynamical results and to put them into the scope of geoscientific concepts.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Knowledge of fundamentals in mathematical physics, linear algebra, time series analysis.

Content:
The module consists of one lecture "Introduction to Earth System Science". It is split up into two main topics: part A "Outer System" and part B "Inner System" and is connecting earth's interior and earth's surface up to Earth's orbits.
Part A: Outer System:
- components of the Earth System (atmosphere, ocean, cryosphere, solid Earth),
- electromagnetic radiation and matter,
- solar radiation and the Earth system,
- radiation balance, greenhouse effect,
- spatial and temporal variations, astronomical rhythms (day/night, seasons, Milankovitch cycle),
- atmospheric circulation,
- oceans
- continental hydrology
- cryosphere
- the role of satellites (active and passive sensors)

Part B: Inner System:
- dynamics of the earth interior,
- heat exchange,
- mantle convection,

- analysis of seismic wave propagation,
- potential fields: magnetic field, gravity field;
- measuring solid Earth processes with satellites (GPS, gravimetry, magnetometry, topography)
- interaction of inner and outer part of the earth system

Intended Learning Outcomes:
Upon successful completion of the module, students are able
- to understand the fundamental principles of the complex Earth system, its main geodynamic processes in the interior and on the surface, as well as their coupling mechanisms,
- to understand the global energy budget,
- to understand the role of satellite observations for the monitoring of geodynamic processes in the Earth system,
- to work with observations, data and models of selected components of the Earth system,
- to apply the mathematical and physical concepts concerning selected components of the Earth system,
- to analyze the results of these data and models,
- to understand these scientific contributions as integral component of geodetic Earth system research,
- to communicate on a scientific level with experts of different geoscientific disciplines.

Teaching and Learning Methods:
The contents of the lectures are communicated by oral presentations or calculations at the blackboard, including interactive discussions with the students.

Media:
- Blackboard
- Lecture notes
- Presentations in electronic form

Reading List:
- Kandel, Robert S. (1980): Earth and Cosmos. A Book Relating the Environment of Man on Earth to the Environment of Earth in the Cosmos. Burlington: Elsevier Scienc
- Grotzinger, John; Jordan, Thomas H.; Press, Frank; Siever, Raymond (2007): Understanding earth. 5. ed. New York: Freeman
- Lowrie, William (2006): Fundamentals of geophysics. 7. print. Cambridge: Cambridge Univ. Press

Responsible for Module:
Roland Pail

Courses (Type of course, Weekly hours per semester), Instructor:
Introduction to Earth System Science (lecture, 4 SWS)
Pail R [L], Pail R, Schuberth B

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU45040: Applied Earth observation

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcome is verified with a parcours examination. The parcours examination is composed by a written exam of 60 min. duration and a seminar presentation of 30 min.by the project teams, where the results of the practical work are shown. The elements of the parcours examination takes places on the same day. In the written exam the theoretical fundament of remote sensing applications shall be are assessed, while in the seminar presentation the practical implementation of an Earth observation application using satellite data shall be are evaluated. For the written exam no learning aids are used. The final module grade is computed by equal weighting the grades of both elements of the parcours examination.

Repeat Examination:
End of Semester

(Recommended) Prerequisites:
Recommended: Knowledge on fundamentals of photogrammetry and remote sensing, as it is provided in the module "Introduction to Photogrammetry, Remote Sensing and Image Processing" (BGU48036), and on fundamentals of computer science, as it is provided in the module "Applied Computer Science" (BGU61030)

Content:
The module consists of the lecture Applied Remote Sensing and the seminar called Seminar Earth Observation Satellite Mission Data Analysis. In the lecture remote sensing sensors, missions, data analyses techniques and applications are introduced, while in the seminar practical work with remote sensing data in form of a project is performed. The topics to be addressed by this module in particular are:
Lecture: Applied Remote Sensing:
- Earth observation systems and sensors
- Data processing and information extraction methods
- Remote sensing applications for environmental monitoring
- Integration into Geo Information Systems (GIS)
- Applications of remote sensing in natural disasters management and humanitarian aid
- Emergency response and early warning systems
- European Earth Observation Program - Copernicus
- Infrastructure for Spatial Information in Europe

Seminar: Earth Observation Satellite Mission Data Analysis:
- Identify an idea for an Earth observation application based on satellite data.
- Preparation of a project proposal
- Definition of system requirements
- Development of a system architecture
- Software development and implementation

- Data analysis (real data)
- Documentation of project
- Presentation of the project and its result and discussion

Intended Learning Outcomes:
After the successful completion of the module, the students are able:
- to know about the most relevant Earth observation missions;
- to analyze their appropriate fields of applications according to the sensor specifications;
- to understand the application of remote sensing and GIS techniques for environmental mapping and monitoring;
- to evaluate the possibilities and limitations of using earth observation for disaster management and emergency mapping;
- to know the relevant international mechanisms, which are put in place by space agencies world-wide
- to provide an overview on the main objectives of the European programs COPERNICUS and INSPIRE.
- to define and develop an idea for an Earth observation application
- to work like a project for a space agency including all required documentation and reviews.
- to present the idea and the project results towards a broader audience and to defend the comtent in a discussion.
- to know the process of developing software and how to use Earth Observation Data;
- to deal with a large amount of satellite data;
- to work in teams and to prepare scientific results.

Teaching and Learning Methods:
The module consists of a lecture and a seminar. The lecture is given with slides and lecture notes with small examples and interactive discussion introducing Earth observation missions and sensors specifically regarding application. In the frame of the seminar the supervisor introduces the task and the procedure about how to run projects for space agencies. The students propose, prepare and develop under guidance of a supervisor an Earth observation application solution as a group work. They present their results in intermediate oral presentations to students and supervisors and discuss their approaches.

Media:
Lecture: Teaching using power point slides and black board. The lectures also contain practical examples and discussions. Seminar: Introduction by power point slides; Oral discussion and written feedback to students (e.g. by e-mail).

Reading List:
Lillesand, Kiefer, Chipman (2015): Remote Sensing and Image Interpretation, 7th Edition, J. Wiley, ISBN 978-1-118-91947-7; Richards (2009): Remote Sensing with Imaging Radar, Springer, ISBN 978-3-642-02019-3

Responsible for Module:
Roland Pail

Courses (Type of course, Weekly hours per semester), Instructor:
FEA - Appplied Remote Sensing (lecture, 2 SWS)
Hoegner L [L], Strunz G

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU45041: Scientific Working in Earth Oriented Space Science and Technology

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	75	75

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The learning outcomes of this module are examined within a research paper. The research paper consists of a written assignment and a presentation for the purpose of assessing the student¿s communication competency in presenting scientific content to an audience. The written part and the presentation are equally weighted.
The research paper will cover a theme from scientific data processing/data analysis by means of examples from the topic of radiative transfer. It will be based on own practical work of the students and will cover 20 to 30 pages. Complementing the written part, the students choose, work out and present a topic that is thematically related to the research paper. The presentations, with a duration of 20 min, are spread over the lecture period, and shall foster the competence to present a scientific topic to a larger audience. During the preparation of their presentation, students are guided by a supervisor who provides information material (in the form of scientific articles, books, slides, etc.) and gives feedback.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basic mathematical and physical knowledge is expected.
In addition, the successful participation in the following modules from the first semester ESPACE is recommended:
- Introduction to Satellite Navigation and Orbit Mechanics
  (BGU61029)
- Introduction to Earth system science (BGU45037)

Content:
The theoretical foundations of the research paper are presented in the lecture "Mie Theory and Radiative Transfer". They cover:
1. Mathematical background: scalar and vector fields; line and surface integrals; nabla operator; differential relationships for vector fields; irrotational and solenoidal fields; Gauss and Stokes theorems.
2. Electrostatic: Coulomb's law; the electrostatic field; divergence and curl of the electrostatic field. Magnetostatic: Ampere's law; the magnetostatic field; divergence and curl of the magnetostatic field.
3. Poisson and Laplace equations. Overview of the finite element method.
4. Electrodynamics: equation of continuity for the electric charge; Maxwell's displacement current; electromotive force; Faraday's law of induction; Maxwell's microscopic and macroscopic equations.
5. Electromagnetic waves: wave equation in time and frequency domains; plane and spherical waves; observables and averages.
6. Electromagnetic scattering theory: Stratton-Chu representation theorem; far-field pattern and amplitude matrix; phase and extinction matrices; extinction, scattering and absorption cross-sections; optical theorem; reciprocity principle.

7. Mie theory: vector wave equation; vector spherical wave functions, solution of the transmission boundary-value problem; computation of the far-field pattern, optical cross-sections and phase function in the framework of the Mie theory.
8. Derivation of the radiative transfer equation starting from Maxwell's equations.
9. Radiance rotation effect. Isotropization of the transmission function

The last four lectures of Mie Theory and Radiative Transfer are devoted to practical aspects and consist in the elaboration project work. Computations will be performed by using a dedicated computer code for radiative transfer calculation. Great importance is attached to the synthesis abilities of the theoretical part and the interpretation of the numerical results. The strategy and results of the computations are presented by the students in their research papers.

Seminar "ESPACE Seminar":
Each student prepares and gives an oral presentation of 20 minutes length on an up-to-date scientific topic from Earth Oriented Space Science and Technology. The presentations are spread over the lecture period. During the preparation of their presentation the students are guided by a supervisor who provides relevant information material (in the form of scientific articles, books, slides, etc.) and gives feedback during the preparation. The presentations are followed by a discussion of the topic in which all participants are encouraged to participate.

Intended Learning Outcomes:
After the successful completion of the module, the students have gained the scientific soft-skill competencies to:
- work independently on solving complex scholarly problems, using the scientific methods of Earth Oriented Space Science and Technology.
- demonstrate their ability to solve scientific problems by means of examples from the topic of electromagnetic scattering/radiative transfer, and to prepare and present the approaches and outcomes in a scientific paper
- to apply the methods for literature research for a selected topic associated with ESPACE;
- to analyze the collected material;
- to develop from it a logically structured presentation;
- to present it to an audience;
- to assess questions from the audience in a public discussion;
- to publicly defend the contents of the scientific presentation.

Teaching and Learning Methods:
Lecture: The contents of the lectures are communicated by oral presentations or calculations at the blackboard, including interactive discussions with the students.
Seminar: The participants prepare under guidance of a supervisor a selected topic from the scientific literature. They present their results in an oral presentation including a discussion. The supervisor assists in scientific questions on the presentation topic. After the presentation, the presenters immediately receive feedback from the supervisor.

Media:
- board content
- presentations in electronic form or as handouts
- Lecture notes
- Topic-related publiations and book chapters

Reading List:
- Albuquerque, Ulysses Paulino de (2015): Speaking in public about science. A quick guide for the preparation of good lectures, seminars, and scientific presentations. Cham: Springer
- Bohren, Craig F. (.; Huffman, Donald R. (2013): Absorption and scattering of light by small particles. New York: Wiley
- van de Hulst, Hendrik C. (ca. 2009): Light scattering by small particles. [Nachdr.]. New York, NY: Dover (Dover classics of science and mathematics)"

Responsible for Module:
Roland Pail

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU45042: Ground and Space Segment Control

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam (duration: 120 min). In the written exam, by means of answering a number of overarching questions under time pressure, the students demonstrate that they are able to understand, analyze and develop concepts of ground segment design, that they are able to reproduce the principles of spacecraft dynamics and of robotic systems dynamics in orbit and the basic principles of orbit control operations. The written form of the exam is required to verify, if the students have reached the expected level of competence, so that they are able to apply these principles for ground validation, that they are able to understand the future potential of robots in orbit, and that they are able use the competencies acquired to link present-day strategies for the design of future systems.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Recommended: Basics of astronautics, mathematics (vector and matrix algebra) and mechanics.
Signal Processing and Microwave Remote Sensing (BGU31006)
Introduction to Satellite Navigation and Orbit Mechanics (BGU61029)

Content:
The module consists of two lectures "On-Orbit Dynamics and Robotics" and "Earth Observation Mission Engineering and Ground Infrastructure" that are addressing aspects of ground and space segment control in a complemenary way:
Lecture: On-Orbit Dynamics and Robotics:
Kinematics and dynamics of mechanical systems, including a material point, a rigid body and a multibody system.
Spacecraft attitude dynamics and control, including also actuators and sensors.
Robot dynamics and control, including open-loop, closed-loop and tele-presence control methods (basics), actuators and sensors, experimental facilities.

Lecture: Earth Observation Mission Engineering and Ground Infrastructure:
Part 1: Mission Engineering: mission concepts, requirements and performance analysis, engineering standards and legal aspects
Part 2: Transfer of remote sensing data to ground and its technical and operational impact on mission and ground infrastructure
Part 3: Payload data handling, processing, data management, archiving and user interfaces. Thematic processing from raw data towards geo-information products
Part 4: Upcoming technologies and new mission concepts

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able - to understand the principles of orbital spacecraft and robotic systems dynamics
- to apply these principles to practical problems and
- to evaluate and asses the results
- to understand the control principles applied for spacecraft attitude and robotic operations,
- to apply them in practical application,
- to apply the techniques for verification of the behaviour of these systems on ground,
- to gain insight into the current and possible future uses of robots in orbit, and
- to develop potential future applications.
- to understand the elements of an Earth observation ground segment and its interaction with the satellite and its sensors,
- to analyze existing ground segments and to develop concepts for new and user specific ground segments based on engineering methods and standards.

Teaching and Learning Methods:
The module contains two lectures. The contents of the lectures are communicated by oral presentations or calculations at the blackboard, including interactive discussions with the students. Within these discussion practical examples help deeping the students' understanding of the content.

Media:
- Power-point presentations
- electronic handouts
- blackboard
- lecture notes

Reading List:
- Walter, Ulrich (2008): Astronautics. Weinheim: WILEY-VCH (Physics textbook)
- Sidi, Marcel J. (2014): Spacecraft dynamics and control. A practical engineering approach. [Elektronische Ressource]. Cambridge: Cambridge Univ. Press (Cambridge aerospace series, 7). Online verfügbar unter http://dx.doi.org/10.1017/CBO9780511815652
- Siciliano, Bruno; Sciavicco, Lorenzo; Villani, Luigi; Oriolo, Giuseppe (Hg.) (2009): Robotics. Modelling, planning and control. London: Springer (Advanced Textbooks in Control and Signal Processing)
- Ley, Wilfried; Wittmann, Klaus; Hallmann, Willi (2009): Handbook of space technology. Chichester: Wiley (Aerospace Series, v.22)

Responsible for Module:
Roland Pail

Courses (Type of course, Weekly hours per semester), Instructor:
On-Orbit Dynamics and Robotics (lecture, 2 SWS)
Walter U [L], Harder J, Kiesbye J

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU48036: Introduction to Photogrammetry, Remote Sensing and Digital Image Processing

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	75	75

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The written exam takes 120 minutes. Answering questions, it is checked whether the studens are able to analyze and group different applications in Photogrammetry and Remote Sensing, whether they understand the concepts of photogrammetric image analysis, whether they remember the foundations of electromagnetic radiaten, whether the know the concepts of classification in Remote Sensing data and whether they can evaluate the quality of such classifications as well as the the quality of recorded images and the resulting products and 3d reconstructions. Using sketches, it is checked, whether the students understand the principles of single image recordings, wehter they understand the stereoscopic measurement and classifications methods. It is cheched, whether the students are able to process digital images and generate fundamental image statistics, calculate correlations and perform segmentation techniques. It is checked, whether the students understand the basic concepts of image convolution are whether they can evaluate different filter masks and their results. The exam contains questions on basic principles of binary image processing vectorization, and feature extraction. Questions contain drawing and explaining figures, answering questions on methods and solutions, calculations or comparisons of methods and their applicability. Additionally, multiple-choice-questions are including with statements that have to be evaluated as true or false. This part does not contain more than 20% of the total points. No aids or materials are allowed. Additionally voluntary course work in the form of 4 - 6 exercises including work reports for selected topics is recommended as a midterm assignment. The midterm assignment is passed if as a minimum of 75 % of the taks have been answered successfully. In this case, the grading can be improved by 0,3 (provided that the original grading is lower or equal 4,0). These exercises contain programming and documenting solutions for practical problems. As programming and documentation quality cannot be checked in an examination, this part is done as study work.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
none

Content:
Introduction: Definition Photogrammetry and Remote Sensing
 - Characteristics of Photogrammetry, applications and development
 - Characteristics of Remote Sensing, applications and development
 - Introduction the Photogrammetry: stereoscopic vision and measurement, photogrammetric image analysis, digital stereo processing
 - Introduction to Remote Sensing: Radiometric basics, multispectral classification
 - Optical basics: models and geometric quality of optical projections, description of image quality
 - Introduction to Image Processing
 - Features of digital images

- Image transformation, convolution, edge detection
- Segmentation
- Binary image processing
- Vectorization and geometric primitives
- Feature extraction

Intended Learning Outcomes:
Participants are capable to:
- Analyse applications from different points of view
- Planning aerial image campaigns
- Understand the principles of stereoscopic records
- Evaluate stereo records and produce anaglyphe images
- Understand concepts of photogrammetric image analysis
- Remember the physical basics of the electromagnetic spectrum and radiometric basics
- Understand the principles of supervised and unsupervised classification
- Apply different classifiers and evaluate the classification results
- Evaluate the influence of different factors on the image quality
- evaluate characteristic features of images,
- Apply different image transformations,
- analyze images by segmenetation and feature extraction
- analyse binary images and to assess results
- compare image processing operations

Teaching and Learning Methods:
The module consists of two lectures and an exercise. The content of the lectures is presented using slides, lecture notes, presentations and board. Apllications and discussions activate the students to understand the contents. Important parts of the lectures are deepened in the exercise where students solve praticial problems in Image Processing by mathematical calculations as well as small programming tasks. Additionally, exercises on application in Photogrammetry and Remote Sensing are offered to transfer the theoretical knowledge to practical applications.

Media:
- presentations in electronic form
- Slides, lecture notes, handout
- exercise sheets
- panel

Reading List:
- Albertz J, Wiggenhagen M (2008) Taschenbuch zur Photogrammetrie und Fernerkundung. Heidelberg: Wichmann
- Kraus K (2003) Photogrammetrie Band 1: Geometrische Informationen aus Photographien und Laserscanner-aufnahmen. Berlin: deGruyter
- Albertz J (2001) Grundlagen der Interpretation von Luft- und Satellitenbildern. Darmstadt: Wissenschaftliche Buchgesellschaft
- Haralick, Shapiro (1992): Computer and Robot Vision (Vol. 1). Addison-Wesley, New York.
- Castleman (1995): Digital Image Processing. Prentice Hall, Englewood Cliff, New Jersey.

Responsible for Module:
Ludwig Hoegner

Courses (Type of course, Weekly hours per semester), Instructor:
Image Processing (lecture, 2 SWS)
Hoegner L

Photogrammetry and Remote Sensing (Espace) (lecture, 2 SWS)
Hoegner L [L], Stilla U

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU57018: Numerical Modeling

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified within a written exam of 120 min duration. In the written exam the students demonstrate that they are able to apply the mathematical methods presented in Numerical Modelling and to perform the required calculations under time pressure. Also they have to demonstrate that they are able to analyze the accuracy of solutions and error budgets in a limited time. A written exam is required in order to check if the students are able to apply the presented mathematical procedures to practical problems of geophysical and satellite data analysis as well as to perform numerical analyses. In addition, voluntary course work in form of ca. 3-5 exercises for selected topics is recommended as a midterm assignment. The midterm assignment is passed if at least 60% of the tasks are answered successfully. In this case, the grading can be improved by 0.3 (provided that the original grading is better or equal to 4.0). The work is usually started during supervised labs and finalized in groups as homework. Hereby the students demonstrate that they are able to apply the mathematical methods and solve specific mathematical problems in a programming environment such as Matlab. In addition to the application and implementation, the students demonstrate that they can interpret the results and verify their plausibility.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basic knowledge in
- Linear algebra, calculus, physics
- Statistics
- Signal Processing
- MATLAB

Content:
- Series expansions
- Finite difference methods
- Solutions of 1-D differential equations
- Solutions of Initial value problems
- Solution of partial differential equations
- Metods of data representation

Intended Learning Outcomes:
Upon successful completion of the module, students are able
- to solve mathematical problems such as partial differential equations (PDEs),
- to apply the methods to given problems and to simulated data and real measurements;
- to understand, how physical/mathematical problems can be solved appropriately by numerical methods;
- to apply MATLAB routines for solving physical/mathematical problems;

- to analyse the accuracy of solutions and error budgets

Teaching and Learning Methods:
The module consists of a lecture and an exercise. The contents of the lectures are communicated by oral presentations or calculations at the whiteboard, including interactive discussions with the students. In the labs, numerical exercises on the topics covered by the lecture are performed using MATLAB;

Media:
- Presentation slides
- Lecture notes
- Selected text books and scientific publications

Reading List:
Burden, Richard L.; Faires, J. Douglas (op. 2011): Numerical analysis. 9th ed., International ed. [Boston, MA]: Brooks/Cole, Cengage Learning.
Christensen, Ole (2005): Approximation Theory. From Taylor Polynomials to Wavelets. Boston, MA: Birkhäuser Boston (Applied and Numerical Harmonic Analysis).

Responsible for Module:
Prof. Florian Seitz

Courses (Type of course, Weekly hours per semester), Instructor:
Labs in Numerical Modeling (exercise, 1 SWS)
Schmidt M

Numerical Modeling (lecture, 3 SWS)
Schmidt M

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU61029: Introduction to Satellite Navigation and Orbit Mechanics

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam of 120 min duration. The form of a written exam is required in order to verify that the students are able to reproduce and to understand the fundamentals of satellite navigation and theoretical and methodological basics of orbit dynamics. By means of dedicated analytical and numerical questions and tasks, it is verified that students are able to apply the mathematical and physical concepts of satellite navigation and orbit dynamics for the solution of practical problems, and that they are able to interpret and assess the results. In addition, the competence to solve daily-work practical and numerical problems is supported by voluntary course work in the form of 5-6 exercise reports for selected topics of satellite navigation and orbit dynamics, which is recommended as a midterm assignment. The midterm assignment is passed if as a minimum 60% of the tasks have been answered successfully. In this case, the grading can be improved by 0,3 (provided that the original grading is lower or equal 4,0). These numerical problems should be implemented in a programming environment such as Matlab. Hence it is ensured that the students have gained the programming skills, that they are able to apply them for the implementation of the main applications of satellite navigation and orbit mechanics, and that they are able to assess and interpret the results. Time to work on the exercises is foreseen during the contact hours.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
None

Content:
The module covers basics of satellite navigation as well as orbit mechanics required to understand satellite orbits. It consists of a lecture and a lecture with integrated exercises. Optional tutor hours support the students in deepening their understanding.
Introduction to Satellite Navigation:
- Principles of satellite navigation
- Space segment and ground segment
- Code and phase observations
- Observation equations
- Differences and linear combinations
- Troposphere and ionosphere
- Ambiguity resolution
- Analysis strategies
Lecture Orbit Mechanics:
- Reference systems in space and time

- Two-body problem and Keplerian motion
- Orbit representations, Keplerian elements, groundtracks, repeat orbits
- Orbit perturbations, osculating elements, Gaussian perturbation equations, types of perturbations
- Gravitational perturbations by third bodies and Earth's gravity field
- Orbits of navigation satellites
- Special orbit types: geostationary, sun-synchronous, critical inclination, frozen orbits

Labs with Matlab:
- Representation of orbits in different frames
- Ephemeris calculation
- Transformation between inertial, earth-fixed and topocentric reference frame

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand the concept and algorithms of satellite navigation and precise positioning,
- to apply them to practical problems of satellite navigation and precise positioning,
- to remember the observation equations,
- to assess the impact of error sources on signal propagation,
- to compute linear combinations and evaluate tracking data quality.
- to understand the basics of satellite motion and Celestial Mechanics,
- to apply the basic concepts and methods for orbit computation and for the conversion between reference frames,
- to understand the concept of orbit perturbations,
- to assess the magnitude of different perturbations on satellite orbits at different heights,
- to analyze and to assess the properties of special orbits and to understand their use for specific applications,
- to understand the concept of ground track repeatability and its relevance in practise

Teaching and Learning Methods:
The module consists of a lecture and a lecture with integrated exercises. The lecture is given using slides and calculations are derived at the blackboard in interaction with the students.
Numerical exercises on the topics covered by the lecture are performed using MATLAB and a planetarium simulator in the scope of the voluntary tasks that are interleaved within themselves. A tutor is available on demand to support the students in performing their assignments and in the use of MATLAB. The tutor also provides feedback on the submitted reports.

Media:
Presentations, blackboard, lecture notes in electronical form, handouts for exercises

Reading List:
- Lecture notes
- Montenbruck and Gill (2000): Satellite Orbits, Springer
- Beutler (2005): Methods of Celestial Mechanics, Springer
- Hofmann-Wellenhof, B., Lichtenegger, H., Wasle, E. (2008): GNSS - Global Navigation Satellite Systems, ISBN: 978-3-211-73012-6, Springer Verlag
- Misra and Enge (2004): Global Positioning System: Signals, Measurements, and Performance, Ganga-Jamuna Press.
- Teunissen and Kleusberg (1998): GPS for Geodesy, Springer

Responsible for Module:
Prof. Dr. phil. nat. Urs Hugentobler

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU61030: Applied Computer Science

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam of 90 min duration. A written exam is required in order to verify that the students are able to know the theoretical and practical basics in computer science, and that they are able to use the respective terminology. Based on dedicated practical questions, it is verified that the students are able to analyze practical problems and that they are able to find appropriate solutions.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basic knowledge in programming or computer science is recommended

Content:
'The module focuses on technical computing concepts for scientific projects. It transfers knowledge, terminology, and theories of applied computer science for interdisciplinary IT topics to work in interdisciplinary teams. The students learn basics in software engineering and design, communication and data processing for research and technology developments. Dealing with microcontrollers for Internet of the Things and distributed systems require knowledge of binary logic, state machines, language theory, binary and ASCII- data formats, numerical aspects, and basics in internet security in combination with practical programming tasks. The goal of this module is to bring the students coming from a range of different Bachelor studies to the same level of knowledge concerning software engineering skills.

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able to
- to understand the theoretical backgrounds of different computer science disciplines in combination with scientific tasks on the example of the Geodetic Observatory Wettzell
- organize scientific software projects,
- practice software engineering,
- understand software development processes,
- to apply and create state machines, e.g. for lexical processing tasks to read formatted files and other control problems,
- to process binary data (e.g. with Matlab-program).
- to process specific file formats relevant for scientific projects
- to understand the challanges of modern intelligent, distributed (mobile) systems of the Internet of the Things (Industry 4.0)
- know basics of internet security
- work as mediator between IT engineers and other disciplines in teams

Teaching and Learning Methods:
The module consists of a lecture and an exercise. The contents of the lectures are communicated by oral presentations and drawings on the blackboard, including interactive discussions with the students. Important parts of the lectures are deepened in the exercises where students get feedback on their solution of praticial problems which cover mathematical calculations as well as programming tasks.

Media:
'The theory part consists of Powerpoint presentations, which are also provided to the students. The slides are extended with white board notes and exercise sheets with solutions for the private studies. The practical part offers code snippets and examples.

Reading List:
Lecture Notes,
Neidhardt A.: Applied Computer Science for GGOS Observatories. Communication, Coordination and Automation of Future Geodetic Infrastructures. Springer Textbooks in Earth Sciences, Geography and Environment 2017

Responsible for Module:
Prof. Dr. phil. nat. Urs Hugentobler
Dr. rer. nat. habil. Alexander Neidhardt

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

BGU61033: Satellite Navigation and Advanced Orbit Mechanics

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	75	75

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam at the end of the semester of 120 min duration. In this written exam the students demonstrate that they are able to understand the concepts and algorithms used for differential satellite navigation and that they are familiar with advanced concepts used in orbit mechanics as outlined in the intended learning outcomes. The students are allowed to use 8 pages of hand-written notes and a programmable pocket calculator. The competence to solve daily-work practical and numerical problems is supported by voluntary course work in the form of 3-5 exercise reports for selected topics of differential navigation and in orbit mechanics. These numerical problems are implemented in a programming environment such as Matlab ensuring that the students have gained the programming skills required to solve specific problems in satellite navigation and orbit theory. Time to work on the exercises is foreseen during the contact hours. This midterm assignment is passed if as a minimum 60% of the tasks have been answered successfully. In this case, the grading can be improved by 0,3 (provided that the original grading is better or equal 4,0).

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Recommended: Mathematics, fundamentals of probability calculations and statistics as well as successful participation in the module Introduction to Satellite Navigation and Orbit Mechanics (BGU61029)

Content:
The module consists of one lecture with integrated exercises (Advanced Orbit Mechanics) and one lecture (Differential Navigation). The module is accompagnied by exercises. Optional tutor hours support the students in deepening their understanding.
The two lectures complement each other in satellite differential navigation and satellite orbits covering the following aspects:
Differential Navigation:
- Differential GPS and GNSS
- Carrier smoothing
- Augmentation systems for aeronautical and other critical navigation tasks
- Linear combinations of measurements
- Carrier phase ambiguity resolution
Advanced Orbit Mechanics:
- Modelling of non-gravitational accelerations
- Orbit determination
- Selected problems: Lagrange points, swing-by
- Analytical orbit theory: Hill-theory

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able:
- to apply processing strategies to analyze GNSS data for precise positioning applications,
- to understand the principles and concepts of differential navigation and augmentation systems,
- to apply phase ambiguity resolution strategies,
- to understand the models used for representing non.gravitational accelerations
- to understand the concepts of orbit determination, analytical orbit theories and the origin of Lagrange points,
- to apply these concepts to practical problems and to analyze and assess the results.

Teaching and Learning Methods:
The module consists of a lecture and a lecture with integrated exercises. The contents of the lectures are communicated by oral presentations or calculations at the whiteboard, including interactive discussions with the students. In the integrated exercises the students work on numerical exercises accompanying the lectures using MATLAB. A tutor is available on demand to support the students in performing their assignments and in the use of MATLAB. The tutor also provides feedback on the submitted reports.

Media:
Presentations, lecture notes in electronical form, exercises

Reading List:
- Montenbruck and Gill (2000): Satellite Orbits, Springer
- Beutler (2005): Methods of Celestial Mechanics, Springer
- Misra and Enge (2004): Global Positioning System: Signals, Measurements, and Performance, Ganga-Jamuna Press.
- Kaplan and Hegarty (1996): Understanding GPS: Principles and Applications, Artech House.
- Parkinson and Spilker Jr. (1996): Global Positioning System: Theory and Applications Vol. I/II, American Institute of Aeronautics and Astronautics.
- Teunissen and Kleusberg (1998): GPS for Geodesy, Springer

Responsible for Module:
Prof. Dr. phil. nat. Urs Hugentobler
Prof. Dr. Christoph Günther
Dr.-Ing. Patrick Henkel

Courses (Type of course, Weekly hours per semester), Instructor:
Differential Navigation (lecture with integrated exercises, 3 SWS)
Günther C [L], Günther C, Henkel P

For further information in this module, please click
campus.tum.de or here.

Module Description

MW2412: Spacecraft Technology 1 (ESPACE) [SCT 1 (ESPACE)]

Spacecraft Technology 1 (ESPACE)
Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The module Spacecraft Technology 1 coveres the theory and physics of rocketry and astronautics. The evaluating and analytical command of this expertise cluster is a fundamental prerequisite for the professional qualification of an academically educated rocket engineer. To proof the learning achievement of this study cluster, the students have to pass a written exam pressed for time. The exam comprises typically 20 tasks, which are short questions as well as calculation problems with a partitioning of about 50% to 50%. To work on the exam, the students are provided with a formulary; besides a non-programmable calculator, no further auxiliary material is allowed.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
none

Content:
The module provides knowledge of the fundamentals of Rocketry: Rocket Equation; Rocket Staging; Rocket Propulsion (chemical and electrical); Launcher Systems; Space Environment; Rocket Ascent; Astrodynamics; Trajectories; Orbit Transfers

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able to apply the basic physics of rocketry and propulsion to carry out a first order desing of a launcher system with respect to the design budgets of mass, power and volume. The students are able to analyse the complexity and the limitations of launching space craft systems and payloads into orbit. Furthermore, the students are able to apply the basic theory of astronautics, especially that of orbital trajectories and transfer maneuvers, with respect to the space craft's propulsion efficiency and the mission time. In general, the students are able to evaluate typical baseline launcher concepts and mission concepts with respect to the typical trade-offs in rocketry, namely mass and power.

Teaching and Learning Methods:
The module consists of a lecture and an ecercise. In the lecture, the topics are taught with the help of presentations and black board sketches. The accompanying exercises repeat and engross the crucial topics. With the help of rough calculations and rule of thumb methods, the studens lern how to do first order system evaluations.

Media:
lecture, presentation, powerpoint assistance, hand-outs, black board

Reading List:
U.Walter, Astronautics - The Physics of Space Flight, Springer Nature Switzerland AG, ISBN 978-3-319-74372-1;
Further literature survey is given in the hand-out

Responsible for Module:
Walter, Ulrich; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Spacecraft Technology 1 - Tutorial (exercise, 1 SWS)
Rott M

Spacecraft Technology 1 (ESPACE) (lecture, 3 SWS)
Rott M

For further information in this module, please click
campus.tum.de or here.

Modules 3. Semester

Specialization Subjects

Specialization Subject 1: Earth System Science

Module Description

BGU45038: Atmosphere and Ocean

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by an written exam of 90 min duration. In this exam, it is verified that the students are able to understand the individual concepts of describing the physical behavior of atmosphere and ocean, the corresponding satellite techniques to observe static and dynamic properties of these two sub-systems of the Earth system, to build interrelations among these concepts and to understand their contribution to the overarching concept of the Earth system. By means of dedicated questions, it is verified that the students are able to interpret results of observation technologies and that they are able to build connections to physical modelling.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Fundamentals in mathematics, experimental physics; mathematical physics, linear algebra, time series analysis
Introduction to Earth System Science (BGU45037)
Numerical Modeling (BGU57018)
Signal Processing and Microwave Remote Sensing (BGU31006)
Applied Earth Observation (BGU45040)

Content:
The module consists of two lectures "Atmospheric Physics and Remote Sensing" and "Oceanography and Satellite Altimetry" that are addressing aspects of the important and tighly coupled Earth system components atmosphere and ocean in a complemenary and integrative manner:
Atmospheric Physics and Remote Sensing:
Introduction to atmospheric physics with an emphasis on remote sensing of atmospheric components and processes from space:
- atmospheric layers, circulation and Greenhouse Effect
- atmospheric composition
- Water Vapor and Carbon Dioxide
- aerosols, clouds, and Earth's radiation budget
- atmospheric dynamics
- passive Remote Sensing
- Lidar Remote Sensing of aerosols
- wind and water vapor Lidars
- meteorology and weather forecasts
- global climate change
- new observational needs

Oceanography and Satellite Altimetry:

- Equation of motion,
- geostrophic currents,
- hydrostatic balance,
- temperature, salinity, and density,
- ocean tides, tidal analysis,
- radar altiemtry: signal theory and estimation process
- radar altimetry: atmosperhic and geophysical corrections to estimate sea level
- altimeter mission overview,
- description of altimetry data products
- repeat pass and crossover analysis,
- mean sea surface, geoid, dynamic ocean topography, sea level variability, sea level rise

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand the basic principles of atmosphere, weather, and climate and the methods for determining atmospheric composition and dynamics from space,
- to apply these principles and methods for practical problems,
- to apply the most basic principles of physical oceanography and recognize satellite altimetry as an operational remote sensing technique with important applications in geodesy, oceanography and other geosciences,
- to understand the concept of satellite altimeter missions,
- to apply altimetric observation techniques and the necessary measurement correction,
- to know about data and product availability and data access,
- to understand important analysis methods in satellite altimetry, and
- to apply them to practical problems,
- to understand the geophysical application of satellite altimetry and,
- to develop overarching concepts for monitoring several components of the Earth system

Teaching and Learning Methods:
The content of the module is tought in two lectures. Both are condicted in interaction with the students whereby the learning success is continuously monitored through questions to the students. Mathematical derivations and calculations are shown at the black board.

Media:
- presentations in electronic form
- blackboard
- selected text books and scientific publications

Reading List:
- U. Schumann, Atmospheric Physics, Research Topics in Aerospace, Springer-Verlag Berlin Heidelberg, 2012
- F.W. Taylor, Elementary Climate Physics, Oxford University Press, 2005.
Further reading:
- J.M. Wallace and P.V. Hobbs, Atmospheric Science: An Introductory Survey, Academic Press, 2nd edition, 2006.
- W. Roedel, Physik unserer Umwelt: Die Atmosphaere, Springer, 3. Auflage, 2000.
- L. Bergmann und C. Schaefer, Lehrbuch der Experimentalphysik Band 7: Erde und Planeten, de Gruyter, 2. Auflage, 2001.
- Stewart, R.: Introduction to Physical Oceanography (OpenSource Book)
- Fu, L.L. and A. Cazenave (Eds.) Satellite Altimetry. International Geophysics Series, Vol. 69, San Diego, CA, 2000

Responsible for Module:
Roland Pail

Courses (Type of course, Weekly hours per semester), Instructor:
Atmospheric Physics and Remote Sensing (lecture, 2 SWS)
Kiemle C

Satellite Altimetry and Physical Oceanography (lecture, 2 SWS)
Seitz F [L], Passaro M

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

BGU45039: Earth Observation Satellites

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	75	75

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam of 90 min duration. In the exam it is verified that the students are able to remember and to understand the main concepts of potential field theory and the observation techniques of the Earth s gravity and magnetic field from space. The students verify that they are able to build interrelations among these concepts, that they are able to apply methods for processing of satellite gravity and magnetic field data and to link them to global potential field modelling. By means of dedicated questions, it is verified that the students are able to interpret results of gravity and magnetic field observation technologies and that they are able to build connections to system Earth processes.

In addition voluntary course work, which is composed of 3-5 exercise reports for selected topics of Earth Observation satellite data analysis, as well as the presentation on a scientific subject related to a topic of the guest lectures, is recommended as a midterm assignment. The midterm assignment is passed if as a minimum 60% of the tasks have been completed successfully. In this case, the grading can be improved by 0,3 (provided that the original grading is lower or equal 4,0). The work is usually started during supervised labs and finalized in groups as homework. Hereby the students demonstrate that they are able to apply mathematical methods and solve problems of Earth Observation data analysis in a programming environment such as Matlab. In addition to the application and implementation, the students demonstrate that that they can interpret the results and verify their plausibility. With the presentation of 15-20 min duration, it is verified that the students are able to prepare and to present a scientific topic to a larger audience.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Recommended:
- Introduction to Earth System Science (BGU45037)
- Introduction to Satellite Navigation and Orbit Mechanics (BGU61029)
- Signal Processing and Microwave Remote Sensing (BGU31006)

Content:
- Introduction to potential field theory
- principles of satellite gravimetry and magnetometry
- mission concept and goals of the satellite gravity missions CHAMP, GRACE, GOCE
- mission concept and goals of the magnetic field missions ØRSTED, SAC-C, SWARM
- applications of satellite gravity and magnetic field data in earth sciences

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able to
- to understand the basics of potential field theory and the mathematical description of the Earth's gravity and magnetic field;
- to understand the basic mission concepts and objectives of satellite gravity and magnetic field missions
- to recognize the relationship between the measurements and the respective potential field parameters
- to apply these concepts for the solution of practical problems of Earth Observation (EO) Data analysis
- to analyze and to interpret the results
- to link the observation of the global gravity and magnetic field and its changes to the global monitoring of the Earth system,
- to develop a logically structured presentation on a topic related to the guest lecture on EO
- to present it to an audience
- to publicly defend the contents of the scientific presentation.

Teaching and Learning Methods:
The module consists of a lecture, an exercise and a seminar. The contents of the lectures are communicated by developing theory and methods on the blackboard, oral presentations with powerpoint support, or calculations/drawings at the blackboard, including interactive discussions with the students. In the exercise (lab), numerical exercises on the topics covered by the lecture are performed using MATLAB. For the most part, the lab is organised as homework with the requirement of preparing a written report on methodology and results.
In the seminar the students perform a self-contained literature research and they are guided interactively how to develop an oral presentation.

Media:
- presentations in electronic form
- blackboard

Reading List:
- handouts
- Torge, Wolfgang; Müller, Jürgen (2012): Geodesy. 4th ed. Berlin, Boston: De Gruyter (De Gruyter textbook)
- Stolle, Claudia; Olsen, Nils; Richmond, Arthur D.; Opgenoorth, Hermann J. (Hg.) (2018): Earth's magnetic field. Understanding geomagnetic sources from the earth's interior and its environment. Dordrecht: Springer Science+Business Media B.V.2018 (Space sciences series of ISSI, vol. 60)

Responsible for Module:
Roland Pail

Courses (Type of course, Weekly hours per semester), Instructor:
Seminar with Guest Lecturers (seminar, 1 SWS)
Pail R

Gravity and Magnetic Field from Space (lecture, 2 SWS)
Pail R [L], Pail R, Gruber T

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU57019: Geokinematics and Continental Hydrology

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam of 120 min duration. In the exam it is verified that the students understand the scientific challenges of space-based geodetic data sets and its potential for geokinematic and hydrological applications, that they are able to process observation data and evaluate it with respect to its accuracy, and that they understand how the data can be used for the calibration of hydrological models. With the discussion of typical examples and specific problem settings the theoretical understanding and the evaluation skills are examined. Through questions at different levels of difficulty, the written exam allows for an individual verification of the understanding and thus a realistic assessment of the acquired competencies.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Recommended:
Basic knowledge in linear algebra, calculus, mechanics, programming with Matlab
Successful participation in the modules
- Introduction to Earth System Science (BGU45037)
- Numerical Modeling (BGU57018)
- Signal Processing and Microwave Remote Sensing (BGU13006)

Content:
1. Introduction: concepts of geodetic reference systems, their realizations, the International Terrestrial Reference System (ITRS)
2. The ITRF: General aspects, review on existing ITRS realizations, geodetic space techniques, combination strategies, inconsistencies and challenges
3. Alternative reference frames: epoch reference frames, regional reference frames
4. Current developments and most recent research topics: non-linear station motions, physical datum definition, the Global Geodetic Observing System (GGOS), inter-disciplinary scientific applications
5. Satellite radar altimetry for inland water bodies, Inland altimetry databases
6. Other space-based hydrogeodetic observation techniques: Laser and Delay Doppler/SAR altimetry, GNSS-reflectometry, GRACE-FO, SWOT
7. Monitoring of rivers systems and estimation of river discharge
8. Volume changes of lakes
9. Observing continental hydrology with the GRACE gravity mission
10. Assimilation/calibaration of hydrologocal models using hydrogeodetic information
11. Numerical exercises: Computation of water levels, river discharge and lake volume changes from satellite altimetry data

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand the definition and the datum realization of the ITRS,
- to classify different realizations of geodetic reference systems (regional, global, epoch-wise, multi-year),
- to evaluate observations of space geodetic observation techniques regarding information content and accuracy,
- to describe different concepts for the realization of the ITRS,
- to discuss inconsistencies and to evaluate current limitations of current ITRS realizations,
- to assess the potential of current developments for the accuracy of terrestrial reference frames,
- to describe the importance of accurate terrestrial reference frames for various inter-disciplinary applications,
- to understand the measurement principle of radar altimetry and its potential for hydrological applications,
- to apply satellite altimetry data for the estimation of lake volumes and river discharge,
- to evaluate the quality of inland altimetry data, and
- to understand the application of satellite data for the calibration of hydrological models.

Teaching and Learning Methods:
The content of the module is tought in two lectures. Both are condicted in interaction with the students whereby the learning success is continuously monitored through questions to the students. Mathematical derivations are shown at the black board. Selected literature is discussed with the students.

The lecture Hydogeodesy contains four supervised practical exercises conducted in the CIP-Pool.

Moreover, two guest lectures by external experts are part of the module.

Media:
- Presentation slides
- Lecture Notes
- Selected Scientific Publications which will be distributed in class

Reading List:
Geokinematics:
- Lecture Notes
- Kovalevsky J., Mueller I., Kolaczek B. (1989): Reference Frames in Astronomy and Geophysics, Kluwer Academic Publishers, Dordrecht
- Seeber G. (2003): Satellite Geodesy, Walter de Gruyter, Berlin
- Xu G. (2010/2013): Sciences in Geodesy-I/II, Springer, Berlin
- Plag H.-P., Pearlman M. (2009): Global Geodetic Observing System, Springer, Berlin
- Selected scientific publications (distributed in the course)

Hydrogeodesy:
- Lecture notes
- Fu L., Cazenave A. (2000): Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications. International Geophysics Series, Vol. 69, San Diego, CA
- Calmant et al (2008): Monitoring Continental Surface Waters by Satellite Altimetry, Surv. Geophys. 29:247-269
- Selected scientific publications (distributed in the course)

Responsible for Module:
Prof. Florian Seitz

Courses (Type of course, Weekly hours per semester), Instructor:
Hydrogeodesy: Monitoring surface waters from space (lecture, 2 SWS)
Seitz F [L], Dettmering D

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

MW2413: Spacecraft Technology 2 (ESPACE) [SCT 2 (ESPACE)]

Spacecraft Technology 2 (ESPACE)
Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	75	75

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam of 90 min duration. A written exam is required to verify that the students are able to understand and apply the concepts of engineering and design of a spacecraft system (mainly satellites) and its mission. The evaluating and analytical command of this expertise cluster is a fundamental prerequisite for the professional qualification of an academically educated rocket engineer. The exam comprises typically 15-20 tasks, which are short questions as well as calculation problems with a partitioning of about 50% to 50%. To work on the exam, the students are provided with a formulary; besides a non-programmable calculator, no further auxiliary material is allowed. In addition a midterm assignment is offered, which covers a scientific proposal for a satellite mission of 5 to 10 pages and 10 min presentation and subsequent discussion of this proposal. The grading of the module grade can be improved by 0,3 (provided that the original grading is lower or equal 4,0). The topic for the satellite mission design and the requirements will be announced by the lecturer (former topics are related to the design of an Earth Observation satellite mission with small satellites). The work should be done in groups of 3 to 5 students. Hereby the students demonstrate that they are able to apply the theoretical elements teached in the lecture and in the exercise and their interactions to a mission proposal.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basic physics; theory and physics of rocketry and astronautics as it is covered in the module Spacecraft Technology 1 (MW2412).

Content:
The content of the module will address the basic components of a satellite system in theory (lecture) and practise (exercise). The seminar intends to offer the students the possibility to perform an Earth observation mission design based on the lecture and exercise content. In particular the topics of the module Spacecraft Technology 2 to be addressed are the following:
- Mission Design (requirements, trade studies)
- Mission Geometry & Orbit Selection
- Orbit Perturbations
- Space Environment
- Satellite Payloads (typical)
- Structure & Mechanisms
- Attitude Determination and Control System
- Propulsion System
- Communication System
- Power System
- Thermal Control System

Satellite Mission Design Project:
In the project the science objectives for an Earth observation mission are defined and the overall design of this mission is developped. Specifically the interaction of the various elements of a mission design, such as instrumentation, orbit, spacecraft and launcher is considered.

Intended Learning Outcomes:
After the successful conclusion of the module Spacecraft Technology 2 the students are able to
- understand all relevant theory and engineering tools for analysing the major elements of a typical space mission with special emphasis on the space element, namely the spacecraft itself
- understand the complex interactions between the spaceflight environment, spacecraft sub-systems and mission needs,
- analyze relevant requirements and find first order solutions for mission planning purposes
- evaluate spacecraft systems and perform basic optimizations with respect to the typical trade-offs comprising power, mass, data rate, lifetime, complexity and reliability
- evaluate the basic interactions between the design drivers for spacecraft systems, and
- implement them in the typical design processes.

Teaching and Learning Methods:
The module consists of a lecture, an exercise and a seminar. In the lecture, the topics are taught with the help of presentations and black board sketches. The accompanying exercises (labs) repeat and engross the crucial topics. With the help of rough calculations and rule of thumb methods, the students learn how to do first order system evaluations.
In the seminar an introduction to mission design is given by the lecturers. The student teams work independently and present their work a final presentation. Feedback to the mission design concepts is given by the lecturers either orally or in written form. Existing software is applied for orbit computations.

Media:
Presentation, powerpoint assistance, hand-outs, black board

Reading List:
- Lecture notes
- U.Walter, Astronautics, Wiley-VCH, ISBN 3-527-40685-9
- Further literature survey is given in the hand-out

Responsible for Module:
Walter, Ulrich; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
. (seminar, 1 SWS)
Gruber T [L], Pfaffenzeller N

Spacecraft Technology 2 (lecture, 3 SWS)
Rott M

For further information in this module, please click
campus.tum.de or here.

Specialization Subject 2: Remote Sensing

Module Description

BGU30062: Geoinformation [Geoinformation]

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	105	45

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
A written exam of 60 min takes place in the end of the semester. By answering the questions the students verify that they have gained the required knowledge about spatial data management, the analysis of geodata, spatial data mining and cartographic techniques for visualising spatial data. The exam contains questions in which they have to give valid definitions, explain concepts, theoretically implement and evaluate case studies, as well as mastering design challenges. All learning outcomes are covered by this written exam.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Knowledge of higher mathematics and experiences of handling spatial data

Content:
This module includes the following topics:
- Introduction to GIS;
- Spatio-temporal representations and databases;
- Spatial data analysis;
- Spatial data mining;
- Data retrieval and cartographic techniques;
- Introduction to ArcGIS components;
- Working with multiple data tables;
- Learning spatial analysis methods;
- Building 3D models;
- Creating animations;
- Designing a quality Map in a GIS;
- Collecting spatial data during field work and integrating it to a GIS

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to illustrate the dimensions of geoinformation;
- to explain the structure of a GIS;
- to implement concepts of geodata harmonization to integrate geodata into a GIS;
- to implement geoanalytical methods;
- to apply properties of different map projections and to select appropriate projections for specific purpose;
- to implement map generalization concepts and algorithms;
- to evaluate spatial databases and the spatial data quality within geodata-management;

- to generate three dimensional data models

Teaching and Learning Methods:
The module is structured in lectures with integrated exercises. The lectures provide the theoretical foundations of geoinformation. They impart knowledge about spatial data management, the analysis of geodata, spatial data mining and cartographic techniques for visualising spatial data. The integrated exercise part of this module allows the students to employ their GIS knowledge to applied studies. An introduction to ArcGIS will be given and the students can analyse and visualise geodata using a variety of analysis tools and visualisation techniques. A set of exercises put the theoretical knowledge into practice. The exercises are carried out in a computer lab individually, partly under supervision within lecture time and partly in self-study. Feedback on the exercises is given to each student within a personal one-on-one discussion.

Media:
Moodle E-learning, presentations, script, GIS laboratory, hand-outs, recommended literature

Reading List:
Longley, P. A., Goodchild, M. F., Maguire D. J., Rhind, D. W. (Eds.) (2005): Geographical Information Systems ¿ Principles, Techniques, Management and Applications. John Wiley & Sons.
Law, M., Collins, A. (2013): Getting to Know ArcGIS for Desktop. Esri Press.

Responsible for Module:
Prof. Liqiu Meng (liqiu.meng@tum.de)

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU48035: PSC - Photogrammetry - Selected Chapters [PSC]

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The exams consist of a presentation of 30 minutes of a prepared scientific topic and a discussion on the topic of the presentation and the scientific field in general. The student has to show the ability to understand, prepare and present a scientific topic to a scientific auditorium. The discussion is focussed on methodigical details of the presented topic and the scientific field. It is evaluated whether the students understand methods, sensors, and applications in the field of research beyond their topics and whether they can evaluate their topics in the field of research.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Introduction to Photogrammetry, Remote Sensing and Image Processing (BGU48036)

Content:
Lectures on Photogrammetry and remote sensing. Different topics of state-of-the-art Photogrammetry and Remote Sensing like i.e.:
- Extraction of buildings from aerial images, satellite images, LiDAR, SAR
- Extraction of roads from aerial images, satellite images, LiDAR, SAR
- Extraction of vehicles from aerial images, satellite images, LiDAR, IR
- Classification of vegetaion from aerial images, satellite images, LiDAR, SAR
- Glaciers DEM from aerial images, satellite images, LiDAR, SAR

Topics from the fields of photogrammetry, remote sensing and image analysis are selected by the students.

Intended Learning Outcomes:
After the successful conclusion of the module Photogrammetry, the students are able to understand and apply methods of Photogrammatry and Remote Sensing, - evaluate the usability of specific methods for specific tasks, evaluate results in a project report, to present scientific results to an audience, i.e. how to design slides, structure the presentation, and how to defend the content in a discussion. They are able to analyse problems and solution of a specific task in Photogrammetry and Remote Sensing, evaluate actual problems and methods in photogrammetry and remote sensing, and to prepare methodical basics and present elaborated results in a talk and report.

Teaching and Learning Methods:
In the lecture the students evaluate technical possibilities and methods for state-of-the-art sensors (multi- and hyperspectral optical sensors, sensors in thermal infrared, airborne laserscanning, synthetic aperture radar) based on scientific publications. In a combination of lectures given by lecturers and the students themselves and

paperwork, the students specialize on certains individual concepts, sensors, platforms or applications of Photogrammetry and Remote Sensing. Students prepare short lectures on their topic to recap the new knowledge every few lectures. Ongoing discussions during the lectures deepen the understanding of the different topics. By the end of the semester, every student presents his / her favorite topic in a 30 minutes presentation. This presentation should include a summary and explanation of presented methods, an evaluation and a discussion. The results, pros and cons are discussed within the group of attendees.

Media:
- Black / white board
- Presentation as slides
- Literature research

Reading List:
Literatur is individually related to the chosen topics. Possible sources for state-of-the-art articles are:
- ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences (www.ispors.org)
- ISPRS International Journal for Photogrammetry and Remote Sensing (www.journals.elsevier.com/isprs-journal-of-photogrammetry-and-remote-sensing)
- IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (https://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=4609443)

Responsible for Module:
Ludwig Hoegner

Courses (Type of course, Weekly hours per semester), Instructor:
Photogrammetry - Selected Chapters (PSC) (lecture, 4 SWS)
Stilla U, Hoegner L

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU69002: Remote Sensing

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The learning outcomes are examined within a parcours, consisting of
- a written exam of 60 minutes length
- a presentation of about 10 minutes.
The presentations will be given after the written exam in the classroom.

While the written exam is supposed to examine a general understanding of the topics SAR remote sensing, hyperspectral remote sensing, and atmospheric remote sensing, the presentation confirms a deeper involvement in a special topic from the overall field of remote sensing. It is meant to examine to what extent the students are capable of explaining technical, task-oriented solutions within a discourse among peers with foundation both in theory and methodology.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Recommended:
Basic knowledge in photogrammetry, mathematics and physics.
Successful participation in the module Introduction to Photogrammetry, Remote Sensing and Digital Image Processing (BGU48036).

Content:
The module consists of a lecture with integrated exercises Remote Sensing ¿ Advanced Methods and the Seminar Remote Sensing. While the lecture provides the necessary background knowledge, exercises and seminar enable problem-based learning.

Remote Sensing - Advanced Methods:
- Along-Track and Across-Track Interferometry
- Differential SAR Interferometry
- Persistent Scatterer Interferometry
- Remote Sensing of the Atmosphere
- Hyperspectral Remote Sensing

The interferometric processing of SAR data is trained in tutorials.

Seminar Remote Sensing
- deep insight into specific and selected topics of current remote sensing research

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand and apply methods of signal processing in remote sensing
- to evaluate the usability of specific remote sensing methods for practical problems
- to analyze autonomously tasks in the research field of remote sensing
- to prepare methodical basics for a selected research topic
- to evaluate alternative approaches in practice and to develop own solutions
- to present the elaborated results in a report and/or talk

Teaching and Learning Methods:
The module is comprised of a lecture with integrated exercises and a seminar. In the lecture, the content will be conveyed by presentations and consolidated by exercises. In the seminar, the basics conveyed by the lecture are applied by self-reliant work on a recent research topic, as well as by presentation and discussion of the achieved results.

Media:
Slides, lecture notes, exercise sheets, white-/blackboard

Reading List:
Remote Sensing - Advanced Methods:
- Fletcher, Karen: InSAR Principles - Guidelines For SAR Interferometry Processing and Interpretation. ESA, 2007

Seminar Remote Sensing:
- selected literature (such as scientific papers) will be provided for each topic individually

Responsible for Module:
Prof. Dr.-Ing. habil. Xiaoxiang Zhu

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Module Description

MW2413: Spacecraft Technology 2 (ESPACE) [SCT 2 (ESPACE)]

Spacecraft Technology 2 (ESPACE)
Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	75	75

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam of 90 min duration. A written exam is required to verify that the students are able to understand and apply the concepts of engineering and design of a spacecraft system (mainly satellites) and its mission. The evaluating and analytical command of this expertise cluster is a fundamental prerequisite for the professional qualification of an academically educated rocket engineer. The exam comprises typically 15-20 tasks, which are short questions as well as calculation problems with a partitioning of about 50% to 50%. To work on the exam, the students are provided with a formulary; besides a non-programmable calculator, no further auxiliary material is allowed. In addition a midterm assignment is offered, which covers a scientific proposal for a satellite mission of 5 to 10 pages and 10 min presentation and subsequent discussion of this proposal. The grading of the module grade can be improved by 0,3 (provided that the original grading is lower or equal 4,0). The topic for the satellite mission design and the requirements will be announced by the lecturer (former topics are related to the design of an Earth Observation satellite mission with small satellites). The work should be done in groups of 3 to 5 students. Hereby the students demonstrate that they are able to apply the theoretical elements teached in the lecture and in the exercise and their interactions to a mission proposal.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basic physics; theory and physics of rocketry and astronautics as it is covered in the module Spacecraft Technology 1 (MW2412).

Content:
The content of the module will address the basic components of a satellite system in theory (lecture) and practise (exercise). The seminar intends to offer the students the possibility to perform an Earth observation mission design based on the lecture and exercise content. In particular the topics of the module Spacecraft Technology 2 to be addressed are the following:
- Mission Design (requirements, trade studies)
- Mission Geometry & Orbit Selection
- Orbit Perturbations
- Space Environment
- Satellite Payloads (typical)
- Structure & Mechanisms
- Attitude Determination and Control System
- Propulsion System
- Communication System
- Power System
- Thermal Control System

Satellite Mission Design Project:
In the project the science objectives for an Earth observation mission are defined and the overall design of this mission is developped. Specifically the interaction of the various elements of a mission design, such as instrumentation, orbit, spacecraft and launcher is considered.

Intended Learning Outcomes:
After the successful conclusion of the module Spacecraft Technology 2 the students are able to
- understand all relevant theory and engineering tools for analysing the major elements of a typical space mission with special emphasis on the space element, namely the spacecraft itself
- understand the complex interactions between the spaceflight environment, spacecraft sub-systems and mission needs,
- analyze relevant requirements and find first order solutions for mission planning purposes
- evaluate spacecraft systems and perform basic optimizations with respect to the typical trade-offs comprising power, mass, data rate, lifetime, complexity and reliability
- evaluate the basic interactions between the design drivers for spacecraft systems, and
- implement them in the typical design processes.

Teaching and Learning Methods:
The module consists of a lecture, an exercise and a seminar. In the lecture, the topics are taught with the help of presentations and black board sketches. The accompanying exercises (labs) repeat and engross the crucial topics. With the help of rough calculations and rule of thumb methods, the students learn how to do first order system evaluations.
In the seminar an introduction to mission design is given by the lecturers. The student teams work independently and present their work a final presentation. Feedback to the mission design concepts is given by the lecturers either orally or in written form. Existing software is applied for orbit computations.

Media:
Presentation, powerpoint assistance, hand-outs, black board

Reading List:
- Lecture notes
- U.Walter, Astronautics, Wiley-VCH, ISBN 3-527-40685-9
- Further literature survey is given in the hand-out

Responsible for Module:
Walter, Ulrich; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
. (seminar, 1 SWS)
Gruber T [L], Pfaffenzeller N

Spacecraft Technology 2 (lecture, 3 SWS)
Rott M

For further information in this module, please click
campus.tum.de or here.

Specialization Subject 3: Navigation

Module Description

BGU61031: Advanced Aspects of Navigation Technology

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
A written exam of 120 min takes place in the end of the semester. The aim of the written exam is to ensure that the student has gained the required knowledge and understanding of fundamentals of receiver technology, acquired basic knowledge on signal generation, understands the functionalities of GNSS receiver modules, and are familiar with methods and strategies relevant for applications of GNSS in different fields such as geodynamics, aeronautical and space applications, time synchronization. Students are allowed to use a programmable pocket calculator.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Introduction to Satellite Navigation and Orbit Mechanic (BGU61029)
Signal Processing and Microwave Remote Sensing (BGU31006)

Content:
The two courses in the module gives an overview over adbanced aspects of navigation technology, including GNSS receiver technology and specific applications.
Receiver Technology:
- mathematical fundamentals and GNSS signal structures
- antenna and receiver front end
- signal acquisition, tracking loops, navigation
- mass market receivers
- advanced tracking methods

GNSS Applications: Different lecturers from DLR and from industry highlight various GNSS and navigation applications such as:
- time synchronization
- indoor navigation, sensor fusion
- real time applications
- aeronautical applications, integrity
- space applications
- applications in geodynamics

The course gives insight into current projects performed and applications developed by industry in and around Munich.

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand the fundamentals of GNSS signals,

- to understand the structure and working principles of a GNSS receiver,
- to understand the acquisition, tracking, navigation modules of a GNSS receiver,
- to understand the basic principle of simple signal generators,
- to analyze and to assess typical GNSS applications.

Teaching and Learning Methods:
The module consists of a lecture in receiver technology and a seminar on GNSS applications. The lecture on receiver technology is interleaved with several exercises to the different topics that are completed as home works. This way, the students can apply the concepts presented in the lecture in practice and thus gain a deep understanding on receiver working principles and GNSS signal processing. The seminar consists of a series of invited presentations on specific GNSS topics given by different lecturers from DLR and from Industry. This gives the students also the opportunity to get an overview over industry projects and to get into contact with potential employers.

Media:
Powerpoint presentations, blackboard

Reading List:
- Lecture notes, handouts
- Teunissen P., Montenbruck O. (Eds): GNSS Handbook, Springer, 2017

Responsible for Module:
Prof. Dr. phil. nat. Urs Hugentobler
Dipl. Math. Kathrin Frankl

Courses (Type of course, Weekly hours per semester), Instructor:
Seminar GNSS Applications (seminar, 2 SWS)
Hugentobler U

Receiver Technology (lecture, 2 SWS)
Hugentobler U [L], Frankl K

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU61032: Navigation Labs

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The exam is carried out in the form of Laboratory assignmen. During the semester, the students hand in 4-6 written lab reports of about 10 pages each, which document the labs and the lab results, and provide answers on questions relevant to the lab. These written reports are prepared in small groups and are later on discussed with the lecturer. Discussions take 60-90 min per lab and group. The grade of the module is based with equal weight on the written reports and on individual questions of the lecturer during the discussion. The aim of the written reports is to ensure that the students have gained the required competences to work with GNSS equipment, to characterise GNSS receivers and tracking data, to perform specific analysis tasks in a small team, and to document the used methods and obtained results. With the discussion the competence of the students to defend the methods applied and results obtained in the lab is verified.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Introduction to Satellite Navigation and Orbit Mechanics (BGU61029)
Satellite Navigation and Advanced Orbit Mechanics (BGU61033)

Content:
Exercises and labs on
- GPS mapping
- Receiver characterization
- Multipath and ionopshere analysis
- Software correlation
- Spaceborne GPS tracking

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to work with and handle GNSS equipment
- to understand and apply GNSS data analysis
- understand GNSS processing concepts
- to apply dedicated problems of GNSS including receiver technology and data collection
- to apply methods for the analysis of GNSS data
- to analyze, assess and interprete the results.

Teaching and Learning Methods:
The module consists of an exercise (lab). It is organized as a series of lab exercises where each exercise is introduced with a short presentation; students work in small groups using hardware and software and prepare a

written report; the results of the report are discussed in the group. The work in groups on challenging topics together with immediate feedback and extended discussions of the results allows the students to deepen their understanding in GNSS and relevant applications.

Media:
Handouts for each lab exercise, work with hardware and software, presentation of results with written report and discussions.

Reading List:
Misra P., Enge P.; Global Positioning System (GPS): Signals, Measurements and Performance; Ganga-Jamuna Press (2001).

Responsible for Module:
Prof. phil. nat. Urs Hugentobler
Dr. Oliver Montenbruck
M.Sc. Inga Selmke

Courses (Type of course, Weekly hours per semester), Instructor:
GNSS Lab Exercises (exercise, 4 SWS)
Montenbruck O, Selmke I

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU61034: Precise GNSS

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	75	75

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified with a written exam of 120 min at the end of the semester. The aim of the written exam is to ensure that the student has gained the required knowledge and understanding for precise positioning with GNSS data and of the corresponding mathematical background as listed in the intended learning outcomes and that the students are capable to discuss the methods used and the results achieved in the exercise (lab) and to put them into the proper context. The students are allowed to use 8 pages of hand-written notes and a programmable pocket calculator for the written exam as well as their reports prepared during the exercise (lab). Lab reports can be prepared as homework and are considered as optional midterm exam. The 5-6 reports are graded and contribute, when improving it, to the overall grade with a weight of 25%.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Fundamentals of linear algebra and statistics as well as successful participation in the module " Introduction to Satellite Navigation and Orbit Mechanics" (BGU61029)

Content:
The module include theory lectures with integrated exercises (3h) and exercise (lab) (2h). The aim of the module is
- to get familiar with GNSS, with models involved, and with processing strategies used for precise GNSS positioning applications,
- to get experience with GNSS data in practical work.

The theoretical part covers:
- Review of fundamentals of satellite navigation:
position estimation with iterative least-squares method
- Precise Point Positioning with Melbourne-Wübbena and ionosphere-free phase combinations
- Reliable integer ambiguity resolution with multi-frequency linear combinations
- Estimation of satellite position, clock and bias corrections
with a global network of GNSS receivers
- Cascaded Kalman filtering for multi-stage processing
- Joint subset optimization and integer least-squares estimation
for PPP and RTK
- Best integer-equivariant estimation for ambiguity fixing
- Precise Point Positioning with low-cost single-frequency GNSS receivers

The practical work includes:
- development of a simple point positioning tool using matlab,
- experiments using a scientific software package to study the impact of different effects and analysis strategies on positioning results such as orbit precision, troposphere, modelling, ambiguity resolution.

The practical work is accompanied by short presentations by the participants of their results.

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand the theory, the basic methodologies and algorithms, and the current trends for Precise Point Positioning and Real-Time Kinematic (RTK) positioning with GPS and Galileo signals
- to evaluate tracking data quality and multipath
- to assess the impact of different model options on the positioning results
- to optimize analysis strategies to specific use cases
- to apply methods for assessing precision and accuracy of obtained positioning solutions
- to understand and apply algorithms and statistical tests for reliable phase ambiguity resolution
- to apply optimized processing strategies to analyze GNSS data for precise positioning applications

Teaching and Learning Methods:
In the lecture with integrated exercises the content is presented with powerpoint presentations with examples and demonstrations using Matlab. Calculations and derivations are written to the blackboard.
The students have the option to participate in a voluntary trial exam in the middle of the semester which allows them to validate that the target competences of the first part of the module have been achieved.
In the exercise (lab) the exercises are based on Matlab and on the Bernese GPS Software, a professional GNSS data analysis software. The students work in groups on specific questions and prepare a report.

Media:
Lecture with power-point presentations with electronic handouts and blackboard, demonstration of Matlab code.
Lab exercises with electronic handouts, software user insrtructions, electronic tutorials with solutions.

Reading List:
Hofmann-Wellenhof, Lichtenegger, Collins (2001): GPS-Theory and Practice, Springer
Mistra (2006): GPS-Signals, Measurements and Performance. Ganga-Jamuna Press
Theunissen, Kleusberg (Eds.) (1998): GPS for Geodesy. Springer
Parkinson, B.W. & Spilker Jr., J.J. (1996), Global Positioning System: Theory and Applications Vol. I/II, American Institute of Aeronautics and Astronautics
Kaplan, E., Hegarty C. (2006), Understanding GPS: Principles and Applications, Second Edition, Artech House (available in the library: www.ub.tum.de)
GPS Interface Control Document, ICD-GPS-200C
Bernese GPS Software Version 5.2 User Manual

Responsible for Module:
Prof. Dr. phil. nat. Urs Hugentobler
Dr.-Ing. Patrick Henkel
M. Sc. Inga Selmke

Courses (Type of course, Weekly hours per semester), Instructor:
Labs in Precise GNSS (exercise, 2 SWS)
Hugentobler U [L], Selmke I

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

MW2413: Spacecraft Technology 2 (ESPACE) [SCT 2 (ESPACE)]

Spacecraft Technology 2 (ESPACE)
Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	75	75

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam of 90 min duration. A written exam is required to verify that the students are able to understand and apply the concepts of engineering and design of a spacecraft system (mainly satellites) and its mission. The evaluating and analytical command of this expertise cluster is a fundamental prerequisite for the professional qualification of an academically educated rocket engineer. The exam comprises typically 15-20 tasks, which are short questions as well as calculation problems with a partitioning of about 50% to 50%. To work on the exam, the students are provided with a formulary; besides a non-programmable calculator, no further auxiliary material is allowed. In addition a midterm assignment is offered, which covers a scientific proposal for a satellite mission of 5 to 10 pages and 10 min presentation and subsequent discussion of this proposal. The grading of the module grade can be improved by 0,3 (provided that the original grading is lower or equal 4,0). The topic for the satellite mission design and the requirements will be announced by the lecturer (former topics are related to the design of an Earth Observation satellite mission with small satellites). The work should be done in groups of 3 to 5 students. Hereby the students demonstrate that they are able to apply the theoretical elements teached in the lecture and in the exercise and their interactions to a mission proposal.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basic physics; theory and physics of rocketry and astronautics as it is covered in the module Spacecraft Technology 1 (MW2412).

Content:
The content of the module will address the basic components of a satellite system in theory (lecture) and practise (exercise). The seminar intends to offer the students the possibility to perform an Earth observation mission design based on the lecture and exercise content. In particular the topics of the module Spacecraft Technology 2 to be addressed are the following:
- Mission Design (requirements, trade studies)
- Mission Geometry & Orbit Selection
- Orbit Perturbations
- Space Environment
- Satellite Payloads (typical)
- Structure & Mechanisms
- Attitude Determination and Control System
- Propulsion System
- Communication System
- Power System
- Thermal Control System

Satellite Mission Design Project:
In the project the science objectives for an Earth observation mission are defined and the overall design of this mission is developped. Specifically the interaction of the various elements of a mission design, such as instrumentation, orbit, spacecraft and launcher is considered.

Intended Learning Outcomes:
After the successful conclusion of the module Spacecraft Technology 2 the students are able to
- understand all relevant theory and engineering tools for analysing the major elements of a typical space mission with special emphasis on the space element, namely the spacecraft itself
- understand the complex interactions between the spaceflight environment, spacecraft sub-systems and mission needs,
- analyze relevant requirements and find first order solutions for mission planning purposes
- evaluate spacecraft systems and perform basic optimizations with respect to the typical trade-offs comprising power, mass, data rate, lifetime, complexity and reliability
- evaluate the basic interactions between the design drivers for spacecraft systems, and
- implement them in the typical design processes.

Teaching and Learning Methods:
The module consists of a lecture, an exercise and a seminar. In the lecture, the topics are taught with the help of presentations and black board sketches. The accompanying exercises (labs) repeat and engross the crucial topics. With the help of rough calculations and rule of thumb methods, the students learn how to do first order system evaluations.
In the seminar an introduction to mission design is given by the lecturers. The student teams work independently and present their work a final presentation. Feedback to the mission design concepts is given by the lecturers either orally or in written form. Existing software is applied for orbit computations.

Media:
Presentation, powerpoint assistance, hand-outs, black board

Reading List:
- Lecture notes
- U.Walter, Astronautics, Wiley-VCH, ISBN 3-527-40685-9
- Further literature survey is given in the hand-out

Responsible for Module:
Walter, Ulrich; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
. (seminar, 1 SWS)
Gruber T [L], Pfaffenzeller N

Spacecraft Technology 2 (lecture, 3 SWS)
Rott M

For further information in this module, please click
campus.tum.de or here.

Specialization Subject of Wuhan University

Elective Modules

Genehmigte individuelle Wahlmodule aus TUM / LMU

Technische Universität München

Module Description

BGUWAHL1: TUM Elective Module

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:

Repeat Examination:

(Recommended) Prerequisites:

Content:

Intended Learning Outcomes:

Teaching and Learning Methods:

Media:

Reading List:

Responsible for Module:

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU900010: Partner University - Elective Module

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:

Repeat Examination:

(Recommended) Prerequisites:

Content:

Intended Learning Outcomes:

Teaching and Learning Methods:

Media:

Reading List:

Responsible for Module:

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Module Description

IN3200: Selected Topics in Computer Graphics and Vision

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	German/English	one semester	irregularly
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5			

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The academic assessment will be done by a written exam. Assignments checking knowledge verify the familiarity with the main concepts of selected topics in Computer Graphics and Vision. Transfer assignments and small scenarios check the ability to apply and evaluate these concepts systematically and in a qualified manner.

Repeat Examination:
End of Semester

(Recommended) Prerequisites:
Bachelor in Informatics

Content:
Different lecturers offer courses about selected topics in Computer Graphics and Image Understanding with a varying amount of credits. Master students in Informatics may choose this module only once as an elective module in the field of Computer Graphics and Image Understanding (CGV).

Intended Learning Outcomes:
Participants know the state of the art in selected topics in Computer Graphics and Vision and are able to deal with current research projects.

Teaching and Learning Methods:
By means of a presentation, either by slides or whiteboard, the lecture presents selected concepts and techniques from the area of Computer Graphics and Image Understanding and illustrates these by examples.
Possbly accompanying assignments for individual study may deepen the understanding of the concepts explained in the
module, train students to apply the learnt concepts and techniques to solve reasonably sized tasks on their own.

Media:
Slides, whiteboard, exercise sheets, excercises, presentation

Reading List:
Primary source scientific literature (e.g. journals, conference proceedings), depending on the topic

Responsible for Module:
Westermann, Rüdiger; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU69001: Multisensor Data Fusion [MDF]

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
3	90	60	30

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
Oral examination (20-30 Minuten). It shall test if the students have comprehended the basic concepts of data fusion of modern sensors and if they are able to reproduce them in a compressed manner. Based on a work sheet that is produced during the lecture, the oral examination shall examine if the students are able to analyze data fusion processes taxonomically.

Repeat Examination:

(Recommended) Prerequisites:
Prerequesite for this lecture is the knowledge about sensors and observation types, as imparted, e.g., in the lectures Photogrammetry and Remote Sensing 1-4 (bachelor degree course Geodesy and Geoinformation). In addition, first experiences in the field of estimation theory, e.g. imparted in the module Least-Squares Adjustment Theory of the bachelor degree course Geodesy and Geoinformation are recommended.

Content:
- Basic motivation
- interdisciplinary definitions
- types of data integration
- levels of data fusion
- generic data fusion model
- data alignment
- parameter estimation in static and dynamic cases
- application examples

Intended Learning Outcomes:
After participation in this module, the students will be able to
- develop an interdisciplinary understanding of data fusion.
- analyze data fusion problems with regard to the level of fusion and the type of data integration.
- apply the generic data fusion model.
- analyze the potentials and limits of different data alignment and parameter estimation methods.
- model data fusion problems.

Teaching and Learning Methods:
The module consists of a lecture with partially seminaristic character. The contents will be conveyed by talk, presentation and slides. The students will work on scientific literature and application examples in individual practice-oriented dates. In the frame of these dates, they will have to prepare short oral presentations and work

sheets. This is meant to encourage the students to discuss the contents of the lecture and to develop a broader understanding of the topic.

Media:
- Electronic presentation
- Lecture notes
- Work sheets

Reading List:
David L. Hall & Sonya A.H. McMullen - Mathematical Techniques in Multisensor Data Fusion. Artech House, Boston, 2004

Responsible for Module:
Dr. Michael Schmitt

Courses (Type of course, Weekly hours per semester), Instructor:
Data Fusion (lecture, 2 SWS)
Schmitt M

For further information in this module, please click
campus.tum.de or here.

Module Description

BV300002: Geostatistics and Geomarketing

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
3	90	60	30

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The examination consists of a written exam of 60 min in total (100%) at the end of the semester. The students have to answer to the questions with own formulations partially they have to sketch issues or circumstances. No auxiliary materials are permitted within the written exam.
The written exam gives the proof that the students have understood, can reflect and can apply statistical methods to spatial data and that they can adapt their skills under time pressure to create visualizations for geomarketing aspects using a combination of spatial and non-spatial data.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Knowledge of higher mathematics and experiences of spatial data handling, as well as a basic understanding of thematic cartography and graphic design are desirable. `R¿ programming experience is not required, but would be an advantage.

Content:
The content of this module covers geostatistics and geomarketing aspects which are combined to gain insights into spatial data analysis using statistical methods and to visualize these insights using advanced visualization techniques.

During the lectures in particular topics like...
¿ geovisualization vs. information visualization;
¿ geospace vs. information space;
¿ point clustering and analysis;
¿ basic statistic methods and applications;
¿ statistical interpolation methods like IDW, kriging, spline etc. and density surfaces;
¿ components, methods and applications of geomarketing;
¿ market data and micro-geographic data;
¿ business areas in geomarketing.
are covered.

Intended Learning Outcomes:
Upon completion of the module, students are able to¿
¿ create visualizations using and combining spatial and non-spatial data;
¿ evaluate visualization approaches of spatial data and build new ones upon the theoretical framework;
¿ analyse spatial data using statistical methods;
¿ apply methods of explorative spatial data analysis and evaluate results;

¿ understand the crucial components of geomarketing;
¿ apply geomarketing methods.

Teaching and Learning Methods:
The module is structured in lectures and exercises. The lectures provide the theoretical foundation of statistics focusing on spatiotemporal datasets and geomarketing. Throughout performing the exercises students will analyse spatial data using the geostatistical methods presented in the lectures. The integration of geographical intelligence into all marketing aspects including sales and distribution are introduced. During the exercises fundamental geomarketing methods will be implemented to exemplary case studies.
The exercises are carried out individually under supervision. Feedback to the exercises is given to the students by one to one discussions during the contact hours. At the end of the semester, the students have to pass the written exam.

Media:
Moodle e learning platform, presentations, script, pc-lab, hand-out, exercise sheets

Reading List:
Slocum, T., McMaster, R. B., Kessler, F. C., Howard, H. H. (2005): Thematic Cartography and Geographic Visualization. 2nd Edition. Pearson.
Tufte, E. R. (1983): The Visual Display of Quantitative Information. Graphics Press.
O´Sullivan, D., Unwin, D. J. (2003): Geographic Information Analysis. John Wiley & Sons, Inc.
Cliquet, G. (2013): Geomarketing: Methods and Strategies in Spatial Marketing. John Wiley & Sons, Inc.

Responsible for Module:
Liqiu Meng, liqiu.meng@tum.de

Courses (Type of course, Weekly hours per semester), Instructor:
Geostatistics and Geomarketing (exercise, 2 SWS)
Cron J [L], Murphy C, Strobl C, Zoßeder K

For further information in this module, please click
campus.tum.de or here.

Module Description

BV610016: Geodetic Astronomy

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
3	90	60	30

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified with a 15 minutes oral exam at the end of the semester. In the exam it is assessed to what extent the students are able to recognize and categorize astronomical objects, to perform astronomical reductions and understand the most important astro-geodetic instruments and measurement techniques.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Requirements are the basics of astronomical reference systems as presented in the module "Physical geodesy" of the Bachelor Geodesy and Geoinformation.

Content:
- Introduction to general astronomical questions (stars, galaxies, cosmology)
- Introduction to astronomical observation techniques
- Astronomical instruments
- Sextant
- Digital astro-photography
- Astronomical objects
- Distance measurements in the universe
- Cosmology
- Astronomical reference frames
- Astrometrical reductions
- Zenith camera for determining the deviation of the vertical
- Astrometry missions Hipparcos and Gaia
- Astronomical observations at the telescope of IAPG

Intended Learning Outcomes:
At the end of the module the students are able
- to identify celestial objects and to grasp the structure of the cosmos,
- to understand the different methods for distance measurements in the universe
- to understand the functioning of basic astro-geodetic instruments,
- to perform the basic astrometric reductions,
- to understand the relevance of astrometric satellite missions.

Teaching and Learning Methods:
The module consists of a lecture with discussions and illustrative examples and Matlab demonstrations to convey competent knowledge of astronomical objects, measurement instruments and methods. The telescope on the roof of TUM is used for astronomical observations.

Media:
Powerpoint slides and handouts. Beamer and pdf-documents (also available online).

Reading List:

Responsible for Module:
Urs Hugentobler (urs.hugentobler@bv.tum.de)

Courses (Type of course, Weekly hours per semester), Instructor:
Project : Geodetic Astronomy (lecture, 2 SWS)
Hugentobler U [L], Schlicht A

For further information in this module, please click
campus.tum.de or here.

Module Description

EI0432: Satellite Navigation

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
6	180	120	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
Students must participate in a written final exam (90 min) where they explain the functionality of sattelite navigation systems.

Furthermore, they might participate in a mid-term exam. The grade of the mid-term counts for 25% of the final score it this improves that score.

Students might bring up to 8 handwritten one-sided A4 pages to the exam and the midterm.

The exercises are provided one week. The students are expected to solve them at home. The solutions are provided in the following week (presentation by the assistant). The assistants do not correct the student's exercises, and they do also not check whether they solved them.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Mathematics, Signal description in time and frequency domain, Fundamentals of probability calculations and statistics

The following modules should have been successfully passed:
- Höhere Mathematik 1-3
- Signale und Systeme
- Nachrichtentechnik 2

It is recommended to participate in the further modules:
-

Content:
Radio based determination of position, time and velocity
Satellite Orbits and Constellations
Navigation Services and Signals (Modulation and Codes)
Receivers: Signal Acquisition and Tracking
Propagation: Multipath, Ionosphere and Troposphere
Measures of Accuracy
GNSS Systems: Time - Relativistic Corrections; and Terrestrial Reference System

Intended Learning Outcomes:
At the end of the lecture, the student
* will understand the functioning of a satellite navigation system
* will be able to evaluate important performance parameters
* will know the algorithms needed for designing a basic receiver.

Teaching and Learning Methods:
Lerning method:
In addition to the lecture, students familiarize themselves with the material by studying their notes or a book, and by attending the mandatory exercises.

Teaching method:
Lectures are delivered in a front style manner. Questions are highly appreciated - they introduce a level of interaction, and mutual adaptation. The exercises are held in a student-centered way.

Media:
The following media are used:
- Presentations (powerpoint slides, and blackboard for derivations).
- Lecture notes (book).
- Exercises with solutions as download.

Reading List:
The following literature is recommended:
- Misra, P., Enge, P., Global Positioning System: Signals, Measurements, and Performance, Ganga-Jamuna Press, 2nd ed. (2006)
- Kaplan, E., Hegarty, C., Understanding GPS: Principles and Applications, Artech House, 2nd ed. (2006).

Responsible for Module:
Günther, Christoph; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Satellite Navigation (lecture with integrated exercises, 4 SWS)
Günther C, Lülf M

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

EI5060: Satellite Communications Lab

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter/summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
6	180	120	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
During an oral examination about the structure and functionality about the radiome in Raisting students have to explain their solution approach for given problems.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basics on satellite navigation and communications engineering

The following modules should be passed before taking the course:
-

It is recommended to take the following modules additionally:
-

Content:
The student contributes to European student satellite projects. Currently this is the European Student Earth Orbiter (ESEO). TUM took the responsibility to build a steerable 2.3 m ground station, including all controlls, as well as the receive and transmit subsystem. Recently, TUM has also joined the European Student Moon Orbiter (ESMO) mission. In this project we intend to reactivate the 24 m antenna in Raisting (out of service since 1984 but kept intact since then). TUM contributions will also address new approaches to multisatellite networking.

Intended Learning Outcomes:
After completion of the module the students are able to

* analyze satellite communication systems (e.g. Phoenix antenna at TUM, radome antenna in Raisting)
* create/ design printed circuit boards for Phoenix and radome antenna
* develop algorithms for autonomous control of satellite antennas
* develop algorithms for precise positioning

Teaching and Learning Methods:
Lerning method:
In addition to the individual methods of the students consolidated knowledge is aspired by repeated lessons in exercises and tutorials.

Teaching method:
The exercises are held in a student-centered way.

Media:
During the Satellite Communications Laboratory the student will work on his/her own project - self-contained but integrated part of the SSIMUC tasks. Because of this, the student is expected to see himself/herself as active part of the SSIMUC team and to work in close collaboration with other team members.
The laboratory work will not follow a strict schedule. Within the time of one semester, the student is free in his/her own time management. Obligatory are an introductory meeting and a final discussion as well as attendence time at the laboratory, especially to report about the individual proceedings. This attendence time will take around 60 hours during the whole semester.
In order to attest the work, the student will prepare a documentation about the project, including work steps and the presentation of the results. This documentation should have an amount of about 20 pages.
To finish the project, each student will perform a short presentation of the results, followed by a brief discussion.
The mark on this Laboratory course will be composed of the quality of work, the quality of the documentation and the quality of the final presentation.
The projects offered within this Laboratory course will give you a good impression about scientific and engineering work in general and will contribute significantly to your experiences with respect to future bachelor/ master or PhD theses.

Reading List:
The following literature is recommended:
- Lutz, E., Werner, M., Jahn, A. (2000), Satellite Systems for Personal and Broadband Communications, Springer.
- Maral, G., Bousquet, M. (2002), Satellite Communications Systems: Systems, Techniques and Technology, Wiley.

Responsible for Module:
Günther, Christoph; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Satellite Communication Laboratory (practical training, 4 SWS)
Günther C, Lülf M

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

EI71018: Machine Learning for Communications [MLComm]

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The module examination is a written exam (90 min). The overall grade will be solely based on the student's result in the written exam. Students demonstrate that they have gained both fundamental and deeper understanding in various aspects of machine learning for communication, e.g. by dealing with interference problems or by applying learning algorithms. They have to answer the questions with self-formulated responses and do quantitative calculations, e.g. with regards to compression. The allowed support material is constrained to a non-programmable calculator.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basics of Digital Communication/Signal Processing/Estimation and Detection

Content:
This course is on model-based machine learning in communication systems. Covered topics
Modelling:
- Probabilistic models
- Graphical models
- Neural networks
Bayesian Inference:
- Probabilistic programming, learning algorithms
- Learning algorithms for sources, compression
- Learning algorithms for channels and transmission formats
Assessment:
- figures of merit compression ratio, reliability, throughput, energy consumption.
- evaluation of model and learning algorithm using information-theoretic criteria

Intended Learning Outcomes:
Upon successful completion of the module, the student
¿ knows probabilistic models, graphical models, neural networks to solve communications problems.
¿ is able to apply Bayesian inference, learning algorithms for sources, channels, and transmission formats.
¿ is able to apply data compression and transmission ¿ is able to model and infer on his computer and to critically assess the results and the model.

Teaching and Learning Methods:
The lecture is complemented by personal study and repeated lessons in exercises and tutorials where typical

scenarios are discussed; weekly programming tasks where students individually apply algorithms and models.

Media:
The following kinds of media are used:
- Presentations with emphasis on visualization
- Lecture notes
- Exercises with solutions
- Programming problems with solutions

Reading List:
Lecture notes with all relevant information are available.

The following literature can be consulted in addition:
¿ MacKay, D. J. (2003). Information theory, inference and learning algorithms.
¿ Bishop, C. M. (2006). Pattern recognition and Machine Learning.
¿ Murphy, K. P. (2012). Machine learning: a probabilistic perspective.

Responsible for Module:
Kramer, Gerhard

Courses (Type of course, Weekly hours per semester), Instructor:
Machine Learning for Communications (lecture with integrated exercises, 4 SWS)
Kramer G, Steiner F

For further information in this module, please click
campus.tum.de or here.

Module Description

EI7342: Inertial Navigation

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
Es gibt eine Zwischen- (midterm) und Abschlussprüfung (final exam, 75 min). Die Midterm-Prüfung zählt zu 25 % und das Final Exam zu 75 % zur Gesamtnote falls das Midterm-Ergebnis besser ist als das Final Exam. Andernfalls wird lediglich das Final Exam mit 100% gewertet.
Damit bietet die Midterm eine einmalige Möglichkeit zur Verbesserung der eigenen Note und zur Überprüfung des eigenen Wissenstands. Für die Prüfung sind 8 handbeschriebene DIN A4 Seiten und ein Taschenrechner erlaubt.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Grundlagen der Statistik

Content:
Introduction to fundamentals of inertial navigation: angular momentum, torque and inertia tensor; coordinate transformations: direction cosines, Euler angles and Quaternions; Euler equation; Inertial sensors: gyroscopes and accelerometers, Integration of inertial measurements, Calibration of inertial sensors with satellite navigation, Integration of inertial navigation and satellite navigation: deep coupling of tracking loops, loose coupling of navigation solution, Estimation of drift and scaling factor of inertial sensors, Attitude determination with and without carrier phase integer ambiguity resolution, MAP Estimation of attitude, Learning of error behavior of inertial sensors with GPS: Artificial Neuronal Networks, Fusion of measurements from inertial sensors, GNSS receivers and magnetometers, Applications of low-cost inertial sensors.

Intended Learning Outcomes:
Nach der Teilnahme an den Modulveranstaltungen sind die Studierende in der Lage, Algorithmen und Verfahren zur Inertialnavigation zu analysieren und zu bewerten, und eigene Algorithmen zur Kopplung von Inertial- und Satellitennavigation zu entwickeln. Die letztere der beiden Fähigkeiten wird in Matlab-Übungsaufgaben trainiert.

Teaching and Learning Methods:
Lernmethoden:
Der Vorlesungsstoff wird in Übungen regelmässig aufgearbeitet. Darüber hinaus wird ein Selbststudium des Vorlesungsskriptes und der -folien erwartet.
Lehrmethoden:
Die Vorlesungen werden abwechslungsreich gestaltet und enthalten Herleitungen an der Tafel, Zusammenfassungen in Powerpoint Folien, und kurze Demonstrationen in Matlab. Die Studenten werden in

Vorlesung und Übung durch Fragestellungen zum Mitmachen angeregt.

Media:
Folgende Medienformen finden Verwendung:
- Tafelanschrift, insbesondere für Herleitungen und Skizzen
- Powerpoint-Folien, insbesondere zur Zusammenfassung der Tafelanschriften und zum Nacharbeiten, verfügbar auf moodle
- Buch-Kapitel, insbesondere zum Nacharbeiten des Vorlesungsskriptes, verfügbar auf moodle
- Matlab-Codebeispiele, zur Veranschaulichung der Algorithmen

Reading List:
Folgende Literatur wird empfohlen:
[1] Inertial Navigation Systems with Geodic Applications, C. Jekeli, Verlag de Gruyter, 2001.
[2] Global Positioning Systems, Inertial Navigation and Integration, M. Grewal, L. Weill and A. Andrews, Wiley, 2007.

Responsible for Module:
Günther, Christoph; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Inertial Navigation (lecture, 4 SWS)
Henkel P [L], Henkel P

For further information in this module, please click
campus.tum.de or here.

Module Description

EI73761: Radar Signals and Systems

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The examination consists of a written examination of 90 min duration.

In the written examination, students demonstrate by answering questions under time pressure and with limited helping material (formula summary, non-programmable pocket calculator) the theoretical knowledge of radar principles and algorithms.

The final grade consists of the grade of the written exam (100%).

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Undergraduate fundamentals:
- Electrodynamics
- Fourier analysis
- Signals and systems

High-Frequency Engineering:
- Electromagnetic wave propagation
- Antenna parameters

Communications:
- Modulation
- Frequency conversion (mixing)
- Filtering

Content:
1. Basics of Radar
- Summary of radio wave propagation
- Continuous wave (CW) Radar
- Frequency modulated CW (FMCW) Radar
- Pulse Radar
- Pseudo-noise (PN) Radar
- Monopulse Radar
- Fundamental system parameters

2. Components of Radar Systems
- Basics of microwave electron tubes
- Magnetron oscillator
- Klystron amplifier
- Solid-state amplifiers
- Low-power Radar chip sets
- Antenna types

3. Target Detection
- Noise in Radar receivers
- Phase noise in oscillators
- Detection theory
- Matched filter
- Ambiguity function
- Pulse compression
- Clutter
- Moving target indication (MTI)
- PRF Staggering
- Constant false-alarm rate (CFAR)
- Target tracking
- RCS fluctuation

4. Synthetic Aperture Radar (SAR)
- Working principle
- Cross range resolution
- Received signal properties
- SAR processing
- SAR interferometry

5. Radar Meteorology
- Polarimetric characterisation of wave propagation
- Propagation in particle fields
- Rainrate and water content estimation
- Polarimetric classification

Intended Learning Outcomes:
At the end of the module students are able to evaluate radar systems as well as approaches and methods of modern radar technology for location, navigation, and meteorology.

Teaching and Learning Methods:
Teaching method:
During the lectures students are instructed in a teacher-centered style. The tutorial lessons are held in a student-centered way.

Learning method:
In addition to the individual methods of the students consolidated knowledge is aspired by repeated lessons in exercises and tutorials.

Media:
The following types of media will be used and also made available for download:

- Presentations
- Lecture notes
- Tutorial problems with sample solutions

Reading List:
Levanon, N. and Mozeson, E.: Radar Signals. Wiley-IEEE Press, 2014.

Kang, E. W.: Radar System Analysis, Design, and Simulation. Norwood, MA: Artech House, 2008.

Skolnik, M. I.: Introduction to Radar Systems. 3rd ed. Auckland: Mc-Graw Hill, 2001.

Skolnik, M. I.: Radar Handbook. Auckland: Mc-Graw Hill, 1990

Bringi, V. N.; Chandrasekar, V.: Polarimetric Doppler Weather Radar. Cambridge: Cambridge University Press, 2001

Cook, C.E. and Bernfeld, M.: Radar Signals. An Introduction to Theory and Application. Boston: Artech House, 1993

Detlefsen, J.: Radartechnik. Berlin: Springer, 1989 (in german)

Ludloff, A.: Praxiswissen Radar und Radarsignalverarbeitung. Vieweg-Verlag, 2002 (in german)

Responsible for Module:
Eibert, Thomas; Prof. Dr.-Ing.

Courses (Type of course, Weekly hours per semester), Instructor:

Uwe Siart (uwe.siart@tum.de)

For further information in this module, please click
campus.tum.de or here.

Module Description

EI7428: Visual Navigation

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The examination includes a midterm and a final exam. The midterm exam contributes 25 % and the final exam (150 min) 75 % to the final grade if the midterm grade is better than the final grade; otherwise the final exam counts for 100 % and the midterm is simply disregarded.
Consequently, the midterm is a unique opportunity to improve your own grade and to check your own knowledge.
You are allowed to bring 8 handwritten DIN A4 pages and a pocket calculator to the exam.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Linear Algebra

Content:
Introduction on two- and three-dimensional image formation and projective geometry. Elements of image processing: feature extraction, feature matching and outlier removal.
Position and Motion representations: parameterization of spatial displacements and rotations in the three-dimensional space, Lie algebra, dual quaternions, linear and rotational kinematics.
Optimization techniques, batch computation, filtering (Kalman, UKF, EKF)
(Relative) Positioning and Attitude determination from two- and three-dimensional images: optimization problems for motion/scene reconstrution in static scenes; optimization problems for motion/scene reconstrution in dynamic scenes; visual odometry.
Review of (non-visual) positioning sensors and attitude sensors; coupling of visual navigation with INS, GNSS and other sensors for a single navigation solution; methods and algorithms for sensor fusion
Cooperative visual navigation: handling of multiple cameras with overlapping field of view.

Intended Learning Outcomes:
After attending the course, the students will be able to apply the basic principles of visual navigation and sensor fusion, and to develop their own algorithms for the navigation and guidance of autonomous vehicles.

Teaching and Learning Methods:
Learning method:
In parallel to the individual studying of the student, the lecture material is repeated regularly with examples and exercises.
Teaching Methods:
The lectures are given in a teacher-centered style, using derivations on the board, summaries in PowerPoint

slides, and short demonstrations in Matlab. The exercises will be performed by the students, with constant guidance by the teacher.
The students are encouraged during lectures and exercises to ask questions and be actively involved.

Media:
The following media will be used:
- Blackboard, mainly used for mathematical derivations and graphical sketches
- Powerpoint slides, mainly for summarizing the blackboard notations and for self-learning, also available at moodle
- Book chapter, especially for learning the subject, available at moodle
- Matlab-code examples, for visualizing the algorithms

Reading List:
The following literature is recommended:
[1] Multiple view geometry in computer vision, R. Hartley and A. Zisserman, Cambridge University Press, March 2004.
[2] Inertial Navigation Systems with Geodic Applications, C. Jekeli, Verlag de Gruyter, 2001.
[3] Global Positioning Systems, Inertial Navigation and Integration, M. Grewal, L. Weill and A. Andrews, Wiley, 2007.

Responsible for Module:
Günther, Christoph; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Visual Navigation (lecture with integrated exercises, 4 SWS)
Giorgi G

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

EI7640: Signals and Array Signal Processing for Global Navigation Satellite Systems [SAGNSS]

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
3	90	45	45

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
mündliche Abschlussprüfung

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basic knowledge of linear algebra, basic knowledge of satellite navigation, basic knowledge of digital modulation, basic knowledge of MATLAB; lecture Satellite Navigation; lectures Nachrichtentechnik 1/2; lecture Adaptive and Array Signal Processing; lecture Introduction to Signal Processing; lecture Statistical Signal Processing

Content:
GNSS receivers are used in many applications, for example navigation of automobiles, aircraft or ships. In this lecture GNSS signals and signal processing are addressed. An overview on signals and digital modulations of different GNSS is provided and the general problem of signal design for ranging applications is discussed. On the other hand array signal processing methods and concepts for synchronization parameter estimation (time-delay, carrier phase, and Doppler frequency) as well as multipath and interference mitigation for GNSS are introduced. Basic GNSS signal processing using delay locked loops (DLL) and phase locked loops (PLL) are recapitulated and extended to multi-antenna systems using beamforming and multi-dimensional parameter estimation. Also the problem of attitude determination of a multi-antenna platforms based on GNSS signals is studied.

The lecture includes the following topics:
" Digital modulation
" Signal interplexing/mapping schemes
" Signal design for ranging
" Satellite payload characteristics
" Multipath propagation and interference
" Signal processing concepts for GNSS
" Signal acquisition and detection
" DLL discriminator types and their performance
" Multi-antenna receiver architectures and systems
" Robust beamforming algorithms
" Direction-of-arrival (DOA) estimation
" Attitude determination of multi-antenna platforms
" Per-whitening and orthogonal projections
" High resolution synchronization parameter estimation

" Space-time adaptive processing for GNSS

Intended Learning Outcomes:
At the end of the module students are able to understand requirements for design of ranging signals, to understand GNSS payload characteristics, and to analyse characteristics of digital modulations used for GNSS. At the end of the module students are able to understand methods and concepts for GNSS attitude determination, to analyse different GNSS signal processing concepts, and to apply different array processing methods for multipath and interference mitigation.

Teaching and Learning Methods:
Learning method:
In addition to the individual methods of the students consolidated knowledge is aspired by repeated lessons in exercises and tutorials.

Teaching method:
During the lectures students are instructed in a teacher-centered style. The exercises are held in a student-centered way.

Media:
Beamer presentation, use of blackboard for mathematical derivations and graphical sketches, tutorials with solutions, MATLAB-code examples

Reading List:
[1] Misra, P. & Enge, P. (2006), Global Positioning System: Signals, Measurements, and Performance, Second Edition, Ganga-Jamuna Press. [2] Kaplan, E., Hegarty C. (2006), Understanding GPS: Principles and Applications, Second Edition, Artech House. [3] S. M. Kay, Fundamentals of Statistical Signal Processing: Estimation Theory, vol. 1, Prentice Hall PTR, 1993. [4] Harry L. Van Trees, Optimum Array Processing. Detection, Estimation and Modulation Theory, Part IV, Wiley Interscience, 2002.

Responsible for Module:
Utschick, Wolfgang; Prof. Dr.-Ing.

Courses (Type of course, Weekly hours per semester), Instructor:
Signals and Array Signal Processing for Global Navigation Satellite Systems (GNSS) (lecture with integrated exercises, 3 SWS)
Antreich F, Rizzello V

For further information in this module, please click
campus.tum.de or here.

Module Description

EI7648: Space Electronics for Sensor Systems

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	German	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	105	45

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
By participation in the module the student receives a deeper understanding and knowledge in the following areas:

- Basics in project- and system engineering management
- Project planning, project exectution tools and (soft-) skills
- Phased ESA development approach according to maturity
- Overview of space missions (mission subject, segments, ...)
- Characterisation of environmental conditions such as cosmic radiation, vacuum, ...
- Interaction of cosmic radiation with electronical, optical and opto-electronical parts
- Design, development and qualification of space systems

During the project work an ESA project will be performed in ""fast-motion"". Group-work will be established to work on separate fields of space-system development. Review meetings between customer and contractor will be conducted on the basis of roll playing. Existing ESA project documentation will be used in order to bridge the gap between theory and praxis.

Repeat Examination:
Next semester / End of Semester

(Recommended) Prerequisites:
Basic principles of Electrical Engineering and/or Physics

Content:
By participation in the module the student receives a deeper understanding and knowledge in the following areas:

- Basics in project- and system engineering management
- Project planning, project exectution tools and (soft-) skills
- Phased ESA development approach according to maturity
- Overview of space missions (mission subject, segments, ...)
- Characterisation of environmental conditions such as cosmic radiation, vacuum, ...
- Interaction of cosmic radiation with electronical, optical and opto-electronical parts
- Design, development and qualification of space systems

During the project work an ESA project will be performed in ""fast-motion"". Group-work will be established to work on separate fields of space-system development. Review meetings between customer and contractor will be conducted on the basis of roll playing. Existing ESA project documentation will be used in order to bridge the gap between theory and praxis.

Intended Learning Outcomes:
After the participation in the module the student is able to

- applying the role distributions in development projects in the frame of space missions and to take part in such projects.
- evaluating the characterisation of environmental conditions such as radiation, temperature variations, vacuum etc. for instruments and systems
- creating, design, development and qualification of space systems

Teaching and Learning Methods:
In addition to the individual methods of learning a deeper understanding of the matter will be achieved by cooperative discussions and teamwork for problem solving and project work.

Media:
The following kinds of media are used:
- Presentations
- Lecture notes (presentation slides and reference documents)
- Download on Moodle

Reading List:
The following literature is recommended:

¿ Handbuch der Raumfahrttechnik, Wilfried Ley (Herausgeber), Carl Hanser Verlag GmbH & CO (Neueste Ausgabe 2011, alte Ausgabe 2008: TUM Bibliothek 0702/VER 820f)
¿ Space Mission Analysis and Design , W. Larson; J. Wertz, Kluwer, 2006, Space mission analysis and design (TUM Bibliothek 0303/VER 820 L 7311)
European Standard for Space Electrical and Electronic Equipments, ECSS-E-ST-20C (see www.ecss.nl)

Responsible for Module:
Koch, Alexander; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Space Electronics for Sensor Systems (research lab training, 1 SWS)
Plattner M (Dong J, Dong X, Jakobi M, Wang S)

Space Electronics for Sensor Systems (lecture, 2 SWS)
Plattner M (Dong J, Dong X, Wang S)

For further information in this module, please click
campus.tum.de or here.

Module Description

EI7772: Seminar Environmental Sensing

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter/summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	105	45

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
Die Prüfungsart ist den verschiedenen Lernergebnissen angepasst: Die Fähigkeit zur
- wissenschaftlichen Arbeitsweise wird durch regelmäßige Gespräche geprüft,
- Präsentation der Ergebnisse vor einem fachlichen Publikum wird durch den Vortrag mit Diskussion geprüft,
- wissenschaftlichen Dokumentation wird durch die Ausarbeitung geprüft.

Die Durchführung incl. der Dokumentation erfordert eigene Recherchen, Rechnungen und Formulierungen. Details zu den Hilfsmitteln werden während der Veranstaltung bekannt gegeben. Die Kompetenz zur wissenschaftlichen Recherche, Dokumentation und Präsentation auf dem Gebiet der Umweltsensorik soll während der Veranstaltung nachgewiesen werden.

Die Endnote setzt sich aus folgenden Prüfungselementen zusammen: jeweils zu einem Drittel
- regelmäßige Gespräche mit den zugeordneten Betreuern über den Fortschritt der Arbeit und das Vorgehen,
- das Anfertigen einer Ausarbeitung, in der Arbeitsinhalte und Ergebnisse dargestellt sind,
- die Präsentation der erarbeiteten Inhalte und Ergebnisse im Rahmen eines 10- bis 15-minütigen Vortrags und anschließender Diskussion (5 bis 10 Minuten).

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Grundlagen in Elektrotechnik, Physik und Optik.

Content:
Die Modulteilnehmer erarbeiten selbständig aktuelle wissenschaftliche Beiträge aus dem Bereich der Umweltsensorik, fertigen eine zu bewertende schriftliche Ausarbeitung an und tragen ihre Resultate vor. Die Thematik wird in der Diskussion intensiv behandelt.

Intended Learning Outcomes:
Durch die Teilnahme an den Modulveranstaltungen erhalten die Studierenden Kenntnisse von Themenfeldern der Umweltsensorik.

Die Studierenden sind anschließend in der Lage eine Aufgabenstellung aus einem aktuellen Themengebiet der Umweltsensorik selbstständig auf wissenschaftliche Weise zu bearbeiten und eine schriftliche Ausarbeitung dazu anzufertigen. Darüber hinaus können die Studierenden die von ihnen erarbeiteten Erkenntnisse vor einem fachlichen Publikum präsentieren.

Teaching and Learning Methods:
Jeder Teilnehmer bearbeitet eine individuelle fachliche Aufgabenstellung. Dies geschieht insbesondere in selbständiger Einzelarbeit der Studierenden. Die Teilnehmer bekommen - abhängig von ihren individuellen Themen - jeweils eigene Betreuer zugeordnet. Die Betreuer hilfen den Studierenden insbesondere zu Beginn der Arbeit, indem sie in das Fachthema einführen, geeignete Literatur zur Verfügung stellen und hilfreiche Tipps sowohl bei der fachlichen Arbeit als auch bei der Erstellung der schriftlichen Ausarbeitung und des Vortrags geben.

Media:
Folgende Medienformen finden Verwendung:
- rechnergestützte Präsentation für den Vortrag der Teilnehmer,
- die Studierenden arbeiten überwiegend an zur Verfügung gestellten Rechnern mit entsprechenden Softwareprogrammen.

Reading List:
Folgende Literatur wird empfohlen:
- abhängig von den einzelnen Themen sind beispielsweise Bücher, Skripte und Forschungsberichte vorhanden.

Responsible for Module:
Chen, Jia; Prof. Dr.-Ing.

Courses (Type of course, Weekly hours per semester), Instructor:
Advanced Seminar Environmental Sensing (advanced seminar, 3 SWS)
Chen J [L], Chen J (Bhattacharjee S, Dietrich F)

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

EI7777: Seminar Navigation

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter/summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	120	30

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
- Understanding of research topic of Satellite Navigation,
  Inertial Navigation, Visual Navigation or Sensor Fusion
  by reading of Journal paper
- Development and implementation of a method for complementing
  the research topic
- Summary of research topic in a 3-pages paper in own words
- Presentation of paper

The evaluation is based on the following criteria:

- understanding of research topic
- complexity of the research topic
- self-dependence of working
- precision of phrasing

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Satellite Navigation

Content:
- Understanding of research topic of Satellite Navigation,
  Inertial Navigation, Visual Navigation or Sensor Fusion
  by reading of Journal paper
  * Phase bias estimation with a network of reference stations
  * Partial integer ambiguity resolution
  * Visual Simultaneous Localization and Mapping (VSLAM)
  * Sensor fusion with tight coupling of GNSS, INS and barometer
    measurements
  * Precise point positioning with single-frequency GNSS receivers
- Development and implementation of method to extend/ improve
  method of research topic
- Summary of research topic in 3-pages paper in own words

Intended Learning Outcomes:
At the end of this module, students are able to understand a komplex research topic in navigation and to develop algorithms and methods to extend/ improve the navigation solution.

Teaching and Learning Methods:
In the seminar, a journal paper shall be carefully read and understood in self-study. Additional explanations from the supervisor includes derivations on the whiteboard, summaries in Powerpoint and code demonstrations in Matlab. The students are encouraged to ask questions.

Media:
The following media will be used:
- Blackboard, mainly used for mathematical derivations and graphical sketches
- Powerpoint slides, mainly for summarizing the blackboard notations and for self-learning, also available at moodle
- Matlab-code examples, for visualizing the algorithms

Reading List:
The following literature is recommended:
[1] Understanding GPS, P. Misra and P. Enge, 2006.
[2] Inertial Navigation Systems with Geodic Applications, C. Jekeli, Verlag de Gruyter, 2001.

Responsible for Module:
Christoph Günther
christoph.guenther@tum.de

Courses (Type of course, Weekly hours per semester), Instructor:
Seminar Navigation 2SWS
Patrick Henkel
patrick.henkel@tum.de

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

MW0141: Advanced Systems Engineering [ASE]

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Bachelor/Master	German	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
3	90	60	30

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
In der mündlichen Prüfung werden die vermittelten theoretischen Inhalte aus der Vorlesung geprüft. Ein weiterer Teil der mündlichen Prüfung besteht aus einem Vortrag zu einem ausgewählten Teil der Vorlesung.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Modul Systems Engineering

Content:
Die Vorlesung Advanced Systems Engineering unterteilt sich thematisch in zwei unterschiedliche Themenbereiche. Im ersten Block der Vorlesung wird anhand eines raumfahrtbezogenen Beispielsystems das allgemeine System Engineering Vorgehen   also von der Problemerfassung bis hin zur Lo sung des Problems   exemplarisch vorgestellt und im Details zusammen mit den Studenten ausgearbeitet.

Der Schwerpunkt des zweiten Blocks der Vorlesung ist aus dem Schwerpunkt der Hauptvorlesung Systems Engineering abgeleitet und soll den Studenten weitere vertiefende Kenntnisse auf dem Gebiet der Modellierung von komplexen technischen Systemen mit Hilfe der Systemmodellierungssprache SysML erla utern und anhand eines raumfahrtbezogenen Beispielsystems demonstriert werden.

Intended Learning Outcomes:
Nach der Teilnahme an der Modulveranstaltung Advanced Systems Engineering sind die Studierenden in der Lage, komplexe technische Systeme selbstständig in einer objektorientierten Modellierungssprache (z.B. SysML) zu modellieren, zu verstehen und die erarbeiteten Modelle zu bewerten.

Teaching and Learning Methods:
In der Vorlesung werden die Lehrinhalte anhand von Vortrag, Präsentation und Tafelanschrieb vermittelt.

Media:
Vortrag, Präsentation, Handzettel, Tafelanschrieb

Reading List:
Systems Engineering - Methodik und Praxis W.F. Daenzer, F. Haberfellner, ISBN 3-85743-998-X

Objektorientierte Softwaretechnik - mit UML, Entwurfsmustern, Java Bernd Brügge, Allen H. Dutoit, ISBN 3-8273-

7082-5

Responsible for Module:
Brandstätter, Markus; Dipl.-Inf. (Univ.)

Courses (Type of course, Weekly hours per semester), Instructor:
Advanced Systems Engineering (lecture, 2 SWS)
Brandstätter M, Schummer F

For further information in this module, please click
campus.tum.de or here.

Module Description

MW0259: Practical Course Systems Engineering

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Bachelor/Master	German	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
4	120	60	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
Die erarbeiteten Ergebnisse des Praktikums Angewandte Systemtechnik müssen innerhalb des Praktikums präsentiert werden. Außerdem muss eine knappe Ausarbeitung verfasst werden. Die Präsentation zusammen mit Ausarbeitung ergeben die Praktikumsnote.

Repeat Examination:
End of Semester

(Recommended) Prerequisites:
Modul Systems Engineering

Content:
Im Praktikum Angewandte Systemtechnik werden die theoretischen Grundlagen des modellbasierten Systems Engineerings aus der Vorlesung Systems Engineering aufgegriffen und anhand eines konkreten Satellitenprojekts deren praktische Anwendung demonstriert.
Im Rahmen des Praktikums sollen die Studenten sowohl die Satellitenmission, als auch sämtliche relevanten Subsysteme des Satelliten modellieren und auslegen, so dass dieser gebaut werden könnte. Dabei kommt insbesondere die objektorientierte Modellierung und das "Concurrent Engineering Vorgehensmodell", also das zeitgleiche Arbeiten an einem Modell des Satelliten, zum Einsatz.
Für die Modellierung und Auslegung des Satelliten wird das am Lehrstuhl entwickelte Programm (v)Sys-ed verwendet. Mit Hilfe dieses Werkzeugs kann eine Satellitenmission, angefangen bei der Vorstudie, bis hin zur Auslegung der Subsysteme modelliert werden.

Intended Learning Outcomes:
Nach der Teilnahme an der Modulveranstaltung Angewandte Systemtechnik sind die Studierenden in der Lage, komplexe technische Systeme zu verstehen, zu bewerten, selbstständig ein einfaches Modell eines Satelliten zu erstellen sowie eine einfache Satellitenmission zu planen und erstellen. Des Weiteren sind die studierenden in der Lage technische Problemstellungen im Umfeld der Satellitenentwicklung mittels des "Concurrent Engineering Vorgehensmodells" zu lösen.

Teaching and Learning Methods:
Im Praktikum werden die Lehrinhalte anhand von Vorträgen, Präsentation, Tafelanschrieb sowie durch praktische Unterstützung vermittelt.

Media:
Vortrag, Präsentation, Handzettel, Tafelanschrieb

Reading List:
Systems Engineering - Methodik und Praxis W.F. Daenzer, F. Haberfellner, ISBN 3-85743-998-X

Responsible for Module:
Brandstätter, Markus; Dipl.-Inf. (Univ.)

Courses (Type of course, Weekly hours per semester), Instructor:
Practical Course Systems Engineering (practical training, 4 SWS)
Brandstätter M, Schummer F

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

MW1790: Near Earth Objects (NEOs)

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
3	90	60	30

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
Oral exam at the end of the semester

Repeat Examination:

(Recommended) Prerequisites:
Basics of spacecraft technology and astrodynamics.

Content:
Basic theories, methods and tools: Detection, tracking, cataloging and characterization of near earth objects.
Methods and technologies: Mitigation of danger, findings, contact, diversion, destruction.
Tools for the simulation and analysis of time, cost and risk in NO project.
Engineering Data and Information sources: National and International Agencies like DLR, NASA, ESA; Institutions like Universities, Observatories ,Amateur Groups like NEAT.
The lecture will be held in English.

1 GENERAL INTRODUCTION (2 HOURS)
2 FROM OBSERVATIONS TO MEASUREMENTS (2 HOURS)
3 ORBIT DETERMINATION AND FIRST IMPACT WARNING (4 HOURS)
4 ASTEROID PHYSICAL PROPERTIES DETERMINATION (4 HOURS)
5 IMPACT EFFECTS AND CONSEQUENCES (2 HOURS)
6 MITIGATION AVOIDING AN IMPACT (4 HOURS)
7 WAR GAME: WHAT TO DO IN CASE OF AN IMMINENT IMPACT THREAT? (2 HOURS)
8 THE NEO DECISION PROCESS AS A SYSTEM (OF SYSTEMS) (2 HOURS)
9 SUMMARY (2 HOURS)

Intended Learning Outcomes:
At the end of the module, the students will understand the physical properties of Near-Earth Objects and their threat potential for Earth. They will further have gained an understanding of the design processes behing NEO-deflection missions, as well as for the political and organizational boundary conditions for such an operation. They will also have gained insight into the technical means of NEO observation and deflection.

Teaching and Learning Methods:
The module contains lectures

Media:
Script of presentation slides

Reading List:
None beyond the lecture slides.

Responsible for Module:
Igenbergs, Eduard; Prof.

Courses (Type of course, Weekly hours per semester), Instructor:
Near Earth Objects (NEOs) - Tutorial (exercise, 1 SWS)
Koschny D, Grill L

Near Earth Objects (NEOs) (lecture, 2 SWS)
Koschny D, Grill L

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

MW1998: Selected Topics of Launcher Propulsion [SLP]

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	German/English	one semester	winter/summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
3	90	60	30

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The performance is checked by a written examination which consists of a questionaire where the knowledge of specific terms and fundamentals is tested. The re-examination may be hold orally.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
"Spacecraft Propulsion 1" or "Astronautics 1/2" recommended

Content:
The course "Selected Topics of Launcher Propulsion" is hold in summer and winter term. As the title suggests, the subjects of the individual lectures deal with different important aspects of launchers such as turbo pumps, ignition, life cycle analysis, specifics of staging and stages, propellants, structural mechanics, combustion, or launcher and mission design and architure. Emphasis is put on the variety of disciplines and their interaction which are all important for a successful launch system.

Intended Learning Outcomes:
After attendance to the lecture series "Selected Topics of Launcher Propulsion" the students have an insight into almost all different aspects of a launch system and are able to distinguish the complexity of the processes taking place in a launcher.

Teaching and Learning Methods:
Within the course, the content of teaching is given by presentation and lecture. Definitions and fundamentals are presented and internalised with the help of real applications and calculational examples. The slides of the presentation, additional information, exercises with sample solution and a comprehensive questionaire are provided via TUM E-Learning system. A question time will be arranged some time before examination. Specific questions may be discussed with the lecturers after each lecture or during consultation-hour (on appointment). The module is complemented by a voluntary excursion.

Media:
lecture, presentation, PC with projector, slide library, exercises with sample solution for private study when appropriate

Reading List:
George P. Sutton, Oscar Biblarz: "Rocket Propulsion Elements"; 7th Ed., Wiley-Interscience, 2000, ISBN 0-471-32642-9

Responsible for Module:
Haidn, Oskar; Prof. Dr.-Ing.

Courses (Type of course, Weekly hours per semester), Instructor:
Selected Topics of Launcher Propulsion (MW1998) (lecture, 2 SWS)
Sternin A [L], Haidn O

For further information in this module, please click
campus.tum.de or here.

Module Description

MW2079: Thermal Space Simulation

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:

Credits:*	Total Hours:	Self-study Hours:	Contact Hours:
4			

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:

Repeat Examination:

(Recommended) Prerequisites:

Content:

Intended Learning Outcomes:

Teaching and Learning Methods:

Media:

Reading List:

Responsible for Module:

Courses (Type of course, Weekly hours per semester), Instructor:
Practical Course Thermal Space Simulation (practical training, 4 SWS)
Walter U [L], Reiß P

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

MW2155: Human Spaceflight [HSF]

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	German	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	105	45

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
After the lecture period there will be a written exam (90 min). In mostly open questions, some multiple choice questions and a few math problems the students have to demonstrate their knowledge of the basic processes, relationships, engineering issues, figures of merit and their general scale in the area of human spaceflight. This knowledge has to be transferred quantitatively to problems that were not specificly covered in the lecture or the tutorial.
Allowed aids: non-programmable calculator, dictionary for foreign students.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basic knowledge in the area of spaceflight and system design, as it is for instance conveyed in the Bachelor module "Fundamentals of Spaceflight", is required. It is not a compulsory prerequisite, but it immensely aids understanding the contents of this module.

Content:
Contents of the lecture:
Astronaut selection, training and education of astronauts, introduction to manned space transportation systems, living and working in space, space environment and its biomedical effects on the human body and psyche during spaceflight, space science, fundamentals of life support systems, physico-chemical vs. bio-regenerative life support systems, design of orbital and planetary habitats, space stations, preparation and execution of extra-vehicular activities, utilization of local resources (e.g. on the Moon) versus full resupply, mission analysis and planning of manned missions

In the tutorials the contents of the lecture are consolidated using a single example mission throughout and providing a weekly overview of current events in spaceflight in general and human spaceflight in particular.

Intended Learning Outcomes:
After participating in the module human spaceflight students have insight into all aspects of human spaceflight. They therefore can differentiate the areas of manned and unmanned spaceflight exactly. They are able to understand the special challenges created by the hostile environment in space and on other celestial bodies and know about their effects on engineering problems during the design of manned spacecraft and missions. The students can use their understanding of the technical and political boundary conditions to analyze the necessary requirements for the technical systems involved (e.g. life support systems). After completing the module, the students are able to independently evaluate system and mission concepts with regard to their basic mission objectives.

Teaching and Learning Methods:
During the lecture the content is conveyed through presentations. The students have online access to a collection of slides.
During the tutorial, the lecture content is consolidated and expanded through a short presentation. Afterwards, the students have to independently solve a problem using the conveyed knowledge. The problems can be either mathematical calculations or conceptual systems designs.

Media:
Lecture, slides, worksheets

Reading List:
Human Spaceflight Mission Analysis and Design, W. Larson and L. Pranke, McGraw-Hill, 2000 ISBN 0-07-236811-X

Responsible for Module:
Olthoff, Claas; Dr.-Ing.

Courses (Type of course, Weekly hours per semester), Instructor:
Tutorial Human Spaceflight (exercise, 1 SWS)
Walter U [L], Walter U, Pütz D, Grill L

Human Spaceflight (lecture, 2 SWS)
Walter U, Pütz D

For further information in this module, please click
campus.tum.de or here.

Module Description

PH2090: Computational Physics 2

Simulation of Classical and Quantum Mechanical Systems
Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
There will be a written exam of 90 minutes duration. Therein the achievement of the competencies given in section learning outcome is tested exemplarily at least to the given cognition level using calculation problems and comprehension questions.
For example an assignment in the exam might be:
- Derive the formula for the discrete Fourier transform by evaluating the integral in the continuous Fourier transform with the trapezoidal rule. How many terms have to be calculated to transform N data points?
- Give the DE that describes a pendulum with friction and a periodic driving force. How would you solve this DE numerically? Sketch several orbits in phase space.

Repeat Examination:
End of Semester

(Recommended) Prerequisites:
No preconditions in addition to the requirements for the Master's program in Physics, but knowledge of the subjects covered in PH2057 is strongly recommended.

Content:
Multiple subjects from Computational Physics are discussed:
- Random Numbers
- Fourier Transform
- Nonlinear Systems and Chaos
- Fractals
- Time evolution of Quantum Wave Packets
- Integral Equations
- Finite Elements
- Wavelets
- Quantum Paths via Functional Integration
- Introduction to Lattice Gauge Theory

Intended Learning Outcomes:
After successful completion of this module, students are able to:
- construct and solve numerical descriptions of classical and quantum mechanical problems.
- apply ordinary and partial differential equations, Monte Carlo methods and chaos theory.
- know (and rate) advanced numerical methods used in current research.

Teaching and Learning Methods:
This module consists of a lecture and an exercise class.
In the lecture, the contents are first explained on a theoretical level on an electronic whiteboard (the slides can be downloaded from the lecturer's web site immediately after the lectures). Then, the algorithms are implemented in the computer algebra system Mathematica to study the practical applicability of the concept. Whenever possible, the students are asked for input during this process, and if a suggested approach fails (e.g. due to numerical instabilities), the causes are discussed and alternatives are presented.
Exercise sheets (which frequently include reproduction of the results of the lecture) are first worked on individually by the students and then discussed in small groups under supervision.

Media:
Presentations on an electronic Whiteboard, demonstrations in Mathematica, C and Python ; exercise sheets.
Accompanying web page: http://users.ph.tum.de/srecksie/lehre

Reading List:
- R.H. Landau, M.J. Páez and C.C. Bordeianu: Computational Physics: Problem Solving with Computers, Wiley-Vch, (2007)
- G.P. Lepage: Lattice QCD for Novices, arXiv, (2005), http://arxiv.org/abs/hep-lat/0506036

Responsible for Module:
Recksiegel, Stefan; Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Computational Physics 2: Simulation of Classical and Quantum Mechanical Systems (lecture, 2 SWS)
Recksiegel S

Exercise to Computational Physics 2: Simulation of Classical and Quantum Mechanical Systems (exercise, 2 SWS)
Recksiegel S

For further information in this module, please click
campus.tum.de or here.

Module Description

PH2101: FPGA based detector signal processing

Civil, Geo and Environmental Engineering

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter/summer semester
Credits:* 5	**Total Hours:** 150	**Self-study Hours:** 90	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
There will be an oral exam of 25 minutes duration. Therein the achievement of the competencies given in section learning outcome is tested exemplarily at least to the given cognition level using comprehension questions and sample calculations.
For example an assignment in the exam might be:
- What is an FPGA?
- Waht components are inside an FPGA?
- What is CDC?

In the exam no learning aids are permitted.
There will be a bonus (one intermediate stepping of "0,3" to the better grade) on passed module exams (4,3 is not upgraded to 4,0). The bonus is applicable to the exam period directly following the lecture period (not to the exam repetition) and subject to the condition that the student passes the mid-term of accomplishing a laboratory assignment.

Repeat Examination:
Next semester / End of Semester

(Recommended) Prerequisites:
No preconditions in addition to the requirements for the Master's program in Physics.

Content:
Detector data acquisition and online signal processing with programmable logic / field programmable gate arrays (FPGAs).
- Introduction to the FPGA design process (modeling, simulation, synthesis, Xilinx design tools)
- Introduction to the VHDL hardware description language (modularity, concurrent/sequential statements, synchronous/asynchronous logic)
- Electronic design with VHDL and FPGAs (pipelined data processing, data flow control, counters, state machines)
- Signal processing basics (signal sampling, FFT, digital filters)
- Detector readout concepts (analog pipeline ASICs, sampling ADCs)
- Debug and measurement equipment (oscilloscope, logic analyzer)
- Design of a data acquisition system based on Xilinx FPGAs for a particle detector. (frontend ASIC configuration and readout, signal baseline correction, trigger decision, amplitude detection, ...)

Intended Learning Outcomes:
After successful completion of the module the students are able to
- understand how FPGAs are built up
- create FPGA projects
- code in VHDL

Teaching and Learning Methods:
The module is divided into a lecture part and a laboratory assignment. The basic theory is covered by the lecture which can be applied immediately to the design software in the laboratory part. The different tasks for the final data acquisition project are shared between the students. The Xilinx FPGA design software is also available for installation on student laptops.

Media:
Blackboard, exercises and examples, lecture notes

Reading List:
- P.A. Simpson: FPGA Design, Spinger, (2010)
- P. J. Ashenden: The Student's Guide to VHDL, Morgan Kaufmann, (2008)
- P. J. Ashenden: The Designer's Guide to VHDL, Morgan Kaufmann, (2008)
- W.R. Leo: Techniques for Nuclear and Particle Physics experiments, Springer, (1994)

Responsible for Module:
Paul, Stephan; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
FPGA Based Detector Signal Processing (lecture, 2 SWS)
Paul S (Huber S)

Exercise to FPGA Based Detector Signal Processing (exercise, 2 SWS)
Paul S [L], Gaisbauer D, Huber S, Levit D, Steffen D

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU30062: Geoinformation [Geoinformation]

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	105	45

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
A written exam of 60 min takes place in the end of the semester. By answering the questions the students verify that they have gained the required knowledge about spatial data management, the analysis of geodata, spatial data mining and cartographic techniques for visualising spatial data. The exam contains questions in which they have to give valid definitions, explain concepts, theoretically implement and evaluate case studies, as well as mastering design challenges. All learning outcomes are covered by this written exam.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Knowledge of higher mathematics and experiences of handling spatial data

Content:
This module includes the following topics:
- Introduction to GIS;
- Spatio-temporal representations and databases;
- Spatial data analysis;
- Spatial data mining;
- Data retrieval and cartographic techniques;
- Introduction to ArcGIS components;
- Working with multiple data tables;
- Learning spatial analysis methods;
- Building 3D models;
- Creating animations;
- Designing a quality Map in a GIS;
- Collecting spatial data during field work and integrating it to a GIS

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to illustrate the dimensions of geoinformation;
- to explain the structure of a GIS;
- to implement concepts of geodata harmonization to integrate geodata into a GIS;
- to implement geoanalytical methods;
- to apply properties of different map projections and to select appropriate projections for specific purpose;
- to implement map generalization concepts and algorithms;
- to evaluate spatial databases and the spatial data quality within geodata-management;

- to generate three dimensional data models

Teaching and Learning Methods:
The module is structured in lectures with integrated exercises. The lectures provide the theoretical foundations of geoinformation. They impart knowledge about spatial data management, the analysis of geodata, spatial data mining and cartographic techniques for visualising spatial data. The integrated exercise part of this module allows the students to employ their GIS knowledge to applied studies. An introduction to ArcGIS will be given and the students can analyse and visualise geodata using a variety of analysis tools and visualisation techniques. A set of exercises put the theoretical knowledge into practice. The exercises are carried out in a computer lab individually, partly under supervision within lecture time and partly in self-study. Feedback on the exercises is given to each student within a personal one-on-one discussion.

Media:
Moodle E-learning, presentations, script, GIS laboratory, hand-outs, recommended literature

Reading List:
Longley, P. A., Goodchild, M. F., Maguire D. J., Rhind, D. W. (Eds.) (2005): Geographical Information Systems ¿ Principles, Techniques, Management and Applications. John Wiley & Sons.
Law, M., Collins, A. (2013): Getting to Know ArcGIS for Desktop. Esri Press.

Responsible for Module:
Prof. Liqiu Meng (liqiu.meng@tum.de)

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU45038: Atmosphere and Ocean

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by an written exam of 90 min duration. In this exam, it is verified that the students are able to understand the individual concepts of describing the physical behavior of atmosphere and ocean, the corresponding satellite techniques to observe static and dynamic properties of these two sub-systems of the Earth system, to build interrelations among these concepts and to understand their contribution to the overarching concept of the Earth system. By means of dedicated questions, it is verified that the students are able to interpret results of observation technologies and that they are able to build connections to physical modelling.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Fundamentals in mathematics, experimental physics; mathematical physics, linear algebra, time series analysis
Introduction to Earth System Science (BGU45037)
Numerical Modeling (BGU57018)
Signal Processing and Microwave Remote Sensing (BGU31006)
Applied Earth Observation (BGU45040)

Content:
The module consists of two lectures "Atmospheric Physics and Remote Sensing" and "Oceanography and Satellite Altimetry" that are addressing aspects of the important and tighly coupled Earth system components atmosphere and ocean in a complemenary and integrative manner:
Atmospheric Physics and Remote Sensing:
Introduction to atmospheric physics with an emphasis on remote sensing of atmospheric components and processes from space:
- atmospheric layers, circulation and Greenhouse Effect
- atmospheric composition
- Water Vapor and Carbon Dioxide
- aerosols, clouds, and Earth's radiation budget
- atmospheric dynamics
- passive Remote Sensing
- Lidar Remote Sensing of aerosols
- wind and water vapor Lidars
- meteorology and weather forecasts
- global climate change
- new observational needs

Oceanography and Satellite Altimetry:

- Equation of motion,
- geostrophic currents,
- hydrostatic balance,
- temperature, salinity, and density,
- ocean tides, tidal analysis,
- radar altiemtry: signal theory and estimation process
- radar altimetry: atmosperhic and geophysical corrections to estimate sea level
- altimeter mission overview,
- description of altimetry data products
- repeat pass and crossover analysis,
- mean sea surface, geoid, dynamic ocean topography, sea level variability, sea level rise

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand the basic principles of atmosphere, weather, and climate and the methods for determining atmospheric composition and dynamics from space,
- to apply these principles and methods for practical problems,
- to apply the most basic principles of physical oceanography and recognize satellite altimetry as an operational remote sensing technique with important applications in geodesy, oceanography and other geosciences,
- to understand the concept of satellite altimeter missions,
- to apply altimetric observation techniques and the necessary measurement correction,
- to know about data and product availability and data access,
- to understand important analysis methods in satellite altimetry, and
- to apply them to practical problems,
- to understand the geophysical application of satellite altimetry and,
- to develop overarching concepts for monitoring several components of the Earth system

Teaching and Learning Methods:
The content of the module is tought in two lectures. Both are condicted in interaction with the students whereby the learning success is continuously monitored through questions to the students. Mathematical derivations and calculations are shown at the black board.

Media:
- presentations in electronic form
- blackboard
- selected text books and scientific publications

Reading List:
- U. Schumann, Atmospheric Physics, Research Topics in Aerospace, Springer-Verlag Berlin Heidelberg, 2012
- F.W. Taylor, Elementary Climate Physics, Oxford University Press, 2005.
Further reading:
- J.M. Wallace and P.V. Hobbs, Atmospheric Science: An Introductory Survey, Academic Press, 2nd edition, 2006.
- W. Roedel, Physik unserer Umwelt: Die Atmosphaere, Springer, 3. Auflage, 2000.
- L. Bergmann und C. Schaefer, Lehrbuch der Experimentalphysik Band 7: Erde und Planeten, de Gruyter, 2. Auflage, 2001.
- Stewart, R.: Introduction to Physical Oceanography (OpenSource Book)
- Fu, L.L. and A. Cazenave (Eds.) Satellite Altimetry. International Geophysics Series, Vol. 69, San Diego, CA, 2000

Responsible for Module:
Roland Pail

Courses (Type of course, Weekly hours per semester), Instructor:
Atmospheric Physics and Remote Sensing (lecture, 2 SWS)
Kiemle C

Technische Universität München

Satellite Altimetry and Physical Oceanography (lecture, 2 SWS)
Seitz F [L], Passaro M

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU45039: Earth Observation Satellites

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	75	75

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam of 90 min duration. In the exam it is verified that the students are able to remember and to understand the main concepts of potential field theory and the observation techniques of the Earth s gravity and magnetic field from space. The students verify that they are able to build interrelations among these concepts, that they are able to apply methods for processing of satellite gravity and magnetic field data and to link them to global potential field modelling. By means of dedicated questions, it is verified that the students are able to interpret results of gravity and magnetic field observation technologies and that they are able to build connections to system Earth processes.

In addition voluntary course work, which is composed of 3-5 exercise reports for selected topics of Earth Observation satellite data analysis, as well as the presentation on a scientific subject related to a topic of the guest lectures, is recommended as a midterm assignment. The midterm assignment is passed if as a minimum 60% of the tasks have been completed successfully. In this case, the grading can be improved by 0,3 (provided that the original grading is lower or equal 4,0). The work is usually started during supervised labs and finalized in groups as homework. Hereby the students demonstrate that they are able to apply mathematical methods and solve problems of Earth Observation data analysis in a programming environment such as Matlab. In addition to the application and implementation, the students demonstrate that that they can interpret the results and verify their plausibility. With the presentation of 15-20 min duration, it is verified that the students are able to prepare and to present a scientific topic to a larger audience.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Recommended:
- Introduction to Earth System Science (BGU45037)
- Introduction to Satellite Navigation and Orbit Mechanics (BGU61029)
- Signal Processing and Microwave Remote Sensing (BGU31006)

Content:
- Introduction to potential field theory
- principles of satellite gravimetry and magnetometry
- mission concept and goals of the satellite gravity missions CHAMP, GRACE, GOCE
- mission concept and goals of the magnetic field missions ØRSTED, SAC-C, SWARM
- applications of satellite gravity and magnetic field data in earth sciences

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able to
- to understand the basics of potential field theory and the mathematical description of the Earth's gravity and magnetic field;
- to understand the basic mission concepts and objectives of satellite gravity and magnetic field missions
- to recognize the relationship between the measurements and the respective potential field parameters
- to apply these concepts for the solution of practical problems of Earth Observation (EO) Data analysis
- to analyze and to interpret the results
- to link the observation of the global gravity and magnetic field and its changes to the global monitoring of the Earth system,
- to develop a logically structured presentation on a topic related to the guest lecture on EO
- to present it to an audience
- to publicly defend the contents of the scientific presentation.

Teaching and Learning Methods:
The module consists of a lecture, an exercise and a seminar. The contents of the lectures are communicated by developing theory and methods on the blackboard, oral presentations with powerpoint support, or calculations/drawings at the blackboard, including interactive discussions with the students. In the exercise (lab), numerical exercises on the topics covered by the lecture are performed using MATLAB. For the most part, the lab is organised as homework with the requirement of preparing a written report on methodology and results.
In the seminar the students perform a self-contained literature research and they are guided interactively how to develop an oral presentation.

Media:
- presentations in electronic form
- blackboard

Reading List:
- handouts
- Torge, Wolfgang; Müller, Jürgen (2012): Geodesy. 4th ed. Berlin, Boston: De Gruyter (De Gruyter textbook)
- Stolle, Claudia; Olsen, Nils; Richmond, Arthur D.; Opgenoorth, Hermann J. (Hg.) (2018): Earth's magnetic field. Understanding geomagnetic sources from the earth's interior and its environment. Dordrecht: Springer Science+Business Media B.V.2018 (Space sciences series of ISSI, vol. 60)

Responsible for Module:
Roland Pail

Courses (Type of course, Weekly hours per semester), Instructor:
Seminar with Guest Lecturers (seminar, 1 SWS)
Pail R

Gravity and Magnetic Field from Space (lecture, 2 SWS)
Pail R [L], Pail R, Gruber T

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU48035: PSC - Photogrammetry - Selected Chapters [PSC]

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The exams consist of a presentation of 30 minutes of a prepared scientific topic and a discussion on the topic of the presentation and the scientific field in general. The student has to show the ability to understand, prepare and present a scientific topic to a scientific auditorium. The discussion is focussed on methodigical details of the presented topic and the scientific field. It is evaluated whether the students understand methods, sensors, and applications in the field of research beyond their topics and whether they can evaluate their topics in the field of research.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Introduction to Photogrammetry, Remote Sensing and Image Processing (BGU48036)

Content:
Lectures on Photogrammetry and remote sensing. Different topics of state-of-the-art Photogrammetry and Remote Sensing like i.e.:
- Extraction of buildings from aerial images, satellite images, LiDAR, SAR
- Extraction of roads from aerial images, satellite images, LiDAR, SAR
- Extraction of vehicles from aerial images, satellite images, LiDAR, IR
- Classification of vegetaion from aerial images, satellite images, LiDAR, SAR
- Glaciers DEM from aerial images, satellite images, LiDAR, SAR

Topics from the fields of photogrammetry, remote sensing and image analysis are selected by the students.

Intended Learning Outcomes:
After the successful conclusion of the module Photogrammetry, the students are able to understand and apply methods of Photogrammatry and Remote Sensing, - evaluate the usability of specific methods for specific tasks, evaluate results in a project report, to present scientific results to an audience, i.e. how to design slides, structure the presentation, and how to defend the content in a discussion. They are able to analyse problems and solution of a specific task in Photogrammetry and Remote Sensing, evaluate actual problems and methods in photogrammetry and remote sensing, and to prepare methodical basics and present elaborated results in a talk and report.

Teaching and Learning Methods:
In the lecture the students evaluate technical possibilities and methods for state-of-the-art sensors (multi- and hyperspectral optical sensors, sensors in thermal infrared, airborne laserscanning, synthetic aperture radar) based on scientific publications. In a combination of lectures given by lecturers and the students themselves and

paperwork, the students specialize on certains individual concepts, sensors, platforms or applications of Photogrammetry and Remote Sensing. Students prepare short lectures on their topic to recap the new knowledge every few lectures. Ongoing discussions during the lectures deepen the understanding of the different topics. By the end of the semester, every student presents his / her favorite topic in a 30 minutes presentation. This presentation should include a summary and explanation of presented methods, an evaluation and a discussion. The results, pros and cons are discussed within the group of attendees.

Media:
- Black / white board
- Presentation as slides
- Literature research

Reading List:
Literatur is individually related to the chosen topics. Possible sources for state-of-the-art articles are:
- ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences (www.ispors.org)
- ISPRS International Journal for Photogrammetry and Remote Sensing (www.journals.elsevier.com/isprs-journal-of-photogrammetry-and-remote-sensing)
- IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (https://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=4609443)

Responsible for Module:
Ludwig Hoegner

Courses (Type of course, Weekly hours per semester), Instructor:
Photogrammetry - Selected Chapters (PSC) (lecture, 4 SWS)
Stilla U, Hoegner L

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU57019: Geokinematics and Continental Hydrology

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified by a written exam of 120 min duration. In the exam it is verified that the students understand the scientific challenges of space-based geodetic data sets and its potential for geokinematic and hydrological applications, that they are able to process observation data and evaluate it with respect to its accuracy, and that they understand how the data can be used for the calibration of hydrological models. With the discussion of typical examples and specific problem settings the theoretical understanding and the evaluation skills are examined. Through questions at different levels of difficulty, the written exam allows for an individual verification of the understanding and thus a realistic assessment of the acquired competencies.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Recommended:
Basic knowledge in linear algebra, calculus, mechanics, programming with Matlab
Successful participation in the modules
- Introduction to Earth System Science (BGU45037)
- Numerical Modeling (BGU57018)
- Signal Processing and Microwave Remote Sensing (BGU13006)

Content:
1. Introduction: concepts of geodetic reference systems, their realizations, the International Terrestrial Reference System (ITRS)
2. The ITRF: General aspects, review on existing ITRS realizations, geodetic space techniques, combination strategies, inconsistencies and challenges
3. Alternative reference frames: epoch reference frames, regional reference frames
4. Current developments and most recent research topics: non-linear station motions, physical datum definition, the Global Geodetic Observing System (GGOS), inter-disciplinary scientific applications
5. Satellite radar altimetry for inland water bodies, Inland altimetry databases
6. Other space-based hydrogeodetic observation techniques: Laser and Delay Doppler/SAR altimetry, GNSS-reflectometry, GRACE-FO, SWOT
7. Monitoring of rivers systems and estimation of river discharge
8. Volume changes of lakes
9. Observing continental hydrology with the GRACE gravity mission
10. Assimilation/calibaration of hydrologocal models using hydrogeodetic information
11. Numerical exercises: Computation of water levels, river discharge and lake volume changes from satellite altimetry data

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand the definition and the datum realization of the ITRS,
- to classify different realizations of geodetic reference systems (regional, global, epoch-wise, multi-year),
- to evaluate observations of space geodetic observation techniques regarding information content and accuracy,
- to describe different concepts for the realization of the ITRS,
- to discuss inconsistencies and to evaluate current limitations of current ITRS realizations,
- to assess the potential of current developments for the accuracy of terrestrial reference frames,
- to describe the importance of accurate terrestrial reference frames for various inter-disciplinary applications,
- to understand the measurement principle of radar altimetry and its potential for hydrological applications,
- to apply satellite altimetry data for the estimation of lake volumes and river discharge,
- to evaluate the quality of inland altimetry data, and
- to understand the application of satellite data for the calibration of hydrological models.

Teaching and Learning Methods:
The content of the module is tought in two lectures. Both are condicted in interaction with the students whereby the learning success is continuously monitored through questions to the students. Mathematical derivations are shown at the black board. Selected literature is discussed with the students.

The lecture Hydogeodesy contains four supervised practical exercises conducted in the CIP-Pool.

Moreover, two guest lectures by external experts are part of the module.

Media:
- Presentation slides
- Lecture Notes
- Selected Scientific Publications which will be distributed in class

Reading List:
Geokinematics:
- Lecture Notes
- Kovalevsky J., Mueller I., Kolaczek B. (1989): Reference Frames in Astronomy and Geophysics, Kluwer Academic Publishers, Dordrecht
- Seeber G. (2003): Satellite Geodesy, Walter de Gruyter, Berlin
- Xu G. (2010/2013): Sciences in Geodesy-I/II, Springer, Berlin
- Plag H.-P., Pearlman M. (2009): Global Geodetic Observing System, Springer, Berlin
- Selected scientific publications (distributed in the course)

Hydrogeodesy:
- Lecture notes
- Fu L., Cazenave A. (2000): Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications. International Geophysics Series, Vol. 69, San Diego, CA
- Calmant et al (2008): Monitoring Continental Surface Waters by Satellite Altimetry, Surv. Geophys. 29:247-269
- Selected scientific publications (distributed in the course)

Responsible for Module:
Prof. Florian Seitz

Courses (Type of course, Weekly hours per semester), Instructor:
Hydrogeodesy: Monitoring surface waters from space (lecture, 2 SWS)
Seitz F [L], Dettmering D

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU61031: Advanced Aspects of Navigation Technology

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
A written exam of 120 min takes place in the end of the semester. The aim of the written exam is to ensure that the student has gained the required knowledge and understanding of fundamentals of receiver technology, acquired basic knowledge on signal generation, understands the functionalities of GNSS receiver modules, and are familiar with methods and strategies relevant for applications of GNSS in different fields such as geodynamics, aeronautical and space applications, time synchronization. Students are allowed to use a programmable pocket calculator.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Introduction to Satellite Navigation and Orbit Mechanic (BGU61029)
Signal Processing and Microwave Remote Sensing (BGU31006)

Content:
The two courses in the module gives an overview over adbanced aspects of navigation technology, including GNSS receiver technology and specific applications.
Receiver Technology:
- mathematical fundamentals and GNSS signal structures
- antenna and receiver front end
- signal acquisition, tracking loops, navigation
- mass market receivers
- advanced tracking methods
GNSS Applications: Different lecturers from DLR and from industry highlight various GNSS and navigation applications such as:
- time synchronization
- indoor navigation, sensor fusion
- real time applications
- aeronautical applications, integrity
- space applications
- applications in geodynamics
The course gives insight into current projects performed and applications developed by industry in and around Munich.

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand the fundamentals of GNSS signals,

- to understand the structure and working principles of a GNSS receiver,
- to understand the acquisition, tracking, navigation modules of a GNSS receiver,
- to understand the basic principle of simple signal generators,
- to analyze and to assess typical GNSS applications.

Teaching and Learning Methods:
The module consists of a lecture in receiver technology and a seminar on GNSS applications. The lecture on receiver technology is interleaved with several exercises to the different topics that are completed as home works. This way, the students can apply the concepts presented in the lecture in practice and thus gain a deep understanding on receiver working principles and GNSS signal processing. The seminar consists of a series of invited presentations on specific GNSS topics given by different lecturers from DLR and from Industry. This gives the students also the opportunity to get an overview over industry projects and to get into contact with potential employers.

Media:
Powerpoint presentations, blackboard

Reading List:
- Lecture notes, handouts
- Teunissen P., Montenbruck O. (Eds): GNSS Handbook, Springer, 2017

Responsible for Module:
Prof. Dr. phil. nat. Urs Hugentobler
Dipl. Math. Kathrin Frankl

Courses (Type of course, Weekly hours per semester), Instructor:
Seminar GNSS Applications (seminar, 2 SWS)
Hugentobler U

Receiver Technology (lecture, 2 SWS)
Hugentobler U [L], Frankl K

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU61032: Navigation Labs

Civil, Geo and Environmental Engineering

Module Level:	**Language:**	**Duration:**	**Frequency:**
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The exam is carried out in the form of Laboratory assignmen. During the semester, the students hand in 4-6 written lab reports of about 10 pages each, which document the labs and the lab results, and provide answers on questions relevant to the lab. These written reports are prepared in small groups and are later on discussed with the lecturer. Discussions take 60-90 min per lab and group. The grade of the module is based with equal weight on the written reports and on individual questions of the lecturer during the discussion. The aim of the written reports is to ensure that the students have gained the required competences to work with GNSS equipment, to characterise GNSS receivers and tracking data, to perform specific analysis tasks in a small team, and to document the used methods and obtained results. With the discussion the competence of the students to defend the methods applied and results obtained in the lab is verified.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Introduction to Satellite Navigation and Orbit Mechanics (BGU61029)
Satellite Navigation and Advanced Orbit Mechanics (BGU61033)

Content:
Exercises and labs on
- GPS mapping
- Receiver characterization
- Multipath and ionopshere analysis
- Software correlation
- Spaceborne GPS tracking

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to work with and handle GNSS equipment
- to understand and apply GNSS data analysis
- understand GNSS processing concepts
- to apply dedicated problems of GNSS including receiver technology and data collection
- to apply methods for the analysis of GNSS data
- to analyze, assess and interprete the results.

Teaching and Learning Methods:
The module consists of an exercise (lab). It is organized as a series of lab exercises where each exercise is introduced with a short presentation; students work in small groups using hardware and software and prepare a

written report; the results of the report are discussed in the group. The work in groups on challenging topics together with immediate feedback and extended discussions of the results allows the students to deepen their understanding in GNSS and relevant applications.

Media:
Handouts for each lab exercise, work with hardware and software, presentation of results with written report and discussions.

Reading List:
Misra P., Enge P.; Global Positioning System (GPS): Signals, Measurements and Performance; Ganga-Jamuna Press (2001).

Responsible for Module:
Prof. phil. nat. Urs Hugentobler
Dr. Oliver Montenbruck
M.Sc. Inga Selmke

Courses (Type of course, Weekly hours per semester), Instructor:
GNSS Lab Exercises (exercise, 4 SWS)
Montenbruck O, Selmke I

For further information in this module, please click
campus.tum.de or here.

Technische Universität München

Module Description

BGU61034: Precise GNSS

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	75	75

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The expected learning outcomes are verified with a written exam of 120 min at the end of the semester. The aim of the written exam is to ensure that the student has gained the required knowledge and understanding for precise positioning with GNSS data and of the corresponding mathematical background as listed in the intended learning outcomes and that the students are capable to discuss the methods used and the results achieved in the exercise (lab) and to put them into the proper context. The students are allowed to use 8 pages of hand-written notes and a programmable pocket calculator for the written exam as well as their reports prepared during the exercise (lab). Lab reports can be prepared as homework and are considered as optional midterm exam. The 5-6 reports are graded and contribute, when improving it, to the overall grade with a weight of 25%.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Fundamentals of linear algebra and statistics as well as successful participation in the module " Introduction to Satellite Navigation and Orbit Mechanics" (BGU61029)

Content:
The module include theory lectures with integrated exercises (3h) and exercise (lab) (2h). The aim of the module is
- to get familiar with GNSS, with models involved, and with processing strategies used for precise GNSS positioning applications,
- to get experience with GNSS data in practical work.
The theoretical part covers:
- Review of fundamentals of satellite navigation:
position estimation with iterative least-squares method
- Precise Point Positioning with Melbourne-Wübbena and ionosphere-free phase combinations
- Reliable integer ambiguity resolution with multi-frequency linear combinations
- Estimation of satellite position, clock and bias corrections
with a global network of GNSS receivers
- Cascaded Kalman filtering for multi-stage processing
- Joint subset optimization and integer least-squares estimation
for PPP and RTK
- Best integer-equivariant estimation for ambiguity fixing
- Precise Point Positioning with low-cost single-frequency GNSS receivers
The practical work includes:
- development of a simple point positioning tool using matlab,
- experiments using a scientific software package to study the impact of different effects and analysis strategies on positioning results such as orbit precision, troposphere, modelling, ambiguity resolution.

The practical work is accompanied by short presentations by the participants of their results.

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand the theory, the basic methodologies and algorithms, and the current trends for Precise Point Positioning and Real-Time Kinematic (RTK) positioning with GPS and Galileo signals
- to evaluate tracking data quality and multipath
- to assess the impact of different model options on the positioning results
- to optimize analysis strategies to specific use cases
- to apply methods for assessing precision and accuracy of obtained positioning solutions
- to understand and apply algorithms and statistical tests for reliable phase ambiguity resolution
- to apply optimized processing strategies to analyze GNSS data for precise positioning applications

Teaching and Learning Methods:
In the lecture with integrated exercises the content is presented with powerpoint presentations with examples and demonstrations using Matlab. Calculations and derivations are written to the blackboard.
The students have the option to participate in a voluntary trial exam in the middle of the semester which allows them to validate that the target competences of the first part of the module have been achieved.
In the exercise (lab) the exercises are based on Matlab and on the Bernese GPS Software, a professional GNSS data analysis software. The students work in groups on specific questions and prepare a report.

Media:
Lecture with power-point presentations with electronic handouts and blackboard, demonstration of Matlab code.
Lab exercises with electronic handouts, software user insrtructions, electronic tutorials with solutions.

Reading List:
Hofmann-Wellenhof, Lichtenegger, Collins (2001): GPS-Theory and Practice, Springer
Mistra (2006): GPS-Signals, Measurements and Performance. Ganga-Jamuna Press
Theunissen, Kleusberg (Eds.) (1998): GPS for Geodesy. Springer
Parkinson, B.W. & Spilker Jr., J.J. (1996), Global Positioning System: Theory and Applications Vol. I/II, American Institute of Aeronautics and Astronautics
Kaplan, E., Hegarty C. (2006), Understanding GPS: Principles and Applications, Second Edition, Artech House (available in the library: www.ub.tum.de)
GPS Interface Control Document, ICD-GPS-200C
Bernese GPS Software Version 5.2 User Manual

Responsible for Module:
Prof. Dr. phil. nat. Urs Hugentobler
Dr.-Ing. Patrick Henkel
M. Sc. Inga Selmke

Courses (Type of course, Weekly hours per semester), Instructor:
Labs in Precise GNSS (exercise, 2 SWS)
Hugentobler U [L], Selmke I

For further information in this module, please click
campus.tum.de or here.

Module Description

BGU69002: Remote Sensing

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
5	150	90	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The learning outcomes are examined within a parcours, consisting of
- a written exam of 60 minutes length
- a presentation of about 10 minutes.
The presentations will be given after the written exam in the classroom.

While the written exam is supposed to examine a general understanding of the topics SAR remote sensing, hyperspectral remote sensing, and atmospheric remote sensing, the presentation confirms a deeper involvement in a special topic from the overall field of remote sensing. It is meant to examine to what extent the students are capable of explaining technical, task-oriented solutions within a discourse among peers with foundation both in theory and methodology.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Recommended:
Basic knowledge in photogrammetry, mathematics and physics.
Successful participation in the module Introduction to Photogrammetry, Remote Sensing and Digital Image Processing (BGU48036).

Content:
The module consists of a lecture with integrated exercises Remote Sensing ¿ Advanced Methods and the Seminar Remote Sensing. While the lecture provides the necessary background knowledge, exercises and seminar enable problem-based learning.

Remote Sensing - Advanced Methods:
- Along-Track and Across-Track Interferometry
- Differential SAR Interferometry
- Persistent Scatterer Interferometry
- Remote Sensing of the Atmosphere
- Hyperspectral Remote Sensing

The interferometric processing of SAR data is trained in tutorials.

Seminar Remote Sensing
- deep insight into specific and selected topics of current remote sensing research

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to understand and apply methods of signal processing in remote sensing
- to evaluate the usability of specific remote sensing methods for practical problems
- to analyze autonomously tasks in the research field of remote sensing
- to prepare methodical basics for a selected research topic
- to evaluate alternative approaches in practice and to develop own solutions
- to present the elaborated results in a report and/or talk

Teaching and Learning Methods:
The module is comprised of a lecture with integrated exercises and a seminar. In the lecture, the content will be conveyed by presentations and consolidated by exercises. In the seminar, the basics conveyed by the lecture are applied by self-reliant work on a recent research topic, as well as by presentation and discussion of the achieved results.

Media:
Slides, lecture notes, exercise sheets, white-/blackboard

Reading List:
Remote Sensing - Advanced Methods:
- Fletcher, Karen: InSAR Principles - Guidelines For SAR Interferometry Processing and Interpretation. ESA, 2007

Seminar Remote Sensing:
- selected literature (such as scientific papers) will be provided for each topic individually

Responsible for Module:
Prof. Dr.-Ing. habil. Xiaoxiang Zhu

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Master's Thesis

Technische Universität München

Module Description

BGUMTES19: Master's Thesis

Civil, Geo and Environmental Engineering

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	summer semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
30	900	900	0

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
In the written thesis, the students verify that they are able to investigate in a self-contained manner a new scientific topic related to earth-oriented space science and technology. This includes, depending on the topic, the search and review of literature, topic-related methods and concepts, the development of theoretical concepts, methodologies, methods, to implement related algorithms, to apply them to specific problems, to analyze and to assess the results, and to develop and derive conclusions. In the oral colloquium, the students verify that they are able to give a presentation on a self-containedly investigated scientific subject in front of a larger audience, and that they are able to discuss and defend their own work in front of the examination board. Different forms of assessment (written and oral) are necessary, because different competencies are verified by this. The Master's Thesis must be submitted in written form, by which mainly thematic and methodical competences, and, depending on the topic, to a minor part social and self-competencies, as well as competencies to structure a written scientific document and to properly reference related work are verified. In contrast, the Master's colloquium must be held in oral form, because via the presentation and defense interactive scientific discussions with the examination board and thus, in addition to overarching understanding of the thesis topic, also self-competencies and soft-skills such as skills of presentation, didactics and rhetoric can be verified. The Master's Colloquium will not be graded but it is compulsory for each student. For the module grade only the written Master's Thesis is evaluated.

Repeat Examination:

(Recommended) Prerequisites:
Required and elective modules of the first 3 semesters

Content:
Under guidance students familiarize themselves with one of the topics covered by the Earth Oriented Space Science and Technology Master's program. They are confronted with a problem in that area which is formulated in a quite general form, i.e. not yet specified concretely. They have to investigate and evaluate different approaches to solve the problem, and then decide for one path which is then to be executed. The accompanying elaboration summarizes the main aspects of the subject area, discusses the different ways to solve the problem, justifies the decision made, and describes the elaborated solution.
This module is offered by selected lecturers of the ESPACE program, which are decided by the Examination Board. These supervisors offer suitable topics from their subject area, mostly an aspect of one of their research projects. They support the students in the acquisition of the scientific skills to investigate broadly an aspect of a subject area and based on that to answer a limited yet general problem in the corresponding area with the use of scientific methods.

Intended Learning Outcomes:
After the successful conclusion of the module, the students are able
- to deeply understand the chosen scientific problem and its embedding in the scientific and technical environment,
- to analyze satellite data,
- to develop algorithms and methods for solving problem-specific tasks,
- to apply dedicated (partly self-developed methods and strategies) to solve the chosen scientific problem,
- to analyze and to assess the results,
- to interpret the results and to place them into a wider scientific and/or technical context,
- to view processes in their entirety,
- to connect the expertise acquired in a certain detail discipline with a more general scope,
- to derive consequences and action rules from it,
- to present the relevance and context of the topic, the scientific questions, the methodologies employed for their solution, the results and discussion in a well structured written document
- to properly reference related work.

Teaching and Learning Methods:
Independent work;
Continuous meetings of the student with the supervisor and discussion of the results and the progess of the thesis;

Media:
Not applicable

Reading List:
To be researched independently according to the scope of work.

Responsible for Module:
Roland Pail

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click
campus.tum.de or here.

Required Additional Fundamental Subjects

Requirement Proof of Proficiency in German

Prüfungsauflagen

Technische Universität München

Index