Program overview

23-Sep-2020 9:09

Year	**2020/2021**
Organization	**Mechanical, Maritime and Materials Engineering**
Education	**Master Systems and Control**

Code	Omschrijving	ECTS	p1 p2 p3 p4 p5
Master SC 2020	**Master Systems and Control 2020**		
S&C Obligatory Courses (30 ECTS)			
SC42015	Control Theory	6	
SC42025	Filtering & Identification	6	
SC42056	Optimization for Systems and Control	3	
SC42061	Nonlinear Systems Theory	3	
SC42095	Control Engineering	3	
SC42145	Robust Control	3	
SC42150	Statistical Signal Processing	3	
SC42155	Modelling of Dynamical Systems	3	
S&C Obligatory Social Courses: choose 1 out of 3 (3 ECTS)			
WM0320TU	Ethics and Engineering	3	
WM0349WB	Philosophy of engineering science and design	3	
WM0801TU	Introduction to Safety Science	3	
S&C Elective Courses (min. 27 ECTS)			
AE4301	Automatic Flight Control System Design	3	
AE4W02TU	Introduction to Wind Turbines: Physics and Technology	4	
AE4W09	Wind Turbine Design	5	
AP3132	Advanced Digital Image Processing	6	
AP3382	Advanced Photonics	6	
AP3391	Geometrical Optics	6	
AP3401	Introduction to Charged Particle Optics	6	
CIE4801-18	Transport Modelling	6	
CIE4811-18	Planning and Operations of Public Transport Systems	6	
CIE4825	Traffic Flow Modelling and Control Part 1	6	
CIE5803-18	Railway Traffic Management	4	
CIE5805-18	Intelligent Vehicles for Safe and Efficient Traffic: Design and Assessment	4	
CIE5826	Railway Operations and Control	4	
CS4220	Machine Learning 1	5	
CS4230	Machine Learning 2	5	
ET4257	Sensors and Actuators	4	
IN4343	Real-time Systems	5	
IN4387	System Validation	5	
ME41000	Automotive Human Factors	3	
ME41005	Musculoskeletal Modelling and Simulation	3	
ME41025	Robotics Practicals	3	
ME41055	Multibody Dynamics B	4	
ME41080	Human-Machine Systems	4	
ME41100	Vehicle Dynamics	4	
ME41116	Vehicle Dynamics B Vehicle Control	4	
ME41125	Introduction to Engineering Research	3	
ME45155	Modelling of Thermo- & Hydrodynamic Systems	5	
ME46010	Intro to Nanoscience and Technology	3	
ME46041	Experimental Dynamics	4	
ME46055	Engineering Dynamics	4	
ME46060	Engineering Optimization: Concepts and Applications	3	
ME46085	Mechatronic System Design	4	
ME47035	Robot Motion Planning and Control	4	
OE44120	Offshore Wind Farms Design	4	
SC42030	Control for High Resolution Imaging	3	
SC42050	Knowledge Based Control Systems	4	
SC42065	Adaptive Optics Design Project	3	
SC42075	Modelling and Control of Hybrid Systems	3	
SC42100	Networked and Distributed Control Systems	3	
SC42110	Dynamic Programming and Stochastic Control	5	
SC42115	Internship	6	
SC42125	Model Predictive Control	4	
SC42130	Fault Diagnosis and Fault Tolerant Control	4	
SC42135	Spectral Analysis of Nonlinear Systems	3	
SC42140	Signal Analysis & Learning for Two-Dimensional Systems	3	
WI4062TU	Transport, Routing and Scheduling	3	
WI4201	Scientific Computing	6	

WI4212	Advanced Numerical Methods	6	
WI4221	Control of Discrete-Time Stochastic Systems	6	
WI4226	Advanced System Theory	6	
WI4260TU	Scientific Programming for Engineers	3	

S&C YEAR 2

S&C Graduation Project Obligatory (45 ECTS)

SC52010	S&C Literature Research	10	
SC52135	S&C MSc Thesis	35	

S&C Elective Courses

SC52055	Research Assignment	10	

Year	**2020/2021**
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Education	**Master Systems and Control**

Master SC 2020	
Director of Education	Prof.dr.ir. J. Hellendoorn
Program Coordinator	Dr.ir. A.J.J. van den Boom
Program Employee	S. van de Velde
Program Title	Master Systems & Control
Program Coordinator	The MSc coordinator is the person for questions or problems related to the individual study programme and for monitoring progress. Every student should consult the MSc coordinator before the end of the first semester to set up an individual study programme using the following ingredients: compulsory courses, current ideas about the theme of the thesis project, the Specialisation Courses that bridge the gap between the compulsory courses and the thesis project and the use of the free elective space. The student submits his/her plan for approval to the Board of Examiners. In order to finish the programme in two years, the student should plan to take an average of 30 credits worth of courses per semester. At the end of the first year, the student and the MSc coordinator will discuss his/her progress and planning. The MSc coordinator is dr. Ton van den Boom Tel: +31 (0)15 27 854052 E-mail: sc-coordinator-dcsc@tudelft.nl
In association with the University of	Relationship with 4TU graduate school The MSc programme in Systems and Control at Delft University of Technology is part of the 4TU MSc programme in Systems and Control. The other participating groups in this programme are: Control Systems Technology Group, Department of Mechanical Engineering, Eindhoven University of Technology, Control Systems Group, Department of Electrical Engineering, Eindhoven University of Technology, Control Engineering Group, Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente, Mathematical Systems and Control Theory Group, Faculty of Applied Mathematics, University of Twente, Laboratory of Mechanical Automation, Faculty of Mechanical Engineering, University of Twente. The University of Wageningen is not involved in the 4TU MSc programme in Systems and Control. Relationship with the national graduate school, DISC The MSc is an excellent way of preparing for the PhD programme offered by the national graduate school, DISC (Dutch Institute of Systems and Control). This is housed in the same research center at Delft University of Technology. http://www.disc.tudelft.nl
Introduction 1	What is the 4TU.Federation? The three leading universities of technology in the Netherlands - Delft University of Technology, Eindhoven University of Technology, the University of Twente, and the University of Wageningen - have joined forces in the 4TU.Federation (www.4tu.nl). This federation maximizes innovation by combining and concentrating the strengths of all three universities in research, education and knowledge transfer. The main advantages for students The 4TU MSc programmes are developed as exclusive programmes of outstanding academic quality that enable you to study at three of the top universities in the Netherlands. These programmes focus on areas of innovation developed with state-of-the-art engineering expertise. You will have the opportunity to acquire qualifications and competences that are in high demand. With successful graduation you will have obtained an outstanding qualification profile. The 4TU masters combine excellent subject based competences, research skills, the capacity for independent analysis and synthesis and an advanced capability to apply knowledge in practice. The core programmes of the 4TU masters are largely identical and can be followed at any of the three locations. The admission procedures, teaching and examination regulations and academic calendars at all three universities have been carefully matched. You benefit from the special strengths of the three universities by choosing a specialization at any of the three locations. You are registered at the location of your choice, but you are automatically co-registered at the other two locations to ensure access to the facilities of all three.
Introduction 2	Universities of Technology in the Netherlands Delft University of Technology (TU Delft) TU Delft (www.tudelft.nl) is an enterprising university at the forefront of technological development. The university trains the engineers of tomorrow by means of its fundamental and applied research and educational programmes. With its broad knowledge base, worldwide reputation and successful alumni, TU Delft contributes significantly to the development of responsible solutions to urgent societal problems worldwide. With approximately 15,000 students, TU Delft is the nations largest university of technology with the most comprehensive range of engineering courses. Eindhoven University of Technology (TU/e) Eindhoven University of Technology (www.tue.nl) offers high-quality education and research for the advancement of engineering science, the development of societal and technological innovations, and the growth of welfare and prosperity. The Eindhoven region has a global reputation in top technology with a strong concentration of high-tech companies (including electronics giant Philips), R&D and higher education institutes. As a main driving force behind the regions internationally oriented knowledge economy, TU/e focuses on innovation and cutting-edge research. University of Twente (UT) Based in the Eastern Dutch town of Enschede, the University of Twente (www.utwente.nl) is one of Europes finest educational establishments encouraging research and entrepreneurship in both technology and social sciences. As a young and innovative institute, UT is internationally respected in a broad range of engineering sciences as well as societal and management disciplines, including cross-disciplinary programmes on e.g. health and technology. And because there is more to life than studying, the Netherlands only university with a residential campus has many sports, cultural and training facilities. For more information visit www.3tu.nl
Introduction 3	Delft Center for Systems and Control (DCSC) The MSc programme in Systems and Control began in September 2003. It is taught by the Delft Center for Systems and Control (DCSC) within the Faculty of Mechanical Engineering and Marine Technology. DCSC is a merger of the three former systems and control groups in the faculties of Mechanical Engineering and Marine Technology (3mE), Information Technology and Systems (EWI) and Applied Sciences (TNW). For more information, visit www.dcsc.tudelft.nl. In consultation with one of the MSc staff members, the student chooses an available thesis project. Most MSc theses fall within the scope of an ongoing research project at the Delft Center for Systems and Control. Alternatively, projects may also be chosen in co-operation with one of the research groups affiliated to the MSc programme.

Program Goals	The MSc programme in Systems and Control covers the analysis and design of reliable and high-performance measurement and control strategies for a wide variety of dynamic technological processes. It centres on fundamental generic aspects of systems and control engineering and stresses the multidisciplinary nature of the field, with applications in mechanical engineering, electrical engineering, applied physics, aerospace engineering and chemical engineering among them the following. - High-accuracy positioning and motion-control systems, mechatronics, micro-systems, production systems, robotics and smart structures. - Petrochemical, chemical, physical and biotechnological production processes. - Transportation systems (automotive, railway, logistics, aerospace). - Infrastructure networks (water, electricity) - Physical imaging systems (acoustic and optical imaging). - Adaptive optics - Energy conversion and distribution. - Biomedical systems, System biology. The programme brings together issues of physical modelling, experiment design, signal analysis and estimation, model-based control design and optimization, hardware and software in a study of systems of high complexity and of different kinds, such as linear and nonlinear dynamics, hybrid and embedded systems, and ranging from small-scale micro-systems to large-scale industrial plants, structures, and networks.
Exit Qualifications	The MSc Systems and Control graduate possesses the following knowledge and skills. 1. Knowledge of engineering sciences (electrical engineering, mechanical engineering, applied physics, mathematics) in breadth and in depth, and the ability to apply this to systems and control engineering at an advanced level. 2. Scientific and technical knowledge of systems and control engineering, in breadth and in depth, and the skills to use this effectively. The discipline is mastered at different levels of abstraction, including a reflective understanding of its structure and its relationships with other fields, and to some extent this knowledge reaches the forefront of scientific or industrial research and development. Moreover, the knowledge possessed can form the basis for innovative contributions to the discipline in the form of new designs or the development of new knowledge. 3. Thorough knowledge of paradigms, methods and tools, as well as the skills to apply that knowledge actively in analysis, modelling, simulation, design and the conduct of research pertaining innovative, technologically dynamically systems, with an appreciation of different areas of application. 4. The ability to solve technological problems independently and in a systematic way, by means of problem analysis, formulating subproblems and providing innovative technical solutions, including in new and unfamiliar situations. A professional attitude towards identifying and acquiring new expertise, towards monitoring and critically evaluating existing knowledge, towards planning and carrying out research, towards adapting to changing circumstances and towards integrating new knowledge with an appreciation of its ambiguity, incompleteness and limitations. 5. The ability to work both independently and in multidisciplinary teams, interacting effectively with specialists and taking initiatives where necessary. 6. The ability to communicate effectively about his or her work in the English language, to both professionals and non-specialists, including the ability to make presentations and produce reports on, for example, solutions to problems, conclusions, knowledge and considerations. 7. The ability to evaluate and assess the technological, ethical and social impact of his or her work, and to take responsibility with regard to sustainability, economy and social welfare. 8. The willingness to maintain his or her professional competence independently, through life-long learning.
Program Structure 1	FIRST YEAR (60 EC) The 1st year contains four components. - Compulsory courses (30 EC). - Elective Systems and Control courses selected from a list provided (at least 21 EC). - "Free" elective technical courses, chosen by agreement with the MSc thesis supervisor (at least 6 EC). - Social course: The student can choose between three course, namely Philophy of Engineering Science and Design, Ethics and Engineering or Introduction to Safety Science. Most courses are assessed by means of an oral or written examination. SECOND YEAR (60 EC) The 2nd contains four components. - Integration project (5EC) - Reasearch project (10EC) or additional elective courses (7 ECTS Elective Systems and Control courses selected from a list provided, and 3ECTS "Free" elective technical courses, chosen by agreement with the MSc thesis supervisor. - Literature survey (Preparation of MSc thesis project) (15 EC). - MSc thesis project (45 EC). The Reasearch project, the Literature survey and the MSc thesis project are assessed on the basis of a written report and, possibly, an oral presentation. The thesis project is the final assignment in the MSc programme.

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Education	**Master Systems and Control**

S&C Obligatory Courses (30 ECTS)	
Program Coordinator	Dr.ir. A.J.J. van den Boom
Introduction 1	Curriculum The compulsory component of the curriculum, as shown in the table below, consists of a number of basic courses in key areas of systems and control: Control, Modelling, Nonlinear systems, Identification, Optimization and Signal processing. There is also a compulsory project component, namely the integration project. This project is performed in the laboratory, in which the knowledge acquired during the compulsory courses is applied to real-world situations.

SC42015	Control Theory	6
Responsible Instructor	T. Keviczky	
Contact Hours / Week x/x/x/x	6/0/0/0	
Education Period	1	
Start Education	1	
Exam Period	1 2	
Course Language	English	
Course Contents	- State-space description of multivariable linear dynamic systems, interconnections, block diagrams - Linearization, equilibria, stability, Lyapunov functions and the Lyapunov equation - Dynamic response, relation to modes, the matrix exponential and the variation-of-constants formula - Realization of transfer matrix models by state space descriptions, coordinate changes, normal forms - Controllability, stabilizability, uncontrollable modes and pole-placement by state-feedback - LQ regulator, robustness properties, algebraic Riccati equations - Observability, detectability, unobservable modes, state-estimation observer design - Output feedback synthesis (one- and two-degrees of freedom) and separation principle - Disturbance and reference signal modeling, the internal model principle	
Study Goals	The student is able to apply the developed tools both to theoretical questions and to simulation-based controller design projects. More specifically, the student must be able to: - Translate differential equation models into state-space and transfer matrix descriptions - Linearize a system, determine equilibrium points and analyze local stability - Describe the effect of pole locations to the dynamic system response in time- and frequency-domain - Verify controllability, stabilizability, observability, detectability, minimality of realizations - Sketch the relevance of normal forms and their role for controller design and model reduction - Describe the procedure and purpose of pole-placement by state-feedback and apply it - Apply LQ optimal state-feedback control and analyze the controlled system - Reproduce how to solve Riccati equations and describe the solution properties - Explain the relevance of state estimation and build converging observers - Apply the separation principle for systematic 1dof and 2dof output-feedback controller design - Build disturbance and reference models and apply the internal model principle	
Education Method	Lectures and Exercise Sessions	
Computer Use	The exercises will be partially based on Matlab in order to train the use of modern computational tools for model-based control system design.	
Literature and Study Materials	B. Friedland, Control System Design: An Introduction to State-space Methods. Dover Publications, 2005 K.J. Astrom, R.M. Murray, Feedback Systems: An Introduction for Scientists and Engineers, Princeton University Press, Princeton and Oxford, 2009 http://www.cds.caltech.edu/~murray/amwiki/index.php?title=Main_Page	
Assessment	Written online mid-term examination (15%) and written online final examination (85%). For the resit examination there will be a written online examination (100%) for which the mid-term result will not count.	
Remarks	Old Course Code: SC4025	
Department	3mE Department Delft Center for Systems and Control	

SC42025	Filtering & Identification	6
Responsible Instructor	Dr. M. Kok	
Instructor	Dr. C.S. Smith	
Instructor	Dr.ir. K. Batselier	
Contact Hours / Week x/x/x/x	0/4/0/0	
Education Period	2	
Start Education	2	
Exam Period	2 3	
Course Language	English	
Course Contents	The objective of this course is to apply filtering and identification methods. The focus is both on deriving these methods and on using these methods on real-life data sequences. The course focuses on stochastic and recursive least squares, on (extended) Kalman filtering, on prediction error methods and on subspace identification. The course also includes a review of specific topics from linear algebra, dynamical system theory and statistics, that are relevant for filtering and system identification.	
Study Goals	At the end of the course you should be able to: 1) Apply filtering and identification methods to solve previously unseen estimation problems. As sub-learning goals you should be able to: a. Relate basic linear algebra, signal processing techniques and probability theory to physical properties of a (dynamical) system. b. Derive the solution of the stochastic and recursive least squares problems from both a Bayesian and a frequentist perspective. c. Derive the Kalman filter from both a Bayesian and a frequentist perspective. d. Derive subspace and prediction error identification methods. e. Motivate the steps that should be taken in the derivations in b-d. 2) Apply filtering and identification methods to estimate the state and identify the model using real-life data sequences. As sub-learning goals you should be able to: a. Implement a (stochastic / recursive) least squares problem, an (extended) Kalman filter and identification methods in Matlab. b. Apply and motivate practical aspects of filtering and identification.	
Education Method	Lectures 0/6/0/0	
Literature and Study Materials	Book Filtering and System Identification: A Least Squares Approach by Michel Verhaegen and Vincent Verdult. ISBN: 13-9780521875127	
Assessment	Written exam (open book) and practical exercises. The exam will in principle be online due to covid-19 restrictions.	
Remarks	Old course code: SC4040. The software package Matlab is needed to solve the practical exercise.	
Department	3mE Department Delft Center for Systems and Control	

SC42056	Optimization for Systems and Control	3
Responsible Instructor	Prof.dr.ir. B.H.K. De Schutter	
Contact Hours / Week x/x/x/x	4/0/0/0	
Education Period	1	
Start Education	1	
Exam Period	1 2	
Course Language	English	
Expected prior knowledge	basic experience with Matlab	
Course Contents	Essentially, almost all engineering problems are optimization problems. If a civil engineer designs a bridge, then one of the main objectives is to obtain the cheapest design or the design that can be implemented most rapidly, where of course several specifications and constraints such as size, strength, safety, etc. have to be taken into account. When developing a new type of engine, we look for the most economical design, the cheapest design, or the design with the highest performance. A process engineer wants a production unit to deliver a final product of maximal quality, with minimal expenditure of energy or with maximal output flow. When composing a portfolio, a financial engineer tries to maximize the expected profits, subject to the given risk constraints. So we encounter optimization problems in almost every engineering field. How can we solve such an optimization problem? That is the topic that will be addressed in this course. We will in particular discuss several classes of optimization problems and next focus on how to select most efficient numerical algorithms to solve a given optimization problem. The examples and case studies of this course are primarily oriented towards systems and control. More specifically, the following topics will be treated: * Linear Programming * Quadratic Programming * Nonlinear Optimization * Constraints in Nonlinear Optimization * Convex Optimization * Global Optimization * Matlab Optimization Toolbox * Multi-Objective Optimization * Integer Optimization	
Study Goals	After this course the students should be able to select the most efficient and best suited optimization algorithm for a given optimization problem. They should have insight into the basic operation of some of the most important and relevant optimization algorithms. They should be able to reduce the complexity of the problem using simplifications and/or reformulations so as to augment the efficiency of the solution approach. Finally, they should be able to solve the resulting optimization problem in practice.	
Education Method	lectures + 2 assignments online recordings will be available attending the lectures is not mandatory	
Assessment	exam (counts for 75% of the final marks) + 2 assignments (assessed through written reports, count for 25% of the final marks) Important: Partial marks for the exam or the assignments do not carry over from one academic year to the next. Because of measures resulting from COVID-19, the prescribed exam will be an open-book online exam; if the opportunity arises for examinations on campus, the exam will be a closed-book written exam (fully closed-book, no calculators nor formulas sheets allowed).	
Permitted Materials during Tests	none	
Department	3mE Department Delft Center for Systems and Control	
Contact	questions are preferably asked via the Discussion forum on Brightspace	

SC42061	Nonlinear Systems Theory	3
Responsible Instructor	Dr.ing. S. Wahls	
Contact Hours / Week x/x/x/x	6/0/0/0	
Education Period	1	
Start Education	1	
Exam Period	1 2	
Course Language	English	
Course Contents	- Fundamentals of nonlinear systems (basic properties, solvability, types of equilibrium points) - Analysis of planar systems (graphical representations, limit cycles, elementary bifurcations) - Stability theory for autonomous nonlinear systems (Lyapunov's methods, invariance principle) - Advanced stability theory (time-varying systems, input-to-state and input-output stability, interconnections, passivity) - Observers (local, global and high-gain, extended Kalman filter)	
Study Goals	Students can: - determine if a system is nonlinear, time-invariant, autonomous, etc. - determine time intervals over which a system is solvable - sketch and interpret graphical representations of 2d systems - check for the existence or absence of limit cycles in 2d systems, compute bifurcation points, and classify elementary bifurcations - determine if equilibrium points of autonomous nonlinear systems are (asymptotically, exponentially, ...) stable - determine if equilibrium points of certain classes of non-autonomous systems are (asymptotically, exponentially, ...) stable - construct observers for certain classes of nonlinear systems	
Education Method	Lectures, problem sets and instruction sessions.	
Literature and Study Materials	- H. K. Khalil: "Nonlinear Control", Pearson, 1st Global Edition, 2015. - Additional handouts	
Assessment	Written exam, depending on the COVID-19 situation either on campus or online.	
Remarks	2020-2021: new course SC42061 replaces old course SC42060	
Department	3mE Department Delft Center for Systems and Control	

SC42095	Control Engineering	3
Responsible Instructor	T. Keviczky	
Instructor	Dr. A. Dabiri	
Contact Hours / Week x/x/x/x	0/4/0/0	
Education Period	2	
Start Education	2	
Exam Period	2 3	
Course Language	English	
Expected prior knowledge	SC42015, SC42000 or similar. Knowledge of classical control techniques (systematic and realistic PID design, frequency domain approaches) as well as state space theory is required.	
Course Contents	Computer control. Sampling of continuous-time signals. The sampling theorem. Aliasing. Discrete-time systems. State-space systems in discrete-time. The z-transform. Selection of sampling-rate. Analysis of discrete-time systems. Stability. Controllability, reachability and observability. Disturbance models. Reduction of effects of disturbances. Stochastic models. Design methods. Approximations of continuous design. Digital PID-controller. State-space design methods. Observers. Pole-placement. Optimal design methods. Linear Quadratic control. Prediction. LQG-control. Implementation aspects of digital controllers.	
Study Goals	The student must be able to: 1. describe the essential differences between continuous time and discrete-time control 2. transform a continuous time description of a system into a discrete-time description 3. calculate input-output responses for discrete-time systems 4. analyse the system characteristics of discrete-time systems 5. employ a pole-placement method on a discrete-time system 6. implement an observer to calculate the states of a discrete time system 7. apply optimal control on discrete-time systems 8. describe the functioning of the Kalman-filter as a dynamic observer	
Education Method	Lectures and computer exercises	
Computer Use	Matlab/Simulink is used to carry out the exercises of this course.	
Literature and Study Materials	Course material: Lecture notes are made available on Brightspace Textbooks: K.J. Astrom, B. Wittenmark 'Computer-controlled Systems', Prentice Hall ,1997, 3rd edition. L. Keviczky et. al 'Control Engineering', Springer, 2019. L. Keviczky et. al 'Control Engineering: MATLAB Exercises', Springer, 2019. References from literature: B.C. Kuo 'Digital Control Systems', Tokyo, Holt-Saunders, 1980 G.F. Franklin, J.D. Powell 'Digital Control of Dynamic Systems', 1989, 2nd edition, Addison-Wesley	
Assessment	Online final quiz (20%) + Project assignment (80%). In order to complete the course, both types of assessment must be completed with at least a mark of 5,0. In the event of a lower mark, no final mark will be given.	
Remarks	Old course code: WB2305 The project assignment can be completed only during the quarter when the course is offered (i.e. the project has no resit during other periods).	
Department	3mE Department Delft Center for Systems and Control	

SC42145	Robust Control	3
Responsible Instructor	Dr.ir. J.W. van Wingerden	
Contact Hours / Week x/x/x/x	0/4/0/0	
Education Period	2	
Start Education	2	
Exam Period	2 3	
Course Language	English	
Course Contents	· Recap on background in linear systems theory and classical feedback control · Multivariable system control: Nyquist, interaction, decoupling · Directionality in multiloop control, gain and interaction measure · Stabilizing controllers and the concept of the generalized plant · Parametric uncertainty descriptions, approximations · The general framework of robust control · Robust stability analysis · Nominal and robust performance analysis · The H-infinity control problem · The structured singular value: Definition of mu · Mu synthesis, DK-iteration, role of uncertainty structure. · Design of robust controllers, choice of performance criterion and weights	
Study Goals	The student is able to reproduce theory and apply computational tools for robust controller analysis and synthesis. More specifically, the student must be able to: 1. substantiate relation between frequency-domain and state-space description of dynamical systems 2. define stability and performance for multivariable linear time-invariant systems 3. construct generalized plant for complex system interconnections 4. describe parametric and dynamic uncertainties 5. translate concrete controller synthesis problem into abstract framework of robust control 6. reproduce definition of the structured singular value 7. master application of structure singular value for robust stability and performance analysis 8. design robust controllers on the basis of the H-infinity control algorithm 9. apply controller-scalings iteration for robust controller synthesis	
Education Method	Lectures + Assisted lectures+Computer sessions	
Literature and Study Materials	S. Skogestad, I. Postlethwaite, Multivariable Feedback Control, 2nd Edition. John Wiley & Sons, 2005. References from literature: K. Zhou, J.C. Doyle, K. Glover, Robust and optimal control, Prentice Hall, 1996 D.-W. Gu, P.Hr. Petkov, M.M. Konstantinov, Robust Control Design with Matlab. Springer Verlag, London, UK, 2005	
Assessment	Controller design exercise (report and code)	
Remarks	Old course code: SC42010	
Department	3mE Department Delft Center for Systems and Control	

SC42150	Statistical Signal Processing	3

Responsible Instructor	Dr. C.S. Smith
Responsible Instructor	Dr. P. Mohajerin Esfahani
Contact Hours / Week x/x/x/x	4/0/0/0
Education Period	1
Start Education	1
Exam Period	1 2
Course Language	English
Course Contents	1. Introduction concepts a. Dynamic models, measurement models (probabilistic form) with examples b. Introduce concepts estimation, filtering, smoothing and identification 2. Recap modeling deterministic signals: a. Z-transform b. Discrete Fourier transform c. Discrete-time models d. Norms of signals and systems 3. Recap probability theory 4. Estimation a. Maximum Likelihood b. CRLB c. Examples 5. Stochastic signals a. What is the difference between a RV and a RP? b. RPs i. White noise ii. Radom walk iii. Poisson iv. Binary v. Gaussian vi. Autoregressive/moving average c. Wide sense stationary d. Auto/cross correlation and covariance e. Power/cross spectral density 6. Linear filtering a. FIR b. IIR c. Examples i. Noise cancelation ii. Deconvolution iii. One-step a head prediction iv. Ill-posed problems 7. Bayesian filtering and smoothing & Kalman filter a. Markov property b. Build on SLS and derive Kalman filter based on LS c. Derivation smoothing and filtering distributions
Study Goals	After the course, students can - describe and analyze a measurement signals in the time domain and can use these insights to derive a the minimum variance and it's Maximum likelihood estimate - describe and analyze stochastic signals in the time and frequency domain and can use these insights to quantify noise distorted measurement signals; - use the concepts such as auto and cross correlation as well as auto and cross signal spectra; and estimate these quantities from finite series of measurements. - calculating the change in the correlation functions and spectra when stochastic signals are filtered by a linear dynamic system; - solving the inverse problem, i.e. how they can calculate the formative filter from the stochastic spectra. - estimate the information-carrying components from disturbed measuring signals, - derive and use the linear optimal Wiener filter and Least Squares estimators to solve noise reduction problems. - describe and analyze a measurement signals in the time domain and can use these insights to derive a minimum variance estimate take incorporates a-priori statistical information.
Education Method	Lecture with tutorial consisting of theoretical and python exercises
Assessment	Written online exam and homework. The final mark is a weighted average of the mark obtained on the examination and that on the compulsory homework / python assignments.
Department	3mE Department Delft Center for Systems and Control

SC42155	Modelling of Dynamical Systems	3
Responsible Instructor	Dr.ir. A.J.J. van den Boom	
Contact Hours / Week x/x/x/x	0/4/0/0	
Education Period	2	
Start Education	2	
Exam Period	2 3	
Course Language	English	
Course Contents	Modelling. The course will cover the basics of Lagrangian modelling, I.e. employing energy balances and the Euler-Lagrange equations to arrive to closed form state-space dynamical equations for system analysis and control design. Bond-graph modelling will be covered as a powerful tool for modelling engineering systems, especially when different physical domains are involved. The basic ideas of model reduction, a technique to reduce the complexity of dynamical models, is also covered in the course. The fundamental differences and connections between continuous vs discrete time modelling will be discussed. Similarly, frequency domain modelling is also discussed with practical motivations for frequency vs time domain modelling. Finite State Models. A brief introduction to models traditionally employed for computation, e.g. finite state machines, automata, and petri-nets, will be provided. Particular attention will be given to the applicability of these models to provide high-level dynamic descriptions of discrete-event systems and for behaviour specifications of designs. Hybrid systems. The course will finalize with a short introduction to hybrid systems through the formalisms of: Hybrid automata and jump-flow systems, and presenting a brief number of interesting subclasses of hybrid systems, e.g. PWA systems, and timed -automata.	
Study Goals	The purpose of the course is to introduce the students to basic concepts and results in physical modeling and the theory of nonlinear control systems. After successful completion of the course, the student is able to construct models of systems from the knowledge of physics on the basic laws of physics construct models of systems using the theory of bond graphs. construct models of systems using the Euler-Lagrange method perform a model reduction for linear systems using a balanced realization construct finite state models of simple computing and scheduling systems analyze basic properties of finite state systems: blocking, determinism, and language expressed by a model. describe cyber-physical systems as hybrid dynamical models. select the appropriate modelling approach for a given problem.	
Education Method	Lectures 0/4/0/0	
Literature and Study Materials	Lecture notes and additional readers	
Assessment	Written examination	
Department	3mE Department Delft Center for Systems and Control	

Year	**2020/2021**
Organization	**Mechanical, Maritime and Materials Engineering**
Education	**Master Systems and Control**

S&C Obligatory Social Courses: choose 1 out of 3 (3 ECTS)	
Responsible Program Employee	Dr.ir. A.J.J. van den Boom

WM0320TU	Ethics and Engineering	3
Module Manager	Dr. F. Santoni De Sio	
Co-responsible for assignments	Dr. J.B. van Grunsven	
Contact Hours / Week x/x/x/x	4/0/4/0	
Education Period	1 3	
Start Education	1 3	
Exam Period	1 3	
Course Language	English	
Course Contents	This course is identical to the initial part of the course WM0329TU. You will explore the ethical and social aspects and problems related to technology and to your future work as professional or manager in the design, development, management or control of technology. You will be introduced to and make exercises with a range of relevant aspects and concepts, including professional codes, philosophical ethics, individual and collective responsibilities, ethical aspects of technological risks, responsibility within organisations, responsible conduct of companies and the role of law. You will analyse legal, political and organisational backgrounds to existing and emerging ethical and social problems of technology, and you will explore possibilities for resolving, diminishing or preventing these problems.	
Study Goals	After having completed the course you: can better recognise and analyse ethical and social aspects and problems inherent in technology and in the work of professionals and managers active in the design, development, management and control of technology. have insight into how these ethical and social aspects and problems are related to legal, political and organisational backgrounds. are able to explore and assess possibilities for solving or diminishing existing and emerging ethical and social problems that attach to technology and the work of professionals and managers. are better prepared to perform your future work as a professional or manager in the design, development, production and control of technology in an ethical and socially responsible way.	
Education Method	A series of 6 lectures and interactive work sessions with partial assessment, concluded with a written test.	
Literature and Study Materials	Reader Ethics and Engineering, available at Nextprint and as PDF files in Brightspace; Powerpoint slides, materials used in the working groups, and lecture notes.	
Assessment	Written exam (60%), presentation and active participation during the working group sessions (40%). In order to pass the course, a minimal grade of 5.5 should be obtained *both* in the exam *and* in the working group, and the average grade should be higher than 5.75. It is possible to re-take the exam without re-taking the working groups, in this case the working group grade will be kept. If you re-take the exam, it is also possible to re-attend the working groups to improve the final grade.	
Enrolment / Application	Enrolment via Brightspace is required for this course. This is needed in order to plan the workgroups. Please enrol as soon as possible and check Brightspace for more information on the enrolment on the enrolment procedure and timeline.	
Remarks	The course is run twice each year in the first and third quarter. The course is identical to the initial part of the course wm0329tu (6 ects).	
Category	MSc niveau	

WM0349WB	Philosophy of engineering science and design	3
Module Manager	Dr. M.P.M. Franssen	
Instructor	Dr. M.P.M. Franssen	
Responsible for assignments	Dr. M.P.M. Franssen	
Co-responsible for assignments	Ir. S.J. Zwart	
Contact Hours / Week x/x/x/x	4/0/0/0 for students in the MSc programme Systems and Control 0/0/0/4 for students in the MSc programme Mechanical Engineering Students of Systems and Control who expect that it will be very awkward or impossible for them to attend the course in Q1, e.g. due to spending the semester abroad or due to other schedule- or study-related reasons, can send a request to the course manager to be allowed to attend the course in Q4. Similarly students of Mechanical Engineering who expect difficulties to attending the course in Q4 can send a request to be allowed to attend the course in Q1.The granting of such a request, however, is conditional on (1) the students motivation being judged compelling and (2) the availability of seminar instructors being judged sufficient to allow it, given the expected attendance of regular students. Cross-attendance without prior permission will not be accepted.	
Education Period	1 4	
Start Education	1 4	
Exam Period	1 2 4 5	
Course Language	English	
Course Contents	Course contents: (1) The goals of science; the character and scope of scientific claims. (2) The goals of engineering design; the nature of technical artefacts; the value-neutrality of technology. (3) The scientific method and the validation of scientific claims. (4) Methods of engineering design; the character and scope of design claims; the decision-making aspect of design. (5) The development of science; the objectivity of science; the notion of scientific progress. (6) The development of technology; social determinism and technical determinism. (7) The place and role of values in science and in engineering design.	
Study Goals	This course aims first of all to support students in developing a reflective and critical attitude with regard to empirical research underlying engineering science and engineering design at an academic level. Additionally, and in support of this primary goal, it aims to make students acquainted with views on the nature and goals of science and engineering design and how in these activities facts and values both have their role to play and how they interact.	
Education Method	The course is taught in the form of seven weekly sessions which each consist of a plenary lecture of two hours and a seminar of two hours during which students articulate and discuss their answers to a number of questions in smaller groups. Each seminar will be prepared and chaired by a team of about three students. For this task general and specific instructions, recommendations and suggestions will be available.	
Assessment	Assessment is through (1) a final individual written exam, (2) participation in the seminars and (3) performance in preparing and chairing a seminar. The exam result forms 50 percent of the final grade, assessment of general seminar participation 25 percent and assessment of the preparing and chairing role also 25 percent. Assessment of general participation may be done through peer grading; what method will in fact be used will be announced at the start of the course and on the course's Brightspace site. The written exam will either be held on campus or in the form of an on-line exam, depending on the university's policy to be in accordance with the government's restrictions in force at the time of the (re)examination.	
Category	MSc level	

WM0801TU	Introduction to Safety Science	3
Module Manager	Prof.dr.ir. P.H.A.J.M. van Gelder	
Contact Hours / Week x/x/x/x	0/3/0/0	
Education Period	2	
Start Education	2	
Exam Period	2 3	
Course Language	English	
Required for	Students wishing to graduate with a final project in the area of safety supervised by the Safety Science and Security Group should have followed this course or one of the other introductory courses run by the group (WM0808TU, WM0821TU or WM0822TU)	
Expected prior knowledge	Technical academic BSc and common (scientific) sense	
Summary	System Safety Engineering focuses on development of a safety oriented pattern of thinking and a holistic approach. The tools that will be gained in this course will be helpful in recognizing, understanding, and analyzing hazards; and assessing risks in contemporary complex systems. Areas included are (1) Hazard analysis and safety assessment, (2) Human reliability assessment, and (3) Safety management.	
Course Contents	Introduction to system safety engineering Safety performance measurement Hazard analysis Failure modes and effects analysis Preliminary hazard analysis System safety assessment Reliability block diagram Fault & event trees Markov chain analysis Bayesian network Consequence assessment Risk ranking Human reliability assessment Decision making under uncertainty	
Study Goals	The students will learn how to perform safety assessment, reduce risk within acceptable levels, manage risk, improve system safety, and make risk-informed decisions to benefit the organization and the community.	
Education Method	Plenary lectures (mandatory) Exercises (carried out in small groups of 4-5 students)	
Literature and Study Materials	Clifton A. Ericson, Hazard Analysis Techniques for System Safety, John Wiley and Sons; ISBN: 978-0471720195. Harold E. Ronald and Brian Moriarty. (1990). System Safety Engineering and Management, John Wiley and Sons, 2nd Edition.	
Prerequisites	Technical background preferred but certainly not mandatory	
Assessment	Multiple-choice exam (40 questions) based on book, papers, exercises and lecture slides.	
Enrolment / Application	Enrol through Brightspace. Minor students are automatically enrolled into the course.	
Remarks	This course can be expanded to a System Safety/Reliability project	
Category	MSc level	

Year	**2020/2021**
Organization	**Mechanical, Maritime and Materials Engineering**
Education	**Master Systems and Control**

S&C Elective Courses (min. 27 ECTS)

Program Coordinator	Dr.ir. A.J.J. van den Boom
Introduction 1	
Program Structure 1	At least 21 ECTS should be taken from the below mentioned list of electives systems & control courses. At least 6 ECTS are free to choose of technical master courses. Within this 6 ECTS it is possible to select 6 points Internship (SC42115). In the second year the students can choose either to do a research project (10EC) or to take an additional 7 EC elective systems & control courses and 3 EC technical master courses (together 10 EC).

AE4301	Automatic Flight Control System Design	3
Responsible Instructor	Dr.ir. E. van Kampen	
Instructor	Dr.ir. E.J.J. Smeur	
Instructor	Dr. A. Jamshidnejad	
Contact Hours / Week x/x/x/x	4/0/0/0	
Education Period	1	
Start Education	1	
Exam Period	1 2	
Course Language	English	
Required for	AE4303	
Expected prior knowledge	The following prior knowledge is required: AE3302 AE2204 (until 2012/2013) AE2235-I (from 2013/2014)	
Parts	1. Introduction: Course use and arrangement a. Why automatic flight control systems? b. Function of the flight control system in civil aviation c. Recapitulation of theory on flight dynamics d. Review of the different frames of reference: wind, stability, body and geodetic etc. e. Non-linear equations of motion of rigid aircraft. f. Trim and linearization of the non-linear equations of motion. g. The linearized longitudinal aircraft dynamics using a statespace representation and the equivalent frequency domain form. 2. Recapitulation of systems and control theory a. From aircraft dynamics to differential equation a. Laplace transformation c. Elementary closed loop systems d. Transfer functions in Matlab 3. Poles and zeros a. First order systems b. Second order systems c. Pole placement for simple systems 4. Root locus method a. Characteristic equation b. Angle and magnitude conditions c. Root locus in Matlab 5. State space formulation a. Controllability, observability b. Ackerman's formula c. LQR 6. Basic controllers: P,PI,PD,PID 7. Frequency response a. Bode plots b. Bode plots in Matlab 8. Polar plots (Nyquist) 9. Performance and handling qualities a. The military specifications (MIL-SPEC) handling quality criteria b. The Control Anticipation Parameter (CAP) c. Gibsons Phase rate and Frequency criterion 10. Dynamic stability augmentation a. yaw dampers b. pitch dampers c. phugoid dampers 11. Static stability augmentation a. angle of attack feedback to improve static margin b. load factor feedback to improve manoeuvre margin c. sideslip feedback to improve directional static stability 12. Basic longitudinal autopilot modes a. pitch attitude hold mode b. altitude hold mode c. airspeed hold mode (using autothrottle) d. vertical speed 13. Basic lateral autopilot modes a. roll angle hold mode b. coordinated roll angle hold mode c. turn rate at constant altitude and speed d. heading angle hold mode 14. Longitudinal and lateral guidance modes a. glideslope hold mode b. automatic flare mode c. localizer hold mode d. VOR hold mode	
Course Contents	Classical control is still predominantly used in aerospace industry for the design and analysis of automatic flight control systems. Various existing control systems such as Stability Augmentation Systems (SAS), Control Augmentation Systems (CAS) and fly-bywire systems are reviewed in detail. The emphasis of the course lies in demonstrating, through application of classical frequency domain and state space techniques, how to design systems that fulfill the requirements imposed by the aviation authorities, with emphasis on understanding the benefits and limitations of such systems.	
Study Goals	After this course the student should be able to:	

	- substantiate the function of a Flight Control System(FCS) in civil/military aviation. - apply the theory of flight dynamics and control to FCS design. - verify if a given FCS satisfies the handling qualities criteria. - design static and dynamic stability augmentation systems. - design all longitudinal and lateral autopilot modes.
Education Method	Lectures with computer demonstrations
Literature and Study Materials	Course material to support the exercises will be posted on the Brightspace. Recommended literature - M.V. Cook, Principles in flight dynamics, Edward Arnold, London, 1997 ISBN 0-340-63200-3. - B.L. Stevens, F.L.Lewis, Aircraft control and simulation, Wiley, New York, 1992 ISBN 0471613975. - J. Roskam, Airplane flight dynamics and control Part II, , ISBN 1-8845885-18-7.
Assessment	Written closed-book examination
Special Information	Assessment may differ due to COVID-19 measures. In the addendum of the regulations for 2020-2021 (see: https://www.tudelft.nl/studenten/faculteiten/lr-studentenportal/onderwijs/master/regulations-msc/) are the regulations described for alternative assessment. Changes to the assessment method will be communicated via Brightspace.
Remarks	Some chairs may require students to perform a laboratory exercise or practical in conjunction with this course.
Set-up	At the end of each lecture, a simple take home assignment is given in order to gain experience in working with the course material. There will be a written examination at the end of the course. In the related practical AE4301P a control system must be designed that satisfies certain desired requirements.

AE4W02TU	**Introduction to Wind Turbines: Physics and Technology**	**4**
Responsible Instructor	Dr.ir. M.B. Zaayer	
Contact Hours / Week x/x/x/x	0/2/0/0	
Education Period	2	
Start Education	2	
Exam Period	2 3	
Course Language	English	
Required for	AE4W09 (Wind Turbine Design).	
Expected prior knowledge	A proper engineering background in mechanics (Newton's laws of motion), statics (forces, stresses and displacements in structures), dynamics (mass-spring-damper system) and electricity and magnetism (a.o. Lorentz force) is assumed. Knowledge of aerodynamics (lift and drag of aerofoils) is convenient, but not mandatory.	
Course Contents	Wind turbine technology, aerodynamic theory, wind climate, energy production, drive train, control, dynamic modelling, Campbell diagram, strength and fatigue, wind farm aspects.	
Study Goals	Understand wind energy and wind energy conversion systems. Be able to apply knowledge from various fields of engineering related to wind turbine analysis and design.	
Education Method	Self-study of online material, with interactive lectures.	
Literature and Study Materials	Handouts, videos and additional course material on Brightspace.	
Assessment	Written exam at the end of period 2, with a resit at the end of period 3.	
Special Information	Assessment may differ due to COVID-19 measures. In the addendum of the regulations for 2020-2021 (see: https://www.tudelft.nl/studenten/faculteiten/lr-studentenportal/onderwijs/master/regulations-msc/) are the regulations described for alternative assessment. Changes to the assessment method will be communicated via Brightspace.	
Remarks	This course is an elective course for students from various faculties (AE, EEMCS, CEG,...). It is also part of the SET MSc curriculum in several clusters. The course is therefore not tailored to a particular curriculum, but tries to accommodate students with different backgrounds and interests.	
Set-up	Students are expected to study the online course material at home, before the lecture. During the lecture, frequently asked questions will be addressed, difficult topics will be further explained and exercises will be used to test and improve your understanding and application of the course material.	

AE4W09	Wind Turbine Design	5
Responsible Instructor	Dr.ir. M.B. Zaayer	
Contact Hours / Week x/x/x/x	0/0/2/2	
Education Period	3 4	
Start Education	3	
Exam Period	none	
Course Language	English	
Expected prior knowledge	AE4W02TU 'Introduction to wind turbines' or equivalent. When expected prior knowledge from 'Introduction to wind turbines' is missing, extra self-study may be needed to complete 'Wind turbine design' successfully.	
Parts	In this course, students design a wind turbine in a group. This group assignment is divided in two parts. In the first part the preliminary design of the wind turbine is made and this needs to be finished in quarter 3. In the second part the controller is designed and detailed (load) analysis is performed. This part is completed in quarter 4. The assignment runs in parallel with the lectures. In each quarter a software tutorial is given to get familiar with the elements of the software that are relevant in that quarter.	
Course Contents	Overview of the course and the group assignment System design and scaling rules Aerodynamic and structural rotor design and analysis Drive train and electrical system Wind turbine control Blade materials and assessment of fatigue damage Wind data and description The use of standards for load calculations	
Study Goals	The objective is twofold: to obtain creative skills for the applications of knowledge of (technical) design aspects and to understand the coherence between all relevant aspects in a consistent and integrated way.	
Education Method	lectures + software tutorials + group assignment + discussion meetings	
Computer Use	Spreadsheet-type calculations are used to support design decisions. The Matlab/simulink environment is used to develop the controller and to perform detailed analysis of the designed wind turbine. For this purpose Matlab/simulink is connected to 'FAST', a wind turbine simulation package. The use of FAST through the Matlab/simulink environment is explained in the tutorials. FAST only works on computers with MS Windows.	
Literature and Study Materials	Lecture material and some additional information will be published on Brightspace. To execute the assignment, external sources need to be consulted as well.	
Assessment	A group assignment to design a wind turbine has to be executed, reported and discussed with the teachers. The group work is graded and the final individual grade may deviate up or down from the group grade, based on individual contributions to the work. A minimum level is set for both group and individual performance to pass the course.	
Special Information	Assessment may differ due to COVID-19 measures. In the addendum of the regulations for 2020-2021 (see: https://www.tudelft.nl/studenten/faculteiten/lr-studentenportal/onderwijs/master/regulations-msc/) are the regulations described for alternative assessment. Changes to the assessment method will be communicated via Brightspace.	
Remarks	This is multidisciplinary course, attented by students from various faculties (AE, EEMCS, CEG, 3ME, AS), from the 3TU MSc track SET and from the European Wind Energy Master. Supplementary courses are (these treat similar subjects as this course, but more in-depth): AE4W13 Site conditions for wind turbine design AE4135 Rotor / wake aerodynamics AE4W21-14 Wind turbine aeroelasticity ET4117 Electrical machines and drives OE44135 Offshore wind support structures	

AP3132	Advanced Digital Image Processing	6
Responsible Instructor	Dr. B. Rieger	
Instructor	Dr. F.M. Vos	
Contact Hours / Week x/x/x/x	0/0/4/2	
Education Period	3 4	
Start Education	3	
Exam Period	3 4	
Course Language	English	
Expected prior knowledge	Basics of signal processing, image processing, linear algebra, elementary statistics.	
Course Contents	The course Advanced Digital Image Processing covers the principles of several state-of-art image processing techniques. Particularly, students will study the theory of sophisticated algorithms for: 1. Multi-resolution Image Processing: gaussian scale space, windowed Fourier transform, Gabor filters, multi-resolution systems (pyramids, subband coding and Haar transform), multi-resolution expansions (scaling functions and wavelet functions), wavelet Transforms (Wave series expansion, Discrete Wavelet Transform (DWT), Continuous Wavelet Transform (CWT), Fast Wavelet Transform (FWT)); 2. Morpological Image Processing: advanced operations for binary morphology; definitions of gray-scale morphology regarding erosion, dilation, opening, closing; application of gray-scale morphology including smoothing, gradient, second derivatives (top hat) and morphological sieves (granulometry); 3. Image Feature Representation and Description: measurement principles: accuracy vs. precision ; size measurements: area and length (perimeter); shape descriptors of the object outline: form factor, sphericity, eccentricity, curvature signature, bending energy, Fourier descriptors, convex hull, topology; shape descriptors of the gray-scale object: moments, PCA, intensity and density; structure tensor in 2D and 3D: Harris Stephens corner detector, isophote curvature. 4. Motion and optic flow: Taylor expansion method; dual and multi-frame image registration, optic flow; 5. Image Restoration: Noise filtering, Wiener filtering, inverse filtering, geometric transformation, grey value interpolation; 6. Image Segmentation: thresholding, edge and contour detection, data-driven segmentation (boundary detection, region-based segmentation, watersheds, graph-cut, meean shift), model-driven image segmentation (Hough transform, template matching, deformable templates, active contours, ASM/AAM, level sets).	
Study Goals	General learning goals of the course are: 1. acquiring in-depth knowledge of state-of-the-art image processing techniques; 2. being able to solve elementary problems related to the theory mentioned in 1; 3. being able to solve more advanced problems addressing the theory mentioned in 1 by combining mathematical skills and physical insight; 4. being able to acquire new knowledge about an image processing technique; 5. being able to present newly acquired knowledge about a medical imaging technique.	
Education Method	Lectures, practicals and group assignment with plenary presentation and discussion.	
Computer Use	Matlab including the dipimage toolbox and/or other image processing toolboxes.	
Literature and Study Materials	Book 'Digital Image Processing', van R.C. Gonzalez en R.E. Woods, third edition, 2002, ISBN 9780131687288. (Online) Book 'Computer Vision, Algorithms and Applications', R. Szeliski, (http://szeliski.org/Book/). The online version is available for free. We have used the Book Introductory Techniques for 3-D Computer Vision, E. Trucco and A. Verri, ISBN 0-13-261108-2 in the past. Lecture notes Fundamentals of Image Processing (http://homepage.tudelft.nl/e3q6n/education/et4085/sheets/ppt/FIP2.2.pdf) PDF-files of the lecture slides (see Brightspace).	
Assessment	Closed book written exam and assignment. Both parts should be graded 5.8 or higher. A bonus point of 1.5 (to the exam) can be obtained by attending the practicals with 6 out of 8 passed. The final grade is the average of the two parts. The formula for the final grade is: ((0.85*EX + 0.15)+ AS)/ 2 or without the bonus point from the practicals: (EX+AS)/2 With EX the exam grade and AS the grade for the assignment. If you have not passed the exam or the resit, you will need to redo the assignment again next year!	
Permitted Materials during Tests	Closed book exam; books, print-out of pdf files of the lecture slides and lecture notes are not permitted during the written examination.	
Elective	Yes	
Tags	Image processing Matlab Physics	

AP3382	Advanced Photonics	6
Responsible Instructor	Prof.dr. H.P. Urbach	
Instructor	Dr. O. el Gawhary	
Contact Hours / Week x/x/x/x	0/0/2/2	
Education Period	3 4	
Start Education	3	
Exam Period	Exam by appointment	
Course Language	English	
Expected prior knowledge	Electromagnetism bachelor level, optics course bachelor level. Some knowledge about Fourier transforms and mathematics for physicists at the bachelor level will be useful.	
Course Contents	Topics: Embedding in electromagnetism (3 weeks) Maxwell equations in vacuum and in the presence of dielectrics and metals. The electromagnetic spectrum, dispersion and Kramers-Kronig relations. Propagating plane waves in a lossless isotropic medium (including polarisation and energy flux). Field emitted by a time harmonic electric dipole in a homogeneous isotropic medium. Conservation laws for electromagnetic energy and momentum. Time-harmonic scattering problems: Lipmann-Schwinger integral equation. Born approximation and physical optics. Analytical solutions to scattering problems (for cylinders, spheres and multilayers, Sommerfeld half plane problem). Resonances, planar waveguides, plasmonic waves. Diffraction and Interference. (3 weeks) Propagating the e.m. field using the plane wave expansion. Propagating the e.m. field using Rayleigh-Sommerfeld integrals. Kirchhoff boundary conditions. Fresnel & Fraunhofer diffraction formulas. Evanescent waves and homogeneous waves and the limit of propagation of information. Method of stationary phase. Paraxial optics. Equivalence of Fresnel and paraxial theories. Diffraction gratings with applications to spectroscopy and crystal optics. Laser beams. Imaging (4 weeks) Fourier optics theory of imaging. Wide field imaging and confocal imaging. Imaging with partial coherent light. Resolution limits. Telescope with applications to astronomy. The Microscope. Resolution enhancement by solid immersion lens and structured illumination. Increasing the resolution through selective excitation or by saturation. High NA imaging. Applications to lithography. Application: looking around the corner. Inverse Problems (3 weeks) The phase problem. Singular Value Decomposition of Compact Operators. Ill-posed problems. Regularisation methods. Cramer-Rao bound for variance of parameter estimation. Inverse problems of optics in industry. Experimental work: (3 weeks) In groups of maximum 2 students work on 2 experiments: Choose 2 out of following topics: 1. Design your own diffraction pattern with an SLM or by 3D printing. 2. Measure Arago Spot 3. Retrieve object shape from far field measurement. 4. Structured illumination with a SLM. 5. Built an interferometer.	
Study Goals	This course is an introductory course to optics at the master level. Every student who wants to specialize in optics is recommended to follow this course. Apart from basic theory which any graduate in optics should know, topics from current research are treated. Finally it is mandatory for students to perform two experiments during the second half of the course.	
Education Method	oral lectures and/or self-study	
Literature and Study Materials	All lecture materials are handed out and will be put on Brightspace. Most of the material is a selected from lecture notes which are also available on Brightspace.	
Assessment	Written or oral exam (depends on the number of students). Experiments can be done in groups of two students and reports about the experiments will have to be handed in and are part of the exam.	
Special Information	For students from Leiden University: registration as a guest student is required for Brightspace access and registration of grades! See: https://www.tudelft.nl/en/student/administration/enrolment/enrolling-as-a-minor-student-guest-student/	
Elective	Yes	

AP3391	Geometrical Optics	6
Responsible Instructor	Dr. F. Bociort	
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	4	
Course Language	English	
Expected prior knowledge		
Course Contents	This course consists of two parts: the larger part is about the theoretical basis of geometrical optics, the second part is an introduction to optical system design. The topics are: - Fundamentals of geometrical optics (geometrical optics as a limiting case of wave optics, the eikonal function, rays and wave fronts, ray paths in inhomogeneous media) - Ray tracing (Snells law in vector form, formalism for reflection, refraction and transfer, ray failure, aspherical surfaces) - The paraxial approximation (paraxial and finite rays, matrix formalism, characteristics of ideal imaging, principal planes, telescopic systems, aperture and field stops, pupils, vignetting, marginal and chief rays, Lagrange invariant, F number, telecentric systems) - Aberrations (transverse ray aberration, wave front aberration and the relationship between them, power series expansions for optical systems with or without rotational symmetry, rotationally invariant combinations of ray parameters, defocusing, Seidel aberrations. Aberration balancing, caustic, Design aspects: situations when some aberrations are more important than others, aplanatic surfaces, ideal placement of aspheric surfaces.) - Optical design software, local and global optimization of optical systems.	
Study Goals	- Mastery of the concepts, theories and methods listed above at an advanced academic level. - Development of the ability to perform simple lens design tasks with state-of-the-art lens design software.	
Education Method	Oral lectures and independent work with lens design software	
Literature and Study Materials	1. J. Braat, Diktaat Geometrische Optica , TU Delft 1991 (in Dutch; English-speaking students should use Born and Wolf (Ref 5) instead); 2. J. Braat, Paraxial Optics Handout (on Brightspace); 3. W.T. Welford, Aberrations of Optical Systems, Adam Hilger, 1986 (or the earlier version Aberrations of the Symmetrical Optical System, 1974); 4. F. Bociort, Optimization of optical systems (can be found on Brightspace). Supplementary reading (not required for the exam, just if you want extra depth on some subject): 5. M. Born and E. Wolf, Principles of Optics; 6. R.R. Shannon, The Art and Science of Optical Design, Cambridge University Press, 1997; 7. D. Sinclair, Optical Design Software, Handbook of Optics, Chapter 34.	
Assessment	The final mark will be for 70% the mark for the theoretical part (oral exam) and for 30% the mark of the design part (a written report). To pass the exam, for both parts the minimal mark is 5.0.	

AP3401	Introduction to Charged Particle Optics	6
Responsible Instructor	Dr. A. Mohammadi Gheidari	
Instructor	Dr. C.W. Hagen	
Contact Hours / Week x/x/x/x	0/0/2/2	
Education Period	3 4	
Start Education	3	
Exam Period	none	
Course Language	English	
Expected prior knowledge		
Course Contents	Electron and ion lenses, aberrations, deflectors, multipoles, spectrometers, simulation programmes, transmission and scanning electron microscopes, lithography tools, electrical and magnetic fields in vacuum; Laplace equation, Fourier analysis, numerical methods, series expansion, flux lines, equipotential planes, making sketches of these; Geometrical optics: focal point, thick lens model, matrix description, phase space, Liouville, aberrations; Calculation of trajectories: paraxially in lenses, spherical and chromatic aberration constants, paraxially in multipoles, Lagrangians, manual calculations, analytically, numerically far from the axis, adiabatic, wave character; Partical optical elements: magnetic lenses, electrostatic lenses, electron sources, multipoles, analyzers; Partical optical systems: transmission electron microscope, scanning electron microscope (probe calculations), electron beam pattern generator, ion beam pattern generator.	
Study Goals	Understand electron and ion beam instruments and be able to design basic optical components (lenses, quadrupoles)	
Education Method	Explanation of principles, self study of material, assignments, discussion.	
Literature and Study Materials	course book and material on Brightspace.	
Reader	Reader to be obtained through the secretary of the charged particle optics group (10 Euro)	
Assessment	Assignments	
Elective	Yes	
Tags	Physics	
Studyload/Week	8 hours per week	

CIE4801-18	Transport Modelling	6

Responsible Instructor	Dr.ir. R. van Nes
Contact Hours / Week x/x/x/x	6/0/0/0 lectures, assignment 4/0/0/0
Education Period	1
Start Education	1
Exam Period	1 2
Course Language	English
Course Contents	The course consists of lectures and a practical. The lectures focus on theories, concepts and algorithms, and on the application of transport models in practice. The practical focuses on how these theories and algorithms are applied in commercially available transport model software, and the application of this software in a realistic hypothetical case study. This course focusses on knowing and understanding the basic theories, concepts and algorithms of transport models used in practice. 1. Basic concepts: - Role of models in transport system analysis, main model components and their relationships, modelling concepts - System description, zonal segmentation, network description, - Travel choice modelling, utility theory, Logit-models, Nested logit 2. Demand modelling - Trip generation models - Trip distribution models, estimation of deterrence functions - Mode choice models, simultaneous distribution-modal split models - Time of day and departure time models 3 Supply or network modelling - Shortest path trees, uncongested networks and stochastic assignment - Congested networks, equilibrium concept, static and dynamic assignment, system optimal assignment - Public transport assignment 4. Modelling in practice - OD matrix estimation models and forecasting - Transport modelling in practice 5. Special topics - Freight transport models - Land use models, Land-use transport interactions models 6. Exercise using commercial transport modelling software in setting up, performing, and reporting a modelling analysis: assessing a transport system, designing and assessing solution strategies. Studyload: 18 lectures: 36 hours Pre- and post-lecture activities: 26 hours Exercise transport modelling software: 42 hours Self-study, exercise material, preparation for exam: 64 hours Total 168 hours
Study Goals	After following this course students should know and understand the basic theories, concepts and algorithms of transport models used in practice, and should be able to apply the basic algorithms as well as commercially available transport modelling software. After following this course students should be able to: 1. Describe the main components of transport models 2. Discuss the main modelling techniques for the components of the four (five) stage transport model and to apply the basic algorithms 3. Analyse today's transport models 4. Set-up, perform, and report a systematic modelling analysis to assess a transport system and solution strategies.
Education Method	The course consists of lectures and a practical. The lectures focus on theories, concepts and algorithms, and on the application of transport models in practice. Students are asked to prepare upfront by reading sections from the course material, and are provided with post-lecture material to check their understanding of the material discussed. Furthermore, exercise material (i.e. former exam questions) per category of topics is provided to obtain a better understanding and to prepare for the exam. Separate Q&A lectures are included. The practical is aligned with the lectures and consists of two parts: getting acquainted with a commercially available transport model software package, and applying this software in a hypothetical case study for assessing a transport system and analysing the impact of transport policy measures. The latter results in a written professional report. The practical is performed in teams of two. Six morning sessions are scheduled, including supervision or coaching.
Course Relations	This courses provides basic knowledge on transport models that are used in practice and sets the stage for the (courses in the) Transport & Planning specialisation Transport Networks, and partly for topics in the specialisation Public Transport and Railway Systems. This course is also part of the TIL-fundamentals. New developments in transport modelling are addressed in the course CIE5802-18 Advanced Transport Modelling. Furthermore this course relates to courses as CIE4831-18 Empirical Analysis (estimation of choice models), and CIE5830- Freight Transport Systems.
Prerequisites	Technical BSc, especially with respect to calculus, statistics, the concepts of mathematical modelling and algorithms. Knowledge on transport systems in general is recommended.
Assessment	The assessment of the course consists of two parts: - Written exam on knowledge and understanding of the material discussed as well as the application of basic algorithms. (75% of the grade, week 10) - Written report on the analyses done with commercial transport model software (25% of the grade, due week 8) There is no formal formative assessment in this course, however, students can use post-lecture questions per lecture and exercise material (i.e. former exam questions) per category of topics, both including worked-out answers, for self-assessment.
Expected prior Knowledge	Technical BSc, especially with respect to calculus, statistics, the concepts of mathematical modelling and algorithms. Knowledge on transport systems in general is recommended.
Academic Skills	Skills that students will be working on in this course are: - Analytical and critical thinking on models and modelling approaches - Interpretation of modelling results - Using models in problem solving - Awareness of relationship between real world problems and modelling - Writing professional reports
Literature & Study	Obligatory lecture note(s)/textbook(s):

Materials	- Ortuzar, J. de Dios, L.G. Willumsen (2011) Modelling transport 4th edition, John Wiley & Sons, Chichester - Selected papers on Spatial Modelling, references will be provided - Manual of exercises in transport modelling software (Omnitrans) Obligatory other materials: - Lecture slides and exercise material on Brightspace
Judgement	The written exam is 75% of the grade and the written report on the second part of the practical is 25%. Both partial grades are rounded to 0.1 precision and for each a minimum score of 5.0 is required. The final grade is rounded to a 0.5 precision. Minimum passing grade is 6.
Permitted Materials during Exam	Formula sheet (A4, double sided, no text except keywords), (graphical) calculator
Collegerama	Yes

CIE4811-18	Planning and Operations of Public Transport Systems	6
Responsible Instructor	Dr. O. Cats	
Instructor	Prof.dr. R.M.P. Goverde	
Instructor	Dr.ir. R. van Nes	
Instructor	Dr. W.W. Veeneman	
Instructor	Dr.ir. N. van Oort	
Contact Hours / Week x/x/x/x	4/0/0/0	
Education Period	1	
Start Education	1	
Exam Period	1 2	
Course Language	English	
Course Contents	This is an introductory course to the planning and operations of public transport systems. Students will learn how public transport systems are planned, starting from the long-term strategic planning, going through tactical planning and finally discussing its real-time operations. Planning dilemmas and solution approaches to planning topics prevalent in passenger transport systems will be discussed and applied. Lectures are given by a team of teachers. Planning process and objectives Integrated door-to-door planning Service performance measures Service technology capacity, reliability and costs Governance, (de-)regulation and pricing Network design problem definition and solution methods Network structure representation and analysis Service frequency determination and fleet allocation Timetable planning and reliability management Fundamentals of railway traffic operations Characteristics of on-demand transport services	
Study Goals	After following this course, the student is able to perform strategic, tactical and real-time planning of public transport systems at a basic level After successful completion of the course, the student is able to: Explain and relate the functions of strategic, tactical and real-time operation and control of public transport systems. Classify public transport systems based on technology, right-of-way and type of operations. Design and examine public transport networks while considering coverage, accessibility, travel and operational costs Analyse the structure of public transport networks by applying graph-based principles Construct timetables and vehicle schedules for road- and rail-bound public transport services Computing and analysing the efficiency, effectiveness and reliability of public transport services Describe and debate the policy and principles of deregulation of public transport and tendering of services. Evaluate and criticise public transport project appraisals	
Education Method	Pre-lecture material and activities (incl. videos, reading material, quizzes) Lectures (2hr, twice a week), including in-class exercises Post-lecture material and activities (incl. videos, reading material, quizzes) Assignment reports including numerical exercises (in pairs) Oral presentation and group discussion Written exam	
Assessment	Formative feedback on quizzes on Brightspace and exercises in class 4 written assignments: I - network design ; II - network structure; III - railway operations; IV - performance and integrated planning A written exam	
Tags	Policy Analysis Rail & Road Engineering / Planning Transport & Logistics Transport phenomena	
Expected prior Knowledge	This courses provides basic knowledge on planning and operations of curriculum: public transport systems and sets the stage for the (courses in the) Transport & Planning specialisation Public transport and railway systems. This course is also part of the TIL-specialisation Design.	
Academic Skills	Students are expected to exercise the following academic skills: - Problem formulation - Data analysis - Statistical interpretation - Comparing alternatives quantitatively - Working in diverse groups - Report structuring and writing - Reading and summarizing scientific papers	
Literature & Study Materials	Pre- and post-lecture reading material are indicated for each lecture on Brightspace. In addition, the following textbooks are used as references and can be recommended: - Vuchic (2005). Urban Transit : Operations, planning and economics. Wiley. - Vuchic (2007). Urban Transit: Systems and Technology. Wiley. - Ceder (2007). Public Transit Planning and Operation : Theory, modelling and practice. Elsevier.	
Judgement	The written exam is 60% of the grade and the assignments count for 40%.	
Permitted Materials during Exam	Calculator	
Collegerama	No	

CIE4825	Traffic Flow Modelling and Control Part 1	6

Responsible Instructor	Dr. V.L. Knoop
Instructor	Dr.ir. A. Hegyi
Instructor	Dr.ir. A.M. Salomons
Contact Hours / Week x/x/x/x	0/8/0/0 lecture (2x2), assignment 4 (PC)
Education Period	2
Start Education	2
Exam Period	2 3
Course Language	English
Required for	5821
Course Contents	The course discusses traffic flow modelling and control. Students will learn the most used techniques to describe traffic flows at the microscopic (i.e., vehicle) level and macroscopic (road) level. Students will apply the modelling techniques to apply control. Lectures will be given by various lecturers basic concepts of traffic flow theory most important traffic flow phenomena microscopic car-following models multi-lane freeway traffic kinematic wave theory introduction to systems and control freeway control: Ramp Metering, VSL (SPECIALIST) introduction to local intersection control
Study Goals	After successful completion of the course, the student is able to: Comment on different levels of stability for traffic Recognise traffic states from traffic measurements, and derive the causes for the observed traffic states Analyse and explain the differences between observation methods, in particular the effects of moving observers and averaging methods (time mean vs space mean) Construct and interpret x,t plots Apply Edies definitions of density, flow and average speed, and relate these to each other Construct the fundamental diagram in various forms Create and analyse a car-following model, and link this to a representation on the macroscopic level Apply shock wave theory Explain the steps of a shockwave-based method to resolve stop-and-go waves Explain why traffic control is needed Create a traffic control scheme based on road hierarchy Assess traffic simulation outcomes Design a local intersection controller
Education Method	- 2x2 hours per week lectures - 1 afternoon per week supervised exercises - self-study /-preparation of lectures via videos and exercises
Assessment	Assessment consists of (group)assignments and an individual final written exam. Formative testing is present in the first assignment and through feedback on short exercises in class.
Tags	Group work Modelling Numeric Methods Rail & Road Engineering / Planning Transport & Logistics Transport phenomena
Expected prior Knowledge	Calculus, elementray programming
Academic Skills	Thinking (critical, analytical) Interpretation Writing reports, reviews, articles Cooperation Problem solving Judgemental skills Debating and discussion. Reasoning/arguing Logic
Literature & Study Materials	For additional reading and reference (not compulsory, nor explicitly used in class), students could consider the following books: V.L. Knoop, Introduction to Traffic Flow Theory, 2017, ISBN 9789492516718 May, A.D. Traffic flow fundamentals. 1990. Leutzbach, W. Introduction to the theory of traffic flow. Vol. 47. Berlin: Springer-Verlag, 1988. Daganzo, C.F. Fundamentals of transportation and traffic operations. Vol. 30. Oxford: Pergamon, 1997. Treiber, M., and A. Kesting. "Traffic flow dynamics.", Traffic Flow Dynamics: Data, Models and Simulation, Springer-Verlag Berlin Heidelberg (2013). Elefteriadou, L. An introduction to traffic flow theory. Vol. 84. New York, NY, USA: Springer, 2014. Ni, D. Traffic Flow Theory: Characteristics, Experimental Methods, and Numerical Techniques. Butterworth-Heinemann, 2015.
Judgement	The final exam counts for 75% of the grade and the assignments during the course counts for 25%. Both partial grades are rounded to 0.1 precision and for each a minimum score of 5.0 is required. The final grade is rounded to a 0.5 precision. Minimum passing grade is 6.
Permitted Materials during Exam	1 handwritten A4, 2 sides, number of lines and symbols limited.
Collegerama	Yes

CIE5803-18	Railway Traffic Management	4
Responsible Instructor	E. Quaglietta	
Instructor	Prof.dr. R.M.P. Goverde	
Instructor	N. Besinovic	
Contact Hours / Week x/x/x/x	0/0/0/4 lectures and practical (2x2)	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Course Contents	This course is about railway timetabling and real-time railway traffic management. The first part on railway traffic planning includes railway timetable optimization models, timetable stability analysis using max-plus algebra, energy-efficient train operation, and microscopic and macroscopic railway traffic simulation. The second part on real-time railway traffic management includes railway traffic management systems, train delay monitoring and prediction, conflict detection and resolution, Driver Advisory Systems, and disruption management. During the course several software tools are applied in computer assignments, including railway timetable optimization using Matlab, timetable stability analysis of the Dutch national railway timetable using PETER, and microscopic simulation using OpenTrack.	
Study Goals	At the end of this course you will be able to Design a railway timetable using timetable optimization Evaluate railway timetable stability Analyse railway traffic systems using microscopic simulation Evaluate real-time railway traffic management systems Evaluate energy-efficient train operation and Driver Advisory Systems	
Education Method	This course uses blended learning with pre-lecture activities (videos, reading, questions), regular lectures (theory, examples, discussions), guest lectures, and post-lecture activities (reading, exercises, self-tests, assignments). The course includes three computer assignments to apply the theory in case studies. A report must be prepared for each assignment. The course ends with a written examination. Study load: Lectures (18 h), computer practical (14 h), exercises and writing assignment reports (14 h), self-study/reading/videos (52 h), exam preparation (14 h).	
Assessment	The assessment consists of a written exam (50%) and an assignment (50%). The assignment comprises three written reports on the computer assignments. The assessment for this year will be performed on line	
Elective	Yes	
Tags	Algebra Modelling Optimalisation Practicals Rail & Road Engineering / Planning Transport & Logistics	
Expected prior Knowledge	Recommended: Planning and Operations of Public Transport Systems (CIE4811). In particular, blocking time theory is assumed working knowledge. Additional reading (one chapter, 3 hours) is required for those not familiar with blocking time theory. In addition, an introduction course on discrete optimization is recommended, such as Transport Engineering and Optimisation (CIE4835) or Quantitative Methods for Logistics (ME44205).	
Academic Skills	Problem formulation and problem solving Critical and analytical thinking Interpretation Writing reports	
Literature & Study Materials	I.A. Hansen & J. Pachl (eds.), Railway Timetabling & Operations, Eurailpress, Hamburg, 2nd edition, 2014.	
Judgement	For more information on grading, see article 14 in the Rules and Guidelines (RGBE): https://www.tudelft.nl/en/student/faculties/ceg-student-portal/education/education-information/educational-rules-and-regulations/	
Permitted Materials during Exam	Due to temporary National restrictive measures the course exam of this year will be an open-book exam which will be in the form of an on-line Brightspace quiz	
Collegerama	No	

CIE5805-18	Intelligent Vehicles for Safe and Efficient Traffic: Design and Assessment	4
Responsible Instructor	Dr. M. Wang	
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Course Contents	The course starts with system and technological parts of Intelligent Vehicles, followed by behaviour changes of users and the collective impact on traffic safety and traffic flow. The lectures will be given by different lecturers. The course focuses on design and evaluation of intelligent vehicle systems to increase traffic safety, efficiency and sustainability. The course disentangles the relations between individual intelligent vehicle and the collective traffic operations. The course consists of the following parts: 1: Introduction, classification and functional description of intelligent vehicles; 2: System architecture, decision and control methods for intelligent vehicle systems; 3: Technologies for intelligent vehicles, sensors, communication, and actuators; 4: Behavioural adaptation to intelligent vehicles; 5: Impact assessment of intelligent vehicles on traffic safety; 6. Impact assessment of intelligent vehicles on traffic efficiency; 7: Simulation experimental research of impacts of intelligent vehicles on traffic flow using traffic flow/driving simulation. Study load: 14 Lectures (including guest lecture, oral presentation and in-class exercises): 28 hours Self-study: 12 hours 3 graded group reports: 49 hours Preparation for examination: 20 hours Examination: 3 hours	
Study Goals	At the end of this course you will be able to design simple intelligent vehicle systems and apply models and tools to assess the impacts of the designed systems on traffic safety and collective traffic flow characteristics. At the end of the course students are able to: 1. describe and analyse the essential components of intelligent vehicle systems; 2. analyse and design the tactical and/or operational level decision-making systems of your intelligent vehicle system; 3. compare the characteristics of different sensing and communication technologies for intelligent vehicles; 4. identify and assess behavioural adaptation effects of intelligent vehicles; 5. (a) analyse the main methods of traffic safety impact assessment for intelligent vehicle systems; (b) assess the traffic safety impacts of intelligent vehicle systems; 6. (a) analyse the main methods of traffic flow impact assessment for intelligent vehicle systems; (b) assess the traffic flow impact of intelligent vehicle systems; 7. apply traffic simulation to assess the traffic flow impacts of a selected intelligent vehicle system.	
Education Method	Different teaching methods are used: 2 lectures per week Guest lectures from industry Self-study of reader/slides/literature 3 graded group reports Weekly formative assessment (in form of written feedback) Oral presentation In-class exercises (simulation exercises, group discussions, peer reviews and feedback)	
Course Relations	The course is closely related to CIE4825 Traffic Flow Modelling and Control Part 1 and CIE5810-18 Traffic Safety.	
Prerequisites	No pre-requisites, but related courses are recommended.	
Assessment	During the course students conduct 3 graded reports, 1): designing intelligent vehicle systems, 2) analysis and assessment of behavioural adaptation effects, safety impact, and traffic flow impact of a new intelligent vehicle system, and 3) assessment report of a predefined systems using traffic simulation. The 3 reports accounts for 60% of the final grade and the remaining 40% of the final grade is assessed in a written examination. Both partial grades are rounded to 0.1 precision and for each a minimum score of 5.0 is required. The final grade is rounded to a 0.5 precision.	
Expected prior Knowledge	The course is closely related to CIE4825 Traffic Flow Modelling and Control Part 1 and CIE5810-18 Traffic Safety.	
Academic Skills	In addition to the technical materials, students will also practice scientific writing, literature research, presenting, giving feedback and working in teams	
Literature & Study Materials	Reader, recommended papers and slides	
Judgement	For more information on grading, see article 14 in the Rules and Guidelines (RGBE): https://www.tudelft.nl/en/student/faculties/ceg-student-portal/education/education-information/educational-rules-and-regulations/	
Permitted Materials during Exam	Calculator	
Collegerama	No	

CIE5826	Railway Operations and Control	4

Responsible Instructor	Prof.dr. R.M.P. Goverde
Instructor	Dr. D.M. van de Velde
Contact Hours / Week x/x/x/x	0/0/4/0
Education Period	3
Start Education	3
Exam Period	3 4
Course Language	English
Required for	This course is mandatory for the Annotation Railway Systems.
Course Contents	This course considers railway signalling and the coordination of technical and organizational railway subsystems from investments to operations. A good understanding of the railway safety and signalling principles is required to design safe and efficient railway operations. But railway performance depends on the coordination of many more technical and organisational subsystems with constraints and objectives largely influenced by policy and (safety) legislation. Many examples exist of misalignments in the coordination of the various subsystems which resulted in increased costs and decreased performance. A main example is a coordinated deployment strategy for migrating to new signalling systems such as the European Rail Traffic Management System (ERTMS). The topics on railway signalling include history of railway signalling, block signalling, interlocking, automatic train protection, and automatic train operation. The part on the coordination in the railway value chain covers railway governance, railway value chains, short-term and long-term coordination. Migration to ERTMS is a common theme in both parts.
Study Goals	At the end of this course you will be able to Analyse railway signalling systems, including block signalling, interlocking, and automatic train protection systems Discuss railway safety principles and its impact on operations performance Analyse railway value chains and potential coordination misalignments Discuss railway governance and main policy options Discuss signalling migration issues, including ERTMS and ATO
Education Method	This course uses Blended Learning with a mixture of videos, lectures, reading, guest lectures, discussions, oral presentations, and two group assignments including peer reviews. The group assignments consist of a critical review and an essay that must be written in the format of scientific papers. Study load: Lectures (28 h), two assignments with written papers, peer reviews and group presentations (34 h), self-study/reading/videos (36 h), exam preparation (14 h).
Course Relations	This course is related to CIE4811 (railway transport planning, blocking times) and CIE5803 (timetabling and operational railway traffic management). The course is a mandatory part of the Annotation Railway Systems.
Assessment	The assessment consists of a written exam (50%) and assignments (50%). The assignments are done in groups and comprises two written papers and a group presentation.
Elective	Yes
Tags	Group work Policy Analysis Rail & Road Engineering / Planning Technology Transport & Logistics
Expected prior Knowledge	None
Academic Skills	Writing article, critical thinking, literature review, interviewing, cooperation.
Literature & Study Materials	A selection of papers made available on BrightSpace.
Judgement	For more information on grading, see article 14 in the Rules and Guidelines (RGBE): https://www.tudelft.nl/en/student/faculties/ceg-student-portal/education/education-information/educational-rules-and-regulations/
Permitted Materials during Exam	None
Collegerama	No

CS4220	Machine Learning 1	5

Responsible Instructor	Dr. D.M.J. Tax
Instructor	M. Loog
Contact Hours / Week x/x/x/x	0/6/0/0 4h lectures, 2h lab
Education Period	2
Start Education	2
Exam Period	2
Course Language	English
Required for	This course is required for CS4230 Machine Learning 2
Expected prior knowledge	For the course CS4220, you should know the terminology that is taught in the course CSE2510. So, please have a look at the content of CSE2510 in Brightspace. It is not required that you followed the course CSE2510 in full, or made the exam.
Course Contents	Recapitulation of (un)supervised learning, classification, decision theory overfitting. Complexity, regularisation, and support vector classifiers. Regression, linear and kernel regression. Bayesian learning, graphical models. Clustering and mixture models, the EM algorithm. Feature selection and extraction, PCA. Design and analysis of ML experiments.
Study Goals	After successfully completing this course, the student is able to: recognise machine learning problems and select algorithms to solve them; read and comprehend recent articles in engineering-oriented pattern recognition journals, such as IEEE Tr. on PAMI; construct a learning system to solve a given simple machine learning problem, and able to implement algorithms from literature.
Education Method	Lectures, laboratory work (mathematical exercises and computer exercises)
Assessment	One final exam. disclaimer: information may change depending on the developments around the coronavirus.

CS4230	Machine Learning 2	5
Responsible Instructor	M. Loog	
Instructor	Dr. D.M.J. Tax	
Instructor	Dr.ing. J. Kober	
Instructor	Dr. F.A. Oliehoek	
Contact Hours / Week x/x/x/x	0/0/4/4	
Education Period	3 4	
Start Education	3	
Exam Period	4	
Course Language	English	
Expected prior knowledge	This course is the more advanced and research oriented version of CS4220 [Machine Learning 1]. The latter is, therefore, expected as prior knowledge.	
Course Contents	The course will treat a number of machine learning theories and techniques in detail and on an advanced level. Possible topics : - learning theory - Bayesian networks - online learning - Rademacher complexity - Markov decision processes - semi-supervised learning - reinforcement learning - active learning - causal reasoning and discovery	
Study Goals	After successfully completing the course, the student is able to apply the techniques and theories that have been covered in the course. In addition, s/he is able to develop learning strategies for new and previously unseen situations. Moreover, the student can provide reasoned justifications for these strategies based, for instance, on theory and/or experiment.	
Education Method	Lectures + Q&A sessions	
Assessment	Grading is for about 75% based on a written examination. Following the 10 or 11 lectures, there will be an individual assignment that will make up the remaining part of the grade [about 25%]. For the assignment a written report has to be submitted. For both parts a minimum grade of 5.8 must be obtained to successfully get through the course. There is a resit for the written examination, but not for the report. disclaimer: information may change depending on the developments around the coronavirus.	

ET4257	Sensors and Actuators	4
Responsible Instructor	Prof.dr. P.J. French	
Contact Hours / Week x/x/x/x	0/3/0/0	
Education Period	2	
Start Education	2	
Exam Period	2	
Course Language	English	
Expected prior knowledge	P-study	
Course Contents	The course silicon sensors and Actuators gives an overview of the most important principles related to sensors and actuators fabricated in integrated silicon technology. The sensors are divided into those for optical, mechanical, thermal, magnetic and chemical signals. These domains will be dealt with from basic principles leading to the applications. The second part of the course will deal with actuators. The actuators lectures give the range from large machines down to silicon micromachined device in the micron range. The course is designed for students who will perform their thesis work in one of the laboratories within the faculty working on or using sensors	
Study Goals	The aim of this course is to learn about the physics and electronics of transducers. This brings together different disciplines develop these systems.<>	
Education Method	Lectures	
Literature and Study Materials	Lecture notes Part 1 Silicon Sensors part 2 Actuators	
Assessment	Written, essay or oral. Assessment material: at least 6 chapters of the lecture notes including at least one chapter from Actuators. disclaimer: information may change depending on the developments around the coronavirus.	

IN4343	Real-time Systems	5
Responsible Instructor	Prof.dr. K.G. Langendoen	
Contact Hours / Week x/x/x/x	0/0/4/0 and 0/0/4/0 lab	
Education Period	3	
Start Education	3	
Exam Period	3 4	
Course Language	English	
Required for	3TU MSc Embedded Systems; the corresponding courses are 2IN26 at TU Eindhoven, and 312030 at TU Twente	
Expected prior knowledge	Basic software engineering, C system programming, basic Linux operating system knowledge	
Course Contents	- basic concepts of RTS - worst case execution time estimation - scheduling policies - response-time analysis - jitter analysis - handling overload - multiprocessor scheduling - reservation-based scheduling	
Study Goals	The course intends to bring the student into the position to: - Explain the fundamental concepts and terminology of real-time systems - Construct task schedules using different scheduling policies under a given set of realistic system constraints - Analyze the timing behavior of a system for a given system model and scheduling policy - Discuss advantages and disadvantages of different scheduling policies for a given platform or system - Discuss the effect of hardware and software interferences on the timing behavior of a given system - Identify (reverse engineer) parameters of a scheduling scheme or a task set from output traces of the system - Derive (reverse engineer) the system specification from a given implementation (in the lab) - Evaluate the scheduling overheads of a given implementation (in the lab) - Implement event-based scheduling policies on a given microcontroller (in the lab)	
Education Method	lectures with exercises (32 hrs); self study (78 hrs); lab assignments (30 hrs)	
Books	Hard Real-Time Computing Systems by G.C. Buttazzo, Springer 2005	
Assessment	Written exam (grade) + lab work; the exam has a resit disclaimer: information may change depending on the developments around the coronavirus.	
Exam Hours	3	
Permitted Materials during Tests	Simple calculator	

IN4387	System Validation	5
Responsible Instructor	Dr. C.B. Poulsen	
Contact Hours / Week x/x/x/x	2/0/0/0 HC 4/0/0/0 instr & lab	
Education Period	1	
Start Education	1	
Exam Period	1 2	
Course Language	English	
Required for	Embedded Systems Masters	
Expected prior knowledge	There are no strict entry conditions for this course. However, prior knowledge of requirements analysis is recommended. Furthermore, a good basic knowledge about logic and set theory is extremely beneficial.	
Parts	Behavioural specification of sequential and parallel using labelled transition systems, process algebra, and abstract data types; model checking of such systems using the modal mu-calculus. Model-based testing.	
Summary	Everyone who ever designed an embedded system or a communication protocol involving several components executing simultaneously has experienced that such software is inherently susceptible to bugs. Typical problems that occur are race conditions, deadlocks, and unexpected interplay between different components. Due to the parallel nature of these systems, it is notoriously hard to detect such bugs using testing (for example, timing plays a crucial role). The following quote from the famous Dutch computer scientist Edsger W. Dijkstra illustrates a further problem with testing. Program testing can be a very effective way to show the presence of bugs, but it is hopelessly inadequate for showing their absence. Edsger W. Dijkstra In this course, we study model checking, which in contrast to testing can also be used to show the absence of bugs. Model checking is a technique in which we consider all states in (a model of) the system based on an abstract model. Based on this state space we verify whether the model satisfies the desired properties. Properties are typically derived from the requirements of the system. We will restrict ourselves to verification techniques that do not reason about timing (merely about the order in which event happen). Finally, we see how model-based testing can be used to show that an implementation conforms to the specification of the system.	
Course Contents	Behavioral Specification using Process Theory (Labelled Transition Systems, various notions of behavioral equivalence) and process algebra. Model checking the modal mu-calculus, and model-based testing using IOCO.	
Study Goals	Upon completion of the course: 1. The student knows the fundamental theory necessary for specifying the behavior of embedded systems and for reasoning about this behavior. 2. The student can describe simple systems using this theory. 3. The student can formally specify requirements and prove (or disprove) them on the behavior. 4. The student is able to model a concrete embedded system, and verify that it satisfies its requirements. 5. The student is able to show that an implementation of a system conforms to its specification.	
Education Method	Lectures + Programming Assignments + Practical Project The course is structured into two parts: 1. There will be weekly mandatory programming assignments in the first four weeks of course will be a small set of mandatory. The programming assignments are assessed as pass/fail. The programming assignments are due after the first four weeks of the course. 2. In the last four weeks of the course, you will self-organize into groups of (about) 4 students, and will develop and verify a model of an embedded system. You will write a report that documents your model and its development. There will be a written 24 hour exam with programming assignments at the end of the course.	
Computer Use	The theory introduced in this lecture is at the heart of the mCRL2 tool set. This tool set can be used to specify and verify systems, and visualize them. To be able to carry out the project it is required that the mCRL2 tool set is installed on your laptop (or one of the TU Delft systems, if you do not have a laptop you can use). It is open source software, and is free of charge. The software can be obtained from https://www.mcrl2.org.	
Literature and Study Materials	The course is based on the book by Groote and Mousavi (see "Books"). All other materials will be published on Brightspace.	
Books	J.F. Groote and M.R. Mousavi. Modeling and Analysis of Communicating Systems. MIT Press, 2014. ISBN: 9780262027717 (Chapters 1-7,11 are mandatory)	
Assessment	The result of this course will be based upon the results of the written examination (50%) and the practical project (50%). For both the programming exam and the practical project, a minimum of 5.0 is required in order to pass the course. To be eligible for taking the exam you must submit and pass the mandatory programming assignments for the first four weeks of the course. Grades of the project or written exam do not automatically carry over from previous years, so upon retaking the course talk to your lecturer first. For the exam a resit is scheduled. disclaimer: information may change depending on the developments around the coronavirus.	
Permitted Materials during Tests	The exam will be a 24 hour programming exam. You are allowed to use the book and any other static resources. You are not allowed to communicate or discuss exam questions with anyone but members of the teaching team for the course. Discussing or copying code will be considered fraud, and is reason for expulsion from the course.	
Enrolment / Application	Brightspace	
Co-Instructor	Prof.dr. E. Visser	

ME41000	Automotive Human Factors	3
Responsible Instructor	Dr.ir. R. Happee	
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Required for	This course was last given in 2019-2020. Students are recommended to take the new and extended course RO47016 (5 ECTS) offered as part of the new master Robotics. The new course RO47016 can also be followed for Track Vehicle Engineering in the Master Mechanical Engineering	
Summary	Human Factors is covered with a focus on Automated & Supported driving	
Course Contents	The evolution from manual to automated driving Human behaviour in car following versus (Adaptive) Cruise Control Human path following versus Lane Keeping Assistance & Automated Steering Driver vehicle interaction in highly automated driving Situation awareness, workload & vigilance Driver Performance in Take Over Requests Driver State Monitoring Perceived Safety & Trust Calibration Interaction of automated vehicles with other road users: Acceptance, perceived safety, external human machine interfaces Comfort Ergonomic design of the vehicle cockpit Motion comfort and motion sickness	
Study Goals	Upon successful completion of the course you will be able to: 1. Describe and analyse the interaction of drivers and users of automated vehicles, with their vehicles. 2. Describe and analyse the interaction of other road users with automated vehicles. 3. Contribute to the design of vehicle automation with a focus on human factors. 4. Express your own vision on the role of the driver/user in future vehicles.	
Education Method	Lectures (4 hours per week) Self-study Conceptual assignments Group assignment designing an innovative automated driving system. Specify the operation modes and range of the automation. 1) Review the human factors challenges. 2) Design the human machine interface. 3) Propose an experiment to evaluate safe and acceptable user interaction. Optionally teams may design 1) A market introduction strategy 2) Design interface concepts for interaction with other road users 3) Redesign the vehicle interior for non-driving tasks 4) Integrate automated driving in (public) transport	
Assessment	The course was last given in 2019-2020. An additional exam will be offered in 2020-2021. This exam can be taken by students which have already completed the assignments.	
Enrolment / Application	Through Brightspace	
Percentage of Design	25	
Department	3mE Department Biomechanical Engineering	

ME41005	Musculoskeletal Modelling and Simulation	3
Responsible Instructor	A. Seth	
Contact Hours / Week x/x/x/x	0/0/0/6 (2h lectures, 4h practicals per week)	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Expected prior knowledge	Students are expected to have a solid background in 3D kinematics, multibody dynamics, numerical methods, and scientific computing in MATLAB or Python.	
Course Contents	Human and animal movement is often smooth, powerful, and graceful. Animal movement is generated through a cascade of nervous, muscular, and skeletal system dynamics. Even the simple tasks of walking and running require the coordination of hundreds of muscles that pull on bones that move our limbs and generate forces on the environment so we can move. When these systems are disrupted through disease and injury, they result in movement disorders that can be debilitating. In this course you will learn to construct and simulate musculoskeletal models that generate movement. You will learn how to apply models to improve measurements of movement and to predict behavior, thus extracting more insights about human (and animal) movement then from observations alone. We will start with the constituent components of bones, joints, muscles, and tendons and their dynamics, as the building blocks of musculoskeletal systems. You will learn inverse techniques to extract unmeasured quantities, like joint kinematics, work, and power from observations and to use forward dynamic simulations to predict behaviors and answer what if? type questions. You will apply these models and techniques to answer a research question of your own formulation.	
Study Goals	This course is offered to graduate students in Biomechanical engineering and the broader the Faculty of 3mE at TU Delft. The course is intended for mechanical engineering students seeking ways to apply engineering tools to better understand human and animal movement. By the end of this course, you should be able to: 1) explain what is musculoskeletal modeling? and why models can be useful, particularly for answering questions related to human movement disorders 2) define and simulate computational models of muscular and skeletal (multibody) dynamics that represent (aspects of) human and animal movement using OpenSim and MATLAB (or Python) 3) decide what is a necessary and sufficient model to answer a specific question about human/animal movement (or disorder) that accounts for modeling assumptions and limitations 4) formulate a real-world question and/or hypothesis about human or animal movement (ability or dysfunction), for which a musculoskeletal model can be applied 5) answer a compelling question about human or animal movement with a musculoskeletal model	
Education Method	Lectures, practical labs and project work. Literature and Study Materials: lecture slides, readers, papers (provided through Brightspace)	
Assessment	Biweekly practical labs/assignment Midterm exam Final project	
Department	3mE Department Biomechanical Engineering 3mE Department Cognitive Robotics	

ME41025	Robotics Practicals	3
Responsible Instructor	J.F.P. Kooij	
Contact Hours / Week x/x/x/x	4.0.0.0	
Education Period	1	
Start Education	1	
Exam Period	Different, to be announced	
Course Language	English	
Course Contents	** NOTE: Last time this course will be given. See Remarks below. ** This course is meant for students that need to create robotic software for their MSc thesis. Since it is impossible to become an expert in all topics, this course aims to give students sufficient knowledge and experience such that they can proceed learning more about robotics programming by themselves as needed. The course does this by explaining key technologies, and letting students practice the basic skills often used in real world robotic software development. This course does not teach new robotics theory (e.g. perception, planning, control, etc.) which is covered in other courses. Basic familiarity with robot architecture, tasks, and perception methods (such as those found in the OpenCV and PCL libraries) are expected. Instead, Robotics Practicals focuses on improving the programming and collaborative software development skills only. Developing these skills can only be done when students invest a lot of time for self-study and practice outside the fixed lab and lecture contact hours. In total. the allotted 3 ECTS over about 8 weeks means students are expected to invest approximately 10,5 hours/week. Be aware that active participation in all the lab assignments is required, hence it is not recommended to do this course jointly with other labor intensive lab courses. The student get hands on experience in the following subjects: # Linux: Although Windows is the most prevalent operating system on desktop PCs, Linux became very popular for embedded systems such as robots. Developing for embedded Linux systems is most easily done in Linux itself, and this course aims to familiarize students with the use of Linux on the desktop. It encompasses the following topics: Architecture, File system, Shell, Scripting. # Git/gitlab: All exercises will be made using Git, a widely used version control system to manage and collaborate on coding projects. Performing basic tasks with git, solving conflicts, and merging your work with that of your lab partner are important skills that you will practice during the course. # C++: C++is one of the most widely used programming languages. Being an object oriented language brings great advantages comparing to its predecessor C. This practicum is designed to give the student a practical knowledge on C++ programming. The course encompasses the following topics: Introduction to C++, general features, basic programming in C++, functions, pointers, classes and objects, graphical user interface and some advanced topics such as data structures, casting and exception handling. C++ is a must if you want to make software for intelligent - real-time - control of machines or/and image processing. # ROS: The Robot Operating System is a flexible framework for writing robot software. It is a collection of tools, libraries, and conventions that aim to simplify the task of creating complex and robust robot behavior across a wide variety of robotic platforms. Creating truly robust, general-purpose robot software is hard. From the robot's perspective, problems that seem trivial to humans often vary wildly between instances of tasks and environments. Dealing with these variations is so hard that no single individual, laboratory, or institution can hope to do it on their own. # OpenCV / PCL: You will also practice using external libraries in your robotics project, such as OpenCV or PCL. OpenCV is a computer vision library designed for computational efficiency and with a strong focus on real-time applications. The Point Cloud Library (PCL) is a stand-alone, large scale, open project for 2D/3D image processing and point cloud processing. Note that this course is *NOT* about understanding the methods or theory on which these libraries are based.	
Study Goals	The main objective is to obtain hands on experience - beginners level - with Linux, Git & Gitlab, C++, ROS, and integrate with common external libraries such as OpenCV and PCL. By completing this course, students achieve the following learning objectives 1. The student is able to use the command line on a Linux system, perform basic file operations and job management tasks, and automate tasks with shell scripts; 2. The student is able to collaborate with a lab partner on a joint code project, using git to commit integrate incremental code changes, and resolve any code integration conflicts; 3. The student is able to use a Gitlab server to exchange code changes, and use the Gitlab issue tracker to provide and receive feedback on each other's code; 4. The student is able to execute programming tasks in C++, compile the code using Make, debug compile-time, link-time and runtime problems; 5. The student is able to add code comments and basic documentation to their code, lookup documentation of external libraries; 6. The student is able to create new C++ ROS packages, use common ROS development tools, and utilize the ROS API in their C++ programs. 7. The student can investigate and integrate commonly used external libraries for their own ROS project, such as OpenCV or PCL.	
Education Method	Lectures, lab assignments, peer-review tasks	
Assessment	Four obligatory coding lab assignments, where you are evaluated on solution quality, code quality, and documentation. Active participation in each lab assignment is required to participate in the next assignment. Active participation entails that you submit your solution before the given deadline, and that you complete various peer-review tasks. For the first three assignments you will receive formative feedback (what goes well, what to improve). For the last assignment you receive summative feedback (i.e. the PASS/FAIL grade).	
Remarks	Last time this course will be given in this format for 3 ECTS. Unlike previous years, it will be held in Q1, and given jointly with the new RO47003 "Robot Software Practicals" (5 ECTS). This course is only meant for Mechanical Engineering students for whom it is obligatory/recommended and for students who followed the course in 2019-2020 or earlier. ME41025 should NOT be chosen together with RO47003 due to content overlap between the two courses.	
Department	3mE Department Cognitive Robotics	

ME41055	Multibody Dynamics B	4
Responsible Instructor	Dr.ir. A.L. Schwab	
Contact Hours / Week x/x/x/x	0/0/2/2	
Education Period	3 4	
Start Education	3	
Exam Period	3 4	
Course Language	English	
Course Contents	In this course we will cover a systematic approach to the generation and solution of equations of motion for mechanical systems consisting of multiple interconnected rigid bodies, the so-called Multibody Systems. This course differs from 'Advanced Dynamics', which mostly covers theoretical results about classes of idealized systems (e.g. Hamiltonian systems), in that the goal here is to find the motions of relatively realistic models of systems (including, for example, motors, dissipation and contact constraints). Topics covered are: -Newton-Euler equations of motion for a simple planar system, free body diagrams, constraint equations and constraint forces, uniqueness of the solution. -Systematic approach for a system of interconnected rigid bodies, virtual power method and Lagrangian multipliers. -transformation of the equations of motion in terms of generalized independent coordinates, and lagrange equations. -Non-holonomic constraints as in rolling without slipping, degrees of freedom and kinematic coordinates. -Unilateral constraints as in contact problems. -Numerical integration of the equations of motion, stability and accuracy of the applied methods. -Numerical integration of a coupled differential and algebraic system of equations (DAE's), Baumgarte stabilisation, projection method and independent coordinates. -Newton-Euler equations of motion for a rigid three-dimensional body, the need to describe orientation in space, Euler angles, Cardan angles, Euler parameters and Quaternions. Upon request and if time and ability of the instructor allows, related topics are open for discussion.	
Study Goals	The student is able to find the motions of linked rigid body systems in two and three dimensions including systems with various kinematic constraints, like there are: sliding, hinges and rolling, and closed kinematic chains. More specifically, the student must able to: 1. derive the Newton-Euler equations of motion for a simple planar system, draw free body diagrams, set-up constraint equations and introduce constraint forces, and demonstrate the uniqueness of the solution 2. derive the equations of motion for a system of interconnected rigid bodies by means of a systematic approach: virtual power method and Lagrangian multipliers 3. transform the equations of motion in terms of generalized independent coordinates, and derive and apply the Lagrange equations of motion 4. apply the techniques from above to systems having non-holonomic constraints as in rolling without slipping, degrees of freedom and kinematic coordinates 5. apply the techniques from above to systems having unilateral constraints as in contact problems 6. perform various numerical integration schemes on the equations of motion, and predict the stability and accuracy of the applied methods 7. perform numerical integration on a coupled system of differential and algebraic equations (DAE's), apply Baumgarte stabilization, the coordinate projection method and transformation to independent coordinates 8. derive the Newton-Euler equations of motion for a general rigid three-dimensional body system connected by constraints, identify the need to describe orientation in space describe the orientation in 3-D space of a rigid body by means of: Euler angles, Cardan angles, Euler parameters and Quaternions, derive the angular velocity and accelerations in terms of these parameters and their time derivatives, and their inverse 9. derive the equations of motion for flexible multibody systems by means of a Finite Element Method approach, and extend this to linearised equations of motion	
Education Method	Lectures (2 hours per week), livestreamed and recorded, so you can follow the course at any location, even via the recording at a later moment in time.	
Assessment	homework (electronically submitted) + computer exam	
Remarks	There will be weekly assignments.	
Department	3mE Department Biomechanical Engineering	

ME41080	Human-Machine Systems	4
Responsible Instructor	Dr.ir. J.C.F. de Winter	
Contact Hours / Week x/x/x/x	0/4/0/0	
Education Period	2	
Start Education	2	
Exam Period	2 3	
Course Language	English	
Course Contents	The following topics are covered - History and scope of human-machine systems research (pre-WW2 era, knobs and dials, borrowed engineering models, human-computer interaction) - Manual control versus supervisory control - Information-processing concepts (mental workload, vigilance, situation awareness, stimulus-response compatibility) - Automation (function allocation, misuse/disuse/abuse of automation, ironies of automation, stages and levels of automation, adaptive automation) - Human error and accidents (person model versus system model) - Simulation and training (simulator fidelity, perception, learning theories, transfer of learning, augmented feedback, research articles) Examples will be provided from domains such as car driving, shipping, aviation, medicine, and process control. The course will feature a guest lecture from a specialist in the field.	
Study Goals	The student should be able to - provide definitions of the key topics of the course - explain the mechanisms, and pros and cons of training and selection. - explain the historic trends in human-machine systems research, and explain shifts in research emphasis. - explain and reflect on the differences between manual control and supervisory control - explain how humans can benefit from automation, but also explain the disadvantages of automation; explain how automation does not merely supplant but changes human activity, and explain how automation leads to out-of-the-loop problems. - explain how dynamic/adaptive automation works - explain how automation design decisions affect performance and safety - reflect on different human error models (person model versus system model) - explain how human skills develop, and explain how feedback influences skill acquisition - explain how simulator fidelity and training effectiveness of simulators can be assessed.	
Education Method	Written assignments will have to be completed on an individual basis.	
Course Relations	This course is only meant for Mechanical Engineering students for whom it is obligatory/recommended and for students who followed the course in 2019-2020 or earlier. ME41080 should NOT be chosen together with RO47006 due to content overlap between the two courses.	
Assessment	The assignments have to be completed with a grade of 5.0 or higher. The grade of each assignment will be rounded to 1 digit.	
Department	3mE Department Biomechanical Engineering	

ME41100	Vehicle Dynamics	4
Responsible Instructor	B. Shyrokau	
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Course Contents	This course concentrates on main technical principles and aspects of vehicle construction and its subsystems. The course also provides fundamental knowledge on vehicle motion, correlated vehicle dynamics and vehicle-road interaction. This course discusses standard testing procedures to evaluate vehicle motion. Writing proficiency is required.	
Study Goals	The student is able to apply dynamics methods and knowledge on vehicle specific problems. More specifically, the student must be able to: 1. describe principles of vehicle motion, correlated vehicle dynamics and vehicle-road interaction; 2. formulate fundamental equations of vehicle motion for aforementioned concepts; 3. implement the equations in the study of the specific vehicle subsystems; 4. perform standard testing procedures to evaluate vehicle motion via simulation.	
Education Method	Lectures related to Vehicle Dynamics in the course RO47017 "Vehicle Dynamics & Control"	
Computer Use	MatLab/Simulink is used for analysis and simulation for homework assignments and group project	
Literature and Study Materials	Lecture slides	
Books	Heißing and M. Ersoy, Chassis Handbook: Fundamentals, Driving Dynamics, Components: Vieweg + Teubner Verlag, 2011. Pacejka, Tyre and Vehicle Dynamics, 2012 (3rd edition) T. D. Gillespie, Fundamentals of Vehicle Dynamics: SAE International, 1992	
Assessment	Individual homework assignments - 25% Closed-book written exam - 75%	
Enrolment / Application	self enrolment via Brightspace	
Remarks	This course will be given together with the course RO47017 Vehicle Dynamics and Control but will focus on Vehicle Dynamics only This course is only meant for Mechanical Engineering students for whom it is obligatory/recommended and for students who followed the course in 2019-2020 or earlier. ME41100 should NOT be chosen together with RO47017 due to content overlap between the two courses.	
Department	3mE Department Cognitive Robotics	

ME41116	Vehicle Dynamics B Vehicle Control	4
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Course Contents	This course concentrates on main technical principles and aspects of automotive control systems and provides an opportunity to implement control techniques for various interesting automotive applications.	
Study Goals	The student is able to apply control theory in the design of vehicle active safety systems. More specifically, the student must be able to: (1) develop an understanding of the fundamental vehicle dynamic considerations that influence on controller design for vehicle active safety systems. (2) describe principles of vehicle active safety systems like Anti-lock Braking System (ABS), Electronic Stability Program (ESP), lateral control of autonomous vehicle and Vehicle State Estimation (VSE), wheel force/load reconstruction methods and their applications. (3) explore the trade-offs between completeness and simplicity when choosing an appropriate level of modeling abstraction and control theory.	
Education Method	Lectures (4 hours per week), homework assignments and group project	
Assessment	Grading Policy: Homework assignments 25%; Group project 25%; Final written exam 50% The final written exam can be taken after successful completion of the homework assignments and group project Minimum threshold for each subgrade is 5.0	
Remarks	FROM 2020-2021 THIS COURSE WILL BE REPLACED BY RO47017. Old course code: ME41115 ^ SC4230TU.	
Department	3mE Department Cognitive Robotics	

ME41125	Introduction to Engineering Research	3
Responsible Instructor	Prof.dr.ing. H. Vallery	
Instructor	Dr. R.W. Selles	
Contact Hours / Week x/x/x/x	0.0.0.4	
Education Period	4	
Start Education	4	
Exam Period	4	
Course Language	English	
Expected prior knowledge	The ability to derive the equations of motion and to simulate and design a controller for a mechanical system is a prerequisite for this course.	
Course Contents	1) Literature review 2) Academic Writing 3) Preparing data and code for FAIR use 4) Dealing with uncertainty in a) simulations and b) experimental data 5) Reviewing 6) Dealing with feedback 7) Oral presentation	
Study Goals	Learning objectives 1) Literature review The student should be able to: -Perform an effective literature search on a chosen topic -Analyse scientific literature by argumentation strategy -Use sources correctly and when necessary, both in the text and in a list of references Assessment: Report on literature search 2) Writing The student should be able to write an academic paper for the intended target audience. Underlying learning objectives: the student should be able to: -Write a formal academic text, with appropriate use of English -Apply the standard structure elements of an academic paper -Write an argumentative academic text, using sources when necessary -Apply engineering standards for dealing with SI units and mathematical equations Assessment: Academic paper 3) Preparing data and code for FAIR use The student should be able to package and document self-generated software and data in a way that it can be shared with others. Assessment: Generated code / data package 4) Dealing with uncertainty The student should be able to: -Question and analyze validity of models and simulations of mechanical systems -Question and analyze validity of data and statistical analyses Assessment: Academic paper with supplementary code and data analysis 5) Reviewing The student should be able to perform a peer review, using criteria provided by the instructor Assessment: Written peer review, peer grading 6) Dealing with feedback The student should be able to revise an academic text, using teacher and/or peer feedback (underlying learning objective: summarize, interpret peer and/or teacher feedback and make revisions based on a critical assessment of the feedback) Assessment: Rebuttal letter 7) Oral presentation The student should be able to present their own research to a mixed audience. Underlying learning objectives: The student should be able to: -Apply standard structure elements on the presentation (mainly opening and closing segments) -Design an effective storyline to serve the target audience -Design visuals to support the storyline -Answer questions from the audience in a professional and effective way Assessment: Final presentation	
Education Method	Lectures, material provided on Brightspace, assignments.	
Assessment	Assignments and final presentation. See "Study Goals" above for details.	
Department	3mE Department Biomechanical Engineering	

ME45155	Modelling of Thermo- & Hydrodynamic Systems	5
Responsible Instructor	Dr.ir. M.J.B.M. Pourquie	
Instructor	Dr. R. Pecnik	
Instructor	Prof.dr.ir. B.J. Boersma	
Contact Hours / Week x/x/x/x	0/0/4/4	
Education Period	3 4	
Start Education	3	
Exam Period	4 5	
Course Language	English	
Expected prior knowledge	wb1530-14 (thermofluids), ME45040 or ME45041, wi3097tu or WI2031WBMT, some elementary programming skill (matlab or any other)	
Course Contents	This is a basic course on the modeling of physical systems related to process and energy systems. in general the course will cover: (1) general conservation equations for mass, heat and momentum transport (Navier-Stokes equations) (2) examples of specific problems in heat- and mass transfer for the process industry (3) reduction of 3D, time-dependent problems to 1D, lumped models, leading to systems of ODE's combined with algebraic equations (4) numerical solution of reduced problems (5) numerical solution of multi-dimensional, stationary and time-dependent problems as encountered in CFD (Computational Fluid Dynamics) (5.1) numerical schemes (5.2) boundary conditions (5.3) turbulence models, how to use eddy viscosity models in CFD (practical guidelines) (6) wave equations (7) introduction to compressible methods	
Study Goals	After learning the content of the course the student will have the following capabilities: (1) Describe the role of models in Process and Energy Systems Engineering, and describe examples of systems, processes, modeling paradigms, applications, software tools, methods. (2) Represent a process with process flow diagrams, and define and use on-design and off design steady state models, "open loop" dynamic models and their applications to design, operation and control. (3) Describe the two most popular methods in commercial CFD, finite differences and finite volumes (4) solve simple demonstrative problems in fluid flow and heat transfer by programming them in Matlab, using finite differences and finite volumes (5) recognize the effects of numerical methods on the solution, such as numerical diffusion and numerical dispersion and to explain how to make these effects smaller (6) recognize numerical instability, to list several ways to avoid it and to analyze stability of simple methods analytically (7) solve fluid flow and heat transfer problems with the commercial CFD package Fluent, which includes the following: set up a calculation, generate a simple grid, set appropriate boundary conditions, choose suitable discretisation, interpret and validate the results. Alternatively, in some cases, instead of using a commercial package, students can decide to write and validate their own code which they will use for calculating a fluid mechanics problem.	
Education Method	Lectures, practical exercises (2x2 hours per week)	
Literature and Study Materials	Course material: (1) Sheets/handouts (2) J.H. Ferziger and M. Peric, Computational methods for Fluid Dynamics, Springer Verlag. (3) P. Moin, Fundamentals of Engineering Numerical Analysis, Cambridge University Press, 2001. References from literature: (1) C. Hirsch, Numerical computation of internal and external flows, Volume I Fundamentals of numerical discretization, Volume II Computational methods for inviscid and viscous flows, Chicester, Wiley & Sons, 1988, 1990 (2) C.A.J. Fletcher, Computational techniques for Fluid Dynamics, Volume I Fundamental and general techniques, Volume II Specific techniques for different flow categories, Berlin, Springer, 2-nd ed. 1991. (3) H.K. Versteegh, W. Malalasekara, An introduction of computational fluid dynamics. The finite volume method. Second edition. Pearson Education.	
Assessment	Written + Report for assignments; written exam may be online type depending on circumstances	
Department	3mE Department Process & Energy	

ME46010	Intro to Nanoscience and Technology	3
Responsible Instructor	Prof.dr. U. Staufer	
Contact Hours / Week x/x/x/x	0/0/4/0	
Education Period	3	
Start Education	3	
Exam Period	3 4	
Course Language	English	
Required for	Micro and Nano Engineering within the PME track	
Expected prior knowledge	ME46005 or equivalent course on classic physics (mechanics, electrodynamics, waves)	
Summary	Introduction into concepts, methods, instruments, and processes used in nanotechnology	
Course Contents	Nanoscience emerged from the analysis of basic physical, chemical and biological phenomena at the atomic to sub-micrometer scale range. By having investigated and explained fundamental questions, it broke ground for what is now often cited as being one of the most important areas for future technology developments. Based on nanoscientific concepts, new materials, processes, and devices are expected to emerge within the next few years. Nanoscience has developed its own professional jargon with expressions from its parent disciplines, which have to be know if one wants to communicate within the nanoscience community. This course establishes this basic knowledge and introduces the major instruments and methods used in nanoscience and -technology. It thus lays the base for participating in the above mentioned developments. The following chapters will be treated: The basics: - Photon: the quantization of light - de Broglie: Electrons behave like a wave - Uncertainty Principle - Wave-function - Particle-in-a-Box; quantum numbers - quantum mechanical tunnelling - Pauli principle - the structure of atom and molecules; spectroscopy Seeing and sensing at the nanoscale: - The family of scanning probe microscopes "SXM" and - The electron microscopes TEM and SEM, - Nanopore Sensing; Working material at the nanoscale: - Surface modifications by means of SXM -> highly controlled, low throughput - Bottom up synthesis by chemical means -> high throughput, challenging assembly Carbon, the amazingly diverse building block: - bottom up: the C-atom, hydro-carbons, C60, carbon nanotubes - top down: diamond, graphite, graphene, Applications, e.g.: - Nanoparticles as artificial dyes, labels - Nano-clean surfaces - Sensors	
Study Goals	Upon a successful participation in this course, the student shall know, understand be able to explain: - The common expressions and concepts used in nanoscience and -technology, - The main instruments and methods used for measuring and imaging at the nanometer level. - At least one method used for preparing nanomaterial (nanoparticles, -tubes, -wires, -rods etc.)	
Education Method	Lectures will be given either on-line or on-site depending on the situation with respect to Covid-19. Participation in either form is highly recommended. In case of on-line lectures, video-recordings will be made available on Brightspace on a best effort base. Mandatory student participation: For each lecture, a team of maximal 3 persons will be assigned to write a short summary and present it the following lecture. Optional assignments will be given and discussed on a weekly base.	
Books	The book closest to the lecture is: Chin Wee Shon, Sow Chorng Haur and Andrew TS Wee, Science at the Nanoscale - An Introductory Textbook Pan Stanford Publishing, Singapore, 2010 ISBN: 13 978 981 4241 03 8 ISBN: 10 981 421 03 2 [Concise book with exercises and indications for further readings. Some topics are more detailed and other less than what I can do during the lecture. Some topics are not treated.] Alternative with more emphasis on Quantum Mechanics: Introduction to Nanoscience S.M. Lindsay Oxford University Press, Oxford New York, 2010 ISBN 9780199544219 The part on Quantum Mechanics can be found in any university level Physics textbook under the rubric 'Introduction into Modern Physics' or similar. Examples are Alonso-Finn Vol. 3 'Quantum and Statistical Physics' or Chapters 34 - 36 of Tipler-Mosca 'Physics for Scientists and Engineers' E. Meyer, H.J. Hug and R. Bennewitz, Scanning Probe Microscopy - the lab on a tip, Springer Verlag, Berlin, Heidelberg, New York, 2004. ISBN: 3 540 43180 2. [Covers the most important aspects of nanotools, some topics of the course are not treated] E. L. Wolf, Nanophysics and Nanotechnology, Wiley-VCH, Weinheim, 2004 ISBN 3 527 40407 4. [Gives a good introduction to some aspects of nanotechnology, however does not cover the full course and not the full depth.]	
Reader	There is no special reader, however, students will be able to download: - presentation slides, - the protocols of their fellow student teams, - supplementary texts on specific topics.	

Assessment	The examination will be as follows: Written exam on campus [Unless there are less than 20 candidates register for one session, in which case there will be an oral exam given. Details will be published on Brightspace and discussed in class.] In case of unforeseen circumstances or measures resulting from Covid-19, the prescribed assessment will be an on-line oral exam. [Details will be published on Brightspace and discussed in class].
Exam Hours	In case of an oral exam, a special doodle will be installed where students will have to register for a specific time-slot (20 minutes) in addition to the regular registration on OSIRIS
Department	3mE Department Precision & Microsystems Engineering
Contact	e-mail: u.staufer@tudelft.nl (preferred) Office: 34-G-1-350 phone: 015 278 6804 (in connection with working from home less preferred)

ME46041	**Experimental Dynamics**	**4**
Responsible Instructor	Dr.ir. D. de Klerk	
Responsible Instructor	Dr. M.V. van der Seijs	
Contact Hours / Week x/x/x/x	0/0/2/2	
Education Period	3 4	
Start Education	3	
Exam Period	Different, to be announced	
Course Language	English	
Course Contents	Part A: Theory - Modelling of dynamic system in various domains: from the numerical world (FE, mass/damping/stiffness) to the experimental world described by FRF and everything in between. - How does a modern measurement system work? In specific how does it minimize disturbances and does it cope with filter effects? - Pitfalls in Frequency Analysis: Discrete Fourier Transformation, Leakage, Aliasing. Know it or you'll mess up your experiments. - The power of Transfer and Frequency Response Functions (FRF); why are they so useful? - Harmonic excitation (with frequency stepping), hammer impact excitation, stochastic excitation. - Experimental Modal Analysis: Do's and don't, pitfalls & challenges in practice. - Rotor Analysis and operational system analysis in general. - Experimental Dynamic Substructuring. An alternative FEM formulation which can also use experimental data. - Virtual Point Transformation. A method to transform your experimental model in a test-based super-element model compatible with Substructuring. - Transfer Path Analysis, a useful way to identify source excitation and system sensitivities. Motto: In theory, theory and practice are the same... In practice they are not. This course concentrates on pointing where those differences originate from. It'll be valuable for any who performs and analyses measurements in practice and tries to match his / her simulation to the experiment. Part B: Experimental assignments The second part of the course involves working on assignments meant to illustrate concepts described in Part A and to deepen insight. Teams of four students each, carry out multiple assignments involving the analysis of vehicle acoustics and a method called experimental Substructuring.	
Study Goals	In general the student is able to understand and analyse dynamic measurements, being aware of possible pitfalls. More specifically, the student must be able to: 1. describe the effects of Quantization, Leakage, Aliasing in measurements and measurement equipment. 2. explain the principle of extracting modal parameters (resonance frequency, mode shape, damping ratio) from system response both in the time domain and in the frequency domain 3. discuss relative merits of different excitation techniques (shaker with frequency sweep, impact hammer, shaker with random excitation) 4. analyse operational measurements with FFT and waterfall diagrams. 5. Explain the different concepts of Transfer Path Analysis. 6. Carry out an (experimental) Dynamic Substructuring analysis.	
Education Method	Weekly classes followed by laboratory projects.	
Assessment	The examination will be as follows: Assessment by group and personal assignments.	
Department	3mE Department Precision & Microsystems Engineering	

ME46055	Engineering Dynamics	4
Responsible Instructor	Dr. F. Alijani	
Instructor	R.A. Norte	
Contact Hours / Week x/x/x/x	4/0/0/0	
Education Period	1	
Start Education	1	
Exam Period	1 2	
Course Language	English	
Required for	Multibody Dynamics A(ME41050), Multibody Dynamics B (ME41050), Nonlinear mechanics(ME46000), Nonlinear dynamics (ME46072).	
Course Contents	The dynamic behavior of structures (and systems in general) plays an essential role in engineering mechanics and in particular in the design of controllers. In this master course, we will discuss how the equations describing the dynamical behavior of a structure and of a mechatronical system can be set up. Fundamental concepts in dynamics such as equilibrium, stability, linearization and vibration modes are discussed. If time permits, also an introduction to numerical integration techniques is proposed. The course will discuss the following topics: --Review of the virtual work principle and Lagrange equations --Linearization around an equilibrium position: vibrations --Free vibration modes and modal superposition --Forced harmonic response of nondamped and damped structures -- Introduction to time integration techniques	
Study Goals	The student is able to select different ways of setting up the dynamic equations of mechanical systems, to perform an analysis of the system in terms of linear stability and vibration modes and to properly use mode superposition techniques for computing transient and harmonic responses. More specifically, the student must be able to : 1. Explain the dynamic principle of virtual work and Lagrange equations, and discuss their relation to the basic Newton laws. 2. Describe the concept of kinematic constraints and identify a proper set of degrees of freedom to describe a dynamic system. 3. Use Lagrange equations via employing the minimum set of degrees of freedom to find the governing equations of dynamic systems, and construct these equations for systems with kinematic constraints. 4. Use Hamiltons principle to find the governing equations of motion of dynamics systems. 5. Find equilibrium positions and construct the linearized equations of motion by using different contributions of the kinetic and potential energies. 6. Analyze the linear stability of dynamic systems according to their state space formulation. 7. Explain and use the concept of free vibration modes and frequencies for multi degree of freedom systems. 8. Apply the orthogonality properties of modes to describe the forced response of damped and undamped systems.	
Education Method	Lecture	
Computer Use	The assignement will require using Matlablike software.	
Literature and Study Materials	Course material: Lecture notes (available through brightspace) References from literature: 1. M. Géradin and D. Rixen. Mechanical Vibrations. Theory and Application to Structural Dynamics. Wiley & Sons, 2nd edition, 1997. 2. J. Ginsberg. Engineering Dynamics. Cambridge University Press, 2008. 3. D.J. Inman, Engineering Vibration. PrenticeHall, 1996. 4. L. Meirovitch. Principles and Techniques of Vibrations. PrenticeHall, 1997.	
Assessment	written exam (online exam in ANS)+ assignment	
Remarks	1. An assignment will be given which will make up part of the final mark. Since the emphasis of the lectures will be on understanding concepts in dynamics more than memorizing formulas. 2. Old course code: WB1418-07	
Department	3mE Department Precision & Microsystems Engineering	

ME46060	Engineering Optimization: Concepts and Applications	3
Responsible Instructor	Dr.ir. M. Langelaar	
Instructor	Prof.dr.ir. A. van Keulen	
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	Different, to be announced	
Course Language	English	
Expected prior knowledge	Basic knowledge of mechanical engineering and mathematics. MATLAB is used for exercises and the final project, students without MATLAB experience must gain this through self-study. Familiarity with Finite Element modelling is helpful.	
Course Contents	Formulation of optimization problems Typical characteristics of optimization problems Minimization without constraints Constrained minimization Direct and gradient-based optimization algorithms Approximation concepts Sensitivity analysis Topology optimization	
Study Goals	The student is able to formulate a proper optimization problem in order to solve a given design problem, and is able to select a suitable approach for solving this problem numerically. Furthermore, he is able to interpret results of completed optimization procedures. More specifically, the student must be able to: 1. formulate an optimization model for various design problems 2. identify optimization model properties such as monotonicity, (non-)convexity and (non-) linearity 3. identify optimization problem properties such as constraint dominance, constraint activity, well boundedness and convexity 4. apply Monotonicity Analysis to optimization problems using the First Monotonicity Principle 5. perform the conversion of constrained problems into unconstrained problems using penalty or barrier methods 6. compute and interpret the Karush-Kuhn-Tucker optimality conditions for constrained optimization problems 7. describe the complications associated with the use of computational models in optimization 8. illustrate the use of compact modeling and response surface techniques for dealing with computationally expensive and noisy optimization models 9. perform design sensitivity analysis using variational, discrete, semi-analytical and finite difference methods 10. identify a suitable optimization algorithm given a certain optimization problem 11. perform design optimization using the optimization routines implemented in the Matlab Optimization Toolbox 12. derive a linearized approximate problem for a given constrained optimization problem, and solve the original problem using a sequence of linear approximations 13. describe the basic concepts used in structural topology optimization	
Education Method	Lectures (2x2 hours per week), exercises	
Literature and Study Materials	References from literature: R.T. Haftka and Z. Gürdal: Elements of Structural Optimization, and various articles made available on Brightspace.	
Books	Course material: P.Y. Papalambros et al. Principles of Optimal Design: Modelling and Computation. 3rd edition.	
Assessment	Brightspace/MATLAB exercises during education period, optimization project and report.	
Remarks	Old course code: WB1440	
Percentage of Design	80%	
Design Content	The course is focusing on design optimization.	
Department	3mE Department Precision & Microsystems Engineering	

ME46085	Mechatronic System Design	4
Responsible Instructor	Dr. S.H. Hossein Nia Kani	
Contact Hours / Week x/x/x/x	0/4/0/0	
Education Period	2	
Start Education	2	
Exam Period	2 3	
Course Language	English	
Expected prior knowledge	The students should have basic knowledge in Dynamics and electromagnetism. They are expected to analyse the stability using bode and Nyquist diagram.	
Course Contents	Course Contents Mechatronic system design deals with the design of controlled motion systems by the integration of functional elements from a multitude of disciplines. It starts with thinking how the required function can be realised by the combination of different subsystems according to a Systems Engineering approach (V-model). It should be noted that the control principles used in this course place a strong emphasis on frequency domain methods by linearising the system at its working point with the use of Bode- and Nyquist plots. The main reason for this emphasis is the strong focus in other control related courses on (non-linear) time domain related methods while linearised frequency domain related methods are still dominantly applied in the industry. A mechatronic engineer should be able to work with both methods and use them where appropriate. Some supporting disciplines, like power-electronics and electromechanics, are not part of the BSc program of mechanical engineers. For this reason this course introduces these disciplines in connection with mechanical dynamics and PID-motion control principles to realise an optimally designed motion system. The target application for the lectures are motion systems that combine high speed movements with extreme precision. The course covers the following four main subjects: 1: Dynamics of motion systems in the time and frequency domain, including analytical frequency transfer functions that are represented in Bode and Nyquist plots. 2: Electromechanical actuators, mainly based on the electromagnetic Lorentz principle. Reluctance force and piezoelectric actuators will be shortly presented to complete the overview. 3: Motion control in the frequency domain with PID and advanced fractional order PID-feedback and model-based feedforward control-principles that effectively deal with the mechanical dynamic anomalies (resonances and eigenmodes) of the plant. 4: Vibration control and active damping for mechatronics application. The other relevant discipline, electronics and position measurement systems is dealt with in another course: ME46005, Physics and measurement. The most important educational element that will be addressed is the necessary knowledge of the physical phenomena that act on motion systems, to be able to critically judge results obtained with simulation software. The lectures challenge the capability of students to match simulation models with reality, to translate a real system into a sufficiently simplified dynamic model and use the derived dynamic properties to design a suitable, practically realiseable controller. This course increases the understanding what a position control system does in reality in terms of virtual mechanical properties like stiffness and damping that are added to the mechanical plant by a closed loop feedback controller. It is shown how a motion system can be analysed and modelled top-down with approximating (scalar and linearised) calculations by hand, giving a sufficient feel of the problem to make valuable concept design decisions in an early stage. With this method students learn to work more efficiently by starting their design with a quick and dirty global analysis to prove feasibility or direct further detailed modelling in specific problem areas.	
Study Goals	Can analyse and derive improvements to the dynamic behaviour of an actuator-driven mechanical structure with maximum 6th order plant dynamics (incl actuator and amplifier) by means of Bode and Nyquist plots. Can select and calculate a single-axis functional electromagnetic actuator for a given specification, working according to the Lorentz and reluctance force generation principle. Can select a proper amplifier to drive the above mentioned electromagnetic actuator. Can understand the basic concept of piezoelectric actuators and their application in mechatronic systems Can identify and apply feedforward and feedback P-, PD- or PID-motion controller settings for a given plant, consisting of a dynamically realistic power amplifier, electromagnetic actuator and mechanical structure with an ideal sensor, to achieve a stable system targeting a specified maximum bandwidth or disturbance rejection.	
Education Method	Lectures are given in 14*2 lecture hours with presentations on theory and practice of active-controlled motion systems.	
Computer Use	Computer will be used to design motion control using ShapeIt software.	
Assessment	Online quizzes will be 10% of the final grades. Final Assignment will be 40% of the final grades. The rest 50% of the score is based on an open-book online written examination. The examination will consist of questions covering the above-mentioned study goals.	
Permitted Materials during Tests	Only the book is allowed at the examination. So no printed copy of the first edition, no computers, e-readers, smartphones or other items. Notes written on the pages of the book are allowed.	
Remarks	Old course code: WB2414-09	
Department	3mE Department Precision & Microsystems Engineering	

ME47035	Robot Motion Planning and Control	4
Responsible Instructor	Dr. J. Alonso Mora	
Contact Hours / Week x/x/x/x	0.4.0.0	
Education Period	2	
Start Education	2	
Exam Period	2 3	
Course Language	English	
Course Contents	Robot motion planning and control was an elective course for master students interested in motion planning and control for autonomous mobile robots and multi-robot systems. Examples of mobile robots are autonomous cars, service robots, mobile manipulators and aerial vehicles. This course is only meant for Mechanical Engineering students for whom it is obligatory/recommended and for students who followed the course in 2019-2020 or earlier. ME41035 should NOT be chosen together with RO47005 due to content overlap between the two courses.	
Study Goals	The learning objectives of this course are: Define notions of configuration and workspaces for robots Identify different classes of robotic systems and associated mathematical models for their kinematics and dynamics Describe and compare different algorithms for planning and control of multi-robot systems [graph search, sampling-based, constrained optimization, geometrical] Design and implement motion controllers and motion planners for mobile robots; Apply tools from constrained optimization to solve motion problems for mobile robots	
Education Method	Lectures, exercises and group project	
Books	Planning Algorithms, S. LaValle http://planning.cs.uiuc.edu/	
Assessment	10% exercises, 40% project, 50% written exam Due to the covid-19 restrictions, the written exam can be exchanged for an online exam in the 2020/2021 academic year. For a cohort of below 40 students, this will be an oral exam. For a cohort above 40 students an online exam with Brightspaces quizzes will substitute the written exam.	
Remarks	(former course SC42090)	
Department	3mE Department Cognitive Robotics	

OE44120	Offshore Wind Farms Design	4
Responsible Instructor	Dr. E. Lourens	
Instructor	Ir. P. van der Male	
Contact Hours / Week x/x/x/x	0/0/0/6	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Course Contents	The course is designed to make students familiar with the different aspects involved in the design of an offshore wind farm. The topics addressed include environmental load and soil modelling, turbine technology, wind farm economics, environmental impact, installation and maintenance logistics, electrical infrastructure, layout design, cable installation, and support structure design.	
Study Goals	Students successfully completing the course will be able to: a) give an overview of the different components, equipment and parties involved in the design of an offshore wind farm, b) elaborate on the interactions between the different components, and c) make a preliminary design of a support structure for an offshore wind turbine.	
Education Method	Lectures and practical sessions.	
Assessment	Group project (report and presentation) and written exam.	
Department	3mE Department Maritime & Transport Technology	

SC42030	Control for High Resolution Imaging	3
Responsible Instructor	Dr. O.A. Soloviev	
Instructor	Dr. C.S. Smith	
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Required for	sc42065	
Course Contents	High resolution imaging is crucial in scientific breakthroughs, such as discovering exoplanets in the habitable zone, or understanding the origin and progress of diseases at a molecular level. For that purpose special optical instruments like Extreme Large Telescopes or STED microscopy are developed. Optical aberrations are the key obstacle that hampers a clear vision and invites control engineers to step in. These are the disturbances induced by the medium, like turbulence in case of astronomy, or by the specimen under investigation, like the change in refraction index due to inhomogeneities in the biological tissue. Adaptive Optics is a modern way to remove the effect of aberrations. This fascinating and expanding field in science is providing an excellent challenge to control engineers to improve the image quality significantly by active control. This course will review the hardware necessary to control light waves in contemporary optical instruments, their modelling from a control engineering perspective, and discuss model-based control methodologies to do disturbance rejection.	
Study Goals	Understand the propagation of light, imaging and aberrations in the imaging process. Understand the operation principle of pupil -plane and focal-plane sensors to estimate the wavefront aberrations. Understand the design principles of opto-mechatronic wavefront corrector devices to correct the wavefront aberrations. Develop spatial and temporal models of complete imaging systems and use these models in the design of model based controllers for aberration correction.	
Education Method	Oral Presentations	
Literature and Study Materials	Course Notes	
Assessment	SC42030 alone: homework 60% + oral examination 40%. In combination with Design project SC42065: homework 40% + design project report 40% + oral examination 20%.	
Remarks	Old course code: SC4045	
Elective	Yes	
Tags	Broad Mathematics Optimalisation Physics Signals and Systems	
Department	3mE Department Delft Center for Systems and Control	

SC42050	Knowledge Based Control Systems	4
Responsible Instructor	Dr.ing. J. Kober	
Contact Hours / Week x/x/x/x	0/0/4/0	
Education Period	3	
Start Education	3	
Exam Period	3 4	
Course Language	English	
Course Contents	Theory and applications of knowledge-based and intelligent control systems: * Introduction to intelligent control * Fuzzy sets and systems * Intelligent data analysis and system identification * Artificial neural networks, deep learning * Gaussian processes * Direct and supervisory control based on those models (fuzzy, neural, Gaussian process, etc.) * (Deep) reinforcement learning * Examples of real-world applications	
Study Goals	Main objective: understand and be able to apply 'intelligent control' techniques, namely fuzzy logic, Gaussian processes, reinforcement learning, and artificial neural networks to both adaptive and non-adaptive control. After successfully completing the course, the student is able to: * Name the limitations of traditional linear control methods and state the motivation for intelligent control. Give examples of intelligent control techniques and their applications. * Formulate the mathematical definitions of a fuzzy set and the associated concepts and properties. * Explain the properties of Gaussian processes. * Explain the concept of a (deep) artificial neural network, give some examples and explain their properties. Define and apply the back-propagation training algorithm. * Give block diagrams and explain the notions of inverse-model control, predictive control, internal model control, direct and indirect adaptive control. * Explain the motivation and the basic elements of reinforcement learning. Define and explain the concepts of value function, Bellman equation, value iteration, Q-iteration, on-line reinforcement learning algorithms, actor-critic control scheme, deep reinforcement learning. * Implement and apply the above concepts to a simulated nonlinear process or a given data set. * Explain methods to render deep (reinforcement) learning more data efficient.	
Education Method	Lectures and two assignments - literature assignment and practical assignment.	
Literature and Study Materials	Lecture notes: R. Babuska. Knowledge-Based Control Systems. Slides and other course material (software, demos) can be downloaded from BrightSpace.	
Assessment	* SC42050 (TOETS-01) The exam constitutes 60% of the final mark * SC42050 (TOETS-02) Literature assignment 20% of the final mark * SC42050 (TOETS-03) Practical assignment 20% of the final mark. The examination will be as follows: Written exam, Closed book. In case of unforeseen circumstances or measures resulting from COVID-19, the prescribed assessment will be: Remote open book with several fraud prevention measures. If need be, the on-campus assignments will be changed to remote assignments.	
Department	3mE Department Cognitive Robotics	
Contact	Jens Kober, j.kober@tudelft.nl	

SC42065	Adaptive Optics Design Project	3
Responsible Instructor	Dr. O.A. Soloviev	
Instructor	Prof.dr.ir. G.V. Vdovine	
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	Exam by appointment	
Course Language	English	
Expected prior knowledge	Basic knowledge of signal/Fourier analysis, linear algebra, and optimisation is required. Basic skills in Python are desirable.	
Course Contents	Course consists on the realization of laboratory experiments to design and operate Adaptive Optics equipment to realize high resolution imaging systems. Crucial in the design is the alignment of active optics systems and in the operation the development of algorithms for acquiring accurate information about the wavefront aberrations from intensity based imaging components (like Shack-Hartmann sensors or CCD camera's) and using this wavefront information in the tuning of multivariable dynamic controllers to compensate in real-time the wavefront aberrations. The design is conducted under close supervision by world leading experts in the field and is performed in groups of students. The size of the groups depends on the number of participants in this course. The course requires hands-on experiments, Python coding, and presenting the results in a report and a joint final presentation.	
Study Goals	Building insights about the key components in Adaptive Optics such as the wavefront reconstruction and the deformable mirror. As well as building the controller methodology to obtain a smart optics system for high resolution imaging.	
Education Method	Project Based	
Computer Use	Lab computers are available, own laptops can be used	
Course Relations	Participation in SC42030 is required	
Practical Guide	A practical guide subdivided in sessions is provided.	
Assessment	Oral Presentation and evaluation of the written report in combination with the course sc42030	
Remarks	Old course code: SC4115	
Department	3mE Department Delft Center for Systems and Control	

SC42075	Modelling and Control of Hybrid Systems	3
Responsible Instructor	Prof.dr.ir. B.H.K. De Schutter	
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Course Contents	General introduction, examples of hybrid systems and motivation Modeling frameworks (automata, hybrid automata, piecewise-affine systems, complementarity systems, mixed logic dynamical systems, Petri nets) Properties and analysis of hybrid systems (well-posedness, Zeno behavior, stability, liveness, safety, ...) Control of hybrid systems (switching controllers, model predictive control) Verification and tools	
Study Goals	Recent technological innovations have caused a considerable interest in the study of dynamical processes of a mixed continuous and discrete nature. Such processes are called hybrid systems and are characterized by the interaction of time-continuous models (governed by differential or difference equations) on the one hand, and logic rules and discrete-event systems (described by, e.g., automata, finite state machines, etc.) on the other. A hybrid system also arises in practice when continuous physical processes are controlled via embedded software that intrinsically has a finite number of states only (e.g., on/off control). Recent interest in hybrid systems is stimulated by developments in nonlinear control theory, intelligent control, adaptive control, and computer science. The purpose of the course is to introduce a variety of hybrid systems modeling, analysis and control techniques.	
Education Method	lectures + assignment online recordings of the lectures will be available attending the lectures is not mandatory	
Assessment	written exam (closed-book, no calculators, counts for 60% of the final marks) + assignment (assessed through written report, counts for 40% of the final marks) In case of unforeseen circumstances or measures resulting from COVID-19, the exam will be organized as an open-book take-home exam. Important: partial marks for exam or assignment do not carry over from one academic year to the next	
Department	3mE Department Delft Center for Systems and Control	
Contact	questions are preferably asked via the Discussion forum on Brightspace	

SC42100	Networked and Distributed Control Systems	3
Responsible Instructor	T. Keviczky	
Instructor	Dr. M. Mazo Espinosa	
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Course Contents	This course starts with the modelling of so-called networked control systems (NCS). Networked control systems are systems in which the communication between plant and controller takes place via a (e.g. wireless) network. Such network-based communication leads to imperfections in sensor and control signals, such as time-varying and uncertain sampling intervals and delays, packet dropouts, scheduling constraints, etc. The modelling framework introduced in the course is subsequently used to support stability analysis, using characterizations based on linear matrix inequalities (LMI). Such stability analysis allows to study trade-offs between requirements on the controller, the network and plant properties. The second part of the course deals with the aspect of the distributed control of networked systems. In particular, distributed optimization methods and various decomposition techniques (primal, dual, augmented Lagrangian / proximal point method, ADMM), links to consensus algorithms, and their application in networked multi-vehicle distributed robotics problems. Online optimization-based control approaches such as distributed model predictive control for multivehicle cooperation, distributed LQR and decomposition based methods that are applicable to collections of mobile agents. The methods will be illustrated on application examples including cooperative rendezvous, distributed formation control, spacecraft formation flight, and robotic networks.	
Study Goals	The student must be able to: 1. model networked control systems with network-induced uncertainties / effects / imperfections, including time-varying and uncertain sampling intervals, delays, packet dropouts, and scheduling constraints 2. analyse the stability of NCS (involving the above effects), e.g. by applying LMI-based stability characterizations 3. describe and apply decomposition techniques for distributed optimization to various examples 4. describe and apply consensus algorithms to multi-agent coordination problems 5. solve cooperative control problems by implementing a distributed model predictive control approach 6. analyse the stability and convergence of distributed control methods that rely on online optimization	
Education Method	Lectures	
Computer Use	Matlab/Simulink is used to carry out the exercises of this course.	
Literature and Study Materials	Course material: Lecture slides including additional reading material in the form of papers and textbooks are made available online.	
Assessment	1. This course is graded by three assessments: assignment 1 (25%), assignment 2 (25%) and a final oral exam (50%). If the final oral exam cannot be held, then an online final exam will be organized instead. 3. In order to complete the course, each assessment must be completed with at least a mark of 5,0. In the event of a lower mark, no final mark will be given. 2. Participation in the final oral exam (or final online exam) is restricted: Only if the two assignments are submitted before their deadlines, and have been graded with a mark of 5.0 or higher, access to the final oral exam will be granted.	
Department	3mE Department Delft Center for Systems and Control	

SC42110	Dynamic Programming and Stochastic Control	5
Responsible Instructor	Dr. P. Mohajerin Esfahani	
Contact Hours / Week x/x/x/x	0/0/0/4	
Education Period	4	
Start Education	4	
Exam Period	4 5	
Course Language	English	
Expected prior knowledge	Solid knowledge of undergraduate probability, especially conditional distributions and expectations, and Markov chains. Mathematical maturity and the ability to write down precise and rigorous arguments are also important. A class in analysis will be helpful, although this prerequisite will not be strictly enforced.	
Course Contents	The course covers the basic models and solution techniques for problems of sequential decision making under uncertainty (stochastic control). We start with dynamic models of random phenomena, and in particular, the most popular classes of such models: Markov chains and Markov decision processes. We then consider optimal control of a dynamical system over both a finite and an infinite number of stages. We will also discuss approximation methods for problems involving large state spaces. This includes systems with finite or infinite state spaces, as well as perfectly or imperfectly observed systems. Applications of dynamic programming in a variety of fields will be covered in recitations.	
Study Goals	By the end of the course, the student must be able to - Formulate Markov chains models for dynamic uncertain phenomena - Formulate Markov decision process models for dynamic decision problems under uncertainty - Use these models to structure real decision-making situations - Compute relevant performance measures for Markov models - Develop an awareness of the manifold uses of probability theory in engineering and management science	
Education Method	Lectures	
Books	- Dynamic Programming and Optimal Control, 3rd edition, D. Bertsekas, Athena Scientific, 2005 - Introduction to Probability, D. Bertsekas and J. Tsitsiklis, Athena Scientific, 2002	
Assessment	Written exam	
Department	3mE Department Delft Center for Systems and Control	

SC42115	Internship	6
Responsible Instructor	Dr. M. Kok	
Contact Hours / Week x/x/x/x	x/x/x/x	
Education Period	None (Self Study)	
Start Education	1	
Exam Period	none	
Course Language	English	
Course Contents	The internship (new style) is optional (a free technical elective) and has to be chosen with the approval of the responsible teacher (dr. Manon Kok).	
Study Goals	The student has demonstrated his capability, independently and in consultation with specialists, to define, limit, solve and discuss systems and control problems as defined in the internship project description. The student has proven to be capable of communicating about his Internship research project both through an oral presentation and a report. The student has demonstrated his capability to consider and discuss the technological, ethical and societal impact of his internship work. The student has shown his life-long learning competence by investigating the scientific publications related to the problems investigated in his internship thesis and processing this information in his thesis.	
Education Method	Project	
Assessment	Report	
Enrolment / Application	* Students find an interesting internship proposal. * Intake form to be filled out together with the company with - Project description - Learning goals - Academic challenge * Responsible teacher (dr. Manon Kok) checks the intake form and, if OK, approves the internship.	
Department	3mE Department Delft Center for Systems and Control	

SC42125	Model Predictive Control	4
Responsible Instructor	Dr.ing. S. Grammatico	
Contact Hours / Week x/x/x/x	0/0/4/0	
Education Period	3	
Start Education	3	
Exam Period	3 4	
Course Language	English	
Course Contents	Model Predictive Control (MPC) is perhaps the most effective optimal control strategy for constrained dynamical systems. The basic concept of MPC is to exploit a dynamic model to forecast the system behavior, and optimize the forecast to determine the control input as the best decision at the current time. With emphasis on constrained linear systems, the course will present the theoretical fundamentals of MPC, such as Lyapunov stability, optimality and robustness, and its computational methods, such as quadratic programming.	
Study Goals	- Derive state prediction matrices from discrete-time linear models - Design the cost function, state and input constraints - Design MPC controllers with guaranteed recursive feasibility and asymptotic stability via appropriate terminal cost and constraint set - Formulate and solve constrained-linear-quadratic MPC problems via quadratic programming - Implement and simulate closed-loop systems controlled by MPC on Matlab - Design MPC controllers with integral action for reference tracking	
Education Method	Lectures	
Assessment	Final project (Oral exam)	
Elective	Yes	
Tags	Mathematics Matlab Optimalisation	
Department	3mE Department Delft Center for Systems and Control	

SC42130	Fault Diagnosis and Fault Tolerant Control	4
Responsible Instructor	Dr. R. Ferrari	
Contact Hours / Week x/x/x/x	0/4/0/0	
Education Period	2	
Start Education	2	
Exam Period	2 3	
Course Language	English	
Expected prior knowledge	Control Systems Design, System Identification, Signal Processing, Statistics and Probability	
Summary	In critical systems such as transportation systems, power plants, distribution networks or life-support systems it is not enough to design a control system that meets the required performance levels. It is also of paramount importance to guarantee that such requirements, or a subset of them, are met also during non ideal conditions such as in the presence of physical failures or cyber attacks. Most of all, safety must be guaranteed at all times. This can be obtained by designing into the control system additional functionalities that will allow to detect the occurrence of faults or cyber attacks, and deploy adequate countermeasures, which may include the reconfiguration of the control system.	
Course Contents	Faults and failures in dynamical systems; Service levels; FMEA (Failure Modes and Effects Analysis); FMECA (Failure Modes, Effects and Criticality Analysis); Fault tree; Signal based methods for Diagnosis; Model based methods for Diagnosis; Residuals computation and evaluation; Learning of fault model; Scalability to large scale systems; Fault Tolerance by design; Fault Tolerance by fault accommodation;	
Study Goals	after the course the student should be able to analyse and model faults or cyber attacks that can occur in a given dynamical system, design an algorithm for detecting, isolate and identify them and design a policy for reconfiguring the control system in order to accommodate them	
Education Method	Frontal lectures, homework	
Literature and Study Materials	Slides, handouts. Suggested textbook Blanke, M., Kinnaert, M., Lunze, J., Staroswiecki, M., & Schröder, J. (2006). Diagnosis and fault-tolerant control (Vol. 691). Berlin: springer.	
Assessment	Homework 25%, final report 25%, final exam (written) 50%	
Remarks	Due to possible restrictions due to COVID-19 outbreak, the course may be given partly or fully online.	
Elective	Yes	
Tags	Mathematics Matlab Mechatronics Modelling Numeric Methods Process Signals and Systems	
Department	3mE Department Delft Center for Systems and Control	

SC42135	Spectral Analysis of Nonlinear Systems	3
Responsible Instructor	Dr.ing. S. Wahls	
Contact Hours / Week x/x/x/x	0/0/4/0	
Education Period	3	
Start Education	3	
Exam Period	3 4	
Course Language	English	
Course Contents	The course starts with an introduction to linear operators. We discuss bounded and unbounded operators, self-adjoint operators and the spectral theorem. No prior knowledge beyond the systems and control core curriculum is expected. Some typical applications in systems and control are explored. In the second half of the course, we utilize our new knowledge to analyze nonlinear systems using nonlinear Fourier transforms and Koopman operators.	
Study Goals	Students can implement operator-theoretic methods with the Chebfun package for Matlab.	
Education Method	Lectures, practice sessions, assignments. Access to Matlab is required to solve the assignments.	
Assessment	To pass the course, students have to attend the practice sessions, solve the assignments successfully and hand their solutions in on time. The practice sessions will either take place on campus or, depending on the COVID-19 situation, in live online meetings.	
Department	3mE Department Delft Center for Systems and Control	

SC42140	Signal Analysis & Learning for Two-Dimensional Systems	3
Responsible Instructor	R. van de Plas	
Contact Hours / Week x/x/x/x	0/0/4/0	
Education Period	3	
Start Education	3	
Exam Period	3 4	
Course Language	English	
Expected prior knowledge	WB2235 (Signaalanalyse) or equivalent.	
Course Contents	Main concepts from classical signal and systems theory are extended from the 1-D time-centric case to the N-D multidimensional case, with specific focus on 2-D spatial signals and systems. The generalization of sampling theory to two-dimensional systems provides the link between continuous-space signals and their discrete-space measurements, and includes multidimensional views on the Shannon-Niquist theorem, interpolation, and aliasing. The translation of imaging data into alternative transform domains by means of the wavelet, cosine, or Fourier transforms, and the usage of 2-D filters will be introduced as means for image enhancement, de-noising, compression, and the extraction of relevant features. Once filtering and transformation have delivered a more advantageous representation of the imaging data, the course follows up with elementary machine learning methods to mine these often multivariate and multidimensional signals for specific applications. This includes supervised learning methods aimed at answering specific hypotheses or questions, and performing specific image recognition tasks. Within this imaging context, the classical modeling trade-off between overfitting and generalization is addressed, and statistical resampling methods are introduced as ways to manage model selection. The course furthermore includes unsupervised learning methods aimed at open-ended exploration of imaging data, to reveal underlying structure and trends. The main topics of the course are: 1. Two-Dimensional Signals and Systems; 2. Two-dimensional Sampling Theory; 3. Two-Dimensional Discrete-Space Transforms; 4. Signal Processing for Imaging Systems; 5. Supervised Learning (regression, classification); 6. Assessment and selection of learned models (bias-variance trade-off, cross-validation, bootstrap); 7. Unsupervised Learning (clustering, principal component analysis)	
Study Goals	See Course Contents topics.	
Education Method	Lectures and student presentations.	
Literature and Study Materials	- Woods J.W., Multidimensional Signal, Image, and Video Processing and Coding, 2nd Ed., Academic press (2011). - Hastie T., Tibshirani R., and Friedman J., The Elements of Statistical Learning - Data Mining, Inference, and Prediction, Second Edition, Springer Series in Statistics (2009).	
Assessment	Final grade consists of the students presentation grade (40%) and exam grade (60%). The final exam is an oral exam if practically feasible, or a written exam otherwise.	
Department	3mE Department Delft Center for Systems and Control	

WI4062TU	Transport, Routing and Scheduling	3
Responsible Instructor	Dr.ir. J.T. van Essen	
Instructor	Ir. M.J. van Engelen	
Contact Hours / Week x/x/x/x	0/0/2/0	
Education Period	3	
Start Education	3	
Exam Period	3 4	
Course Language	English	
Course Contents	In this course, we deal with combinatorial optimizations methods for the solution of problems that arise when one has to optimally organize transportation of goods, routing of vehicles, and production schedules. We study, amongst others, the shortest path problem, the assignment problem/transportation problem, the travelling salesman problem, the vehicle routing problem, and the job shop scheduling problem.	
Study Goals	- The student is able to recognize a problem as a discrete linear optimization problem and is able to provide a mathematical formulation for it. - The student is able to solve the shortest path problem and the transportation problem as well as some small flow shop problems. - The student is able to solve the travelling salesman problem by the Branch and Bound algorithm. - The student knows several heuristic solution methods for the travelling salesman problem and the vehicle routing problem. - The student knows some basic theorems concerning the mentioned problems and is able to prove some of these theorems. - The student has knowledge about methods to solve large scale problems, especially shortest path and vehicle routing problems. - The student is able to implement several of the algorithms studied in the course.	
Education Method	Lectures	
Literature and Study Materials	Course notes and handouts (made available via Brightspace).	
Assessment	Written exam. A half bonuspoint can be earned by successfully implementing some of the discussed algorithms. disclaimer: information may change depending on the developments around the coronavirus.	

WI4201	Scientific Computing	6
Responsible Instructor	Prof.dr.ir. C. Vuik	
Contact Hours / Week x/x/x/x	2/2/0/0	
Education Period	1 2	
Start Education	1	
Exam Period	2 3	
Course Language	English	
Expected prior knowledge	A basic knowledge on partial differential equations (PDEs), on numerical methods for solving ODEs/PDEs, and on linear algebra.	
Course Contents	During the course, the important steps towards the solution of real-life applications dealing with partial differential equations will be outlined. Based on a well-known basic partial differential equation, which is representative for different application areas, we treat and discuss direct and iterative solution methods from numerical linear algebra in great detail. The discretization of the equation will result in a large system of discrete equations, which can be represented by a sparse matrix. After a discussion of direct solution methods, the iterative solution of such systems of equations is an important step during numerical simulation. Emphasis is laid upon the so-called Krylov subspace methods, like the Conjugate Gradient Methods.	
Study Goals	A. General Study Objectives 1. After having completed this course, the student is able to use finite differences to approximate the solution of a partial differential equation and use an efficient and robust method to compute or approximate the solution of the resulting large system of linear equations. 2. The student will be able to assess the reliability in terms of the accuracy and stability of the numerical approximation of the solution. 3. The student will be able to use methods to approximate eigenvalues of large matrices. B. Specific Study Objectives 1. Finite Difference Method: Boundary Conditions, Grid, Numbering of the unknowns, Error Analysis - The student will be able to discretize 2-dimensional Poisson type problems. The student is able to implement the boundaries in various ways. - The student will be able to analyze the properties of the resulting matrix, as there are symmetry, positive definiteness, M-matrix etc. Also the sparseness of the matrix can be investigated and a notion of band and profile matrices should be known. 2. Direct Solution Methods Gaussian elimination, pivoting, iterative refinement, band and profile methods - The student will be able to understand and use direct solution methods based on Gaussian elimination and LU decomposition. - The student will be able to estimate the error due to rounding errors in the answer and to use pivoting to eliminate most of the errors. - The student will be able to estimate the amount of flops for direct solution methods and how to use more efficient variants as there are Cholesky method, band and profile methods. 3. Basic Iterative Methods - The student will be able to construct Basic Iterative Methods based on the splitting of the matrix. Furthermore an analysis of the convergence could be made. - A comparison of the various method should be possible together with the dependence on the gridsize. - The student will be able to choose suitable starting vectors and stopping criteria. 4. Krylov Subspace methods CG, SPD, preconditioning, general matrices, CGNR, Bi-CGSTAB and GMRES - The student will be able to use and understand the conjugate gradient method, together with a good understanding of the (super)linear convergence. - The student will be able to make a good choice for Krylov Subspace methods in the non-SPD case. - The student will be able to combine Krylov Subspace methods with preconditioners and know three classes of preconditioners: diagonal scaling, BIM and incomplete decompositions. 5. Eigenvalue methods Power method, Lanczos method, Arnoldi method - The student will be able to use the power method and is able to investigate its convergence. - The student will be able to choose suitable starting vectors and stopping criteria. - The student will be able to use the Lanczos and Arnoldi method.	
Education Method	Lectures/computer exercises	
Literature and Study Materials	Lecture notes, for further reading the book Matrix Computations, G.H. Golub and C.F. van Loan, the Johns Hopkins University, Baltimore, 2013, can be used.	
Assessment	The assessment consists of three parts: homework exercises deadline start of Q2 leads to grade G1, take home exam deadline half of January grade G2 and a written exam grade G3. The final grade is (G1+G2+2*G3)/4, provided that all grades are larger than or equal to 5. disclaimer: information may change depending on the developments around the coronavirus.	

WI4212	Advanced Numerical Methods	6
Responsible Instructor	Prof.dr.ir. C. Vuik	
Contact Hours / Week x/x/x/x	0/0/2/2	
Education Period	3 4	
Start Education	3	
Exam Period	none	
Course Language	English	
Expected prior knowledge	Introductory numerical analysis, Introductory partial differential equations, Introductory continuum mechanics.	
Course Contents	This course is an introduction to hyperbolic partial differential equations and a powerful class of numerical methods for approximating their solution, including both linear problems and nonlinear conservation laws. These equations describe a wide range of wave propagation and transport phenomena arising in nearly every scientific and engineering discipline. Several applications are described in a self-contained manner, along with much of the mathematical theory of hyperbolic problems. High -resolution versions of Godunov's method are developed, in which Riemann problems are solved to determine the local wave structure and limiters are then applied to eliminate numerical oscillations. These methods were originally designed to capture shock waves accurately, but are also useful tools for studying linear wave-propagation problems, particularly in heterogeneous material.	
Study Goals	apply numerical methods to hyperbolic systems, study convergence, stability, monotonicity, know methods for 2 dimensional hyperbolic systems	
Education Method	Lectures	
Literature and Study Materials	Finite volume methods for hyperbolic problems R.J. LeVeque Cambridge, UK: Cambridge University Press, 2002. # ISBN-10: 0521009243 # ISBN-13: 978-0521009249	
Assessment	In the first period a set of exercises is given. These should be worked out, strict deadline 26-3-2019 (Grade: G_1). The exercise should be handed in individually. In the middle of April a take home exam including practical exercises is given. This exam can be done by groups of two students. The report of this exam should be returned to us before 11-6-2019 (Grade: G_2). Thereafter an appointment can be made for an oral examination over Chapter 18 (including exercise 18.1, 18.2, and 18.3), 19, and 20 (Grade: G_3). Note that material discussed in Chapter 1 to 9, which is relevant for the material in Chapter 18 to 20 can also be part of the oral examination.The oral exam must be passed with a 6 or higher. Then, provided that G_3 is larger than or equal to 6, the final grade is computed by the formula: (G_1 + G_2 + 2 G_3)/4. disclaimer: information may change depending on the developments around the coronavirus.	

WI4221	Control of Discrete-Time Stochastic Systems	6
Responsible Instructor	Prof.dr.ir. J.H. van Schuppen	
Contact Hours / Week x/x/x/x	0/0/2/2	
Education Period	3 4	
Start Education	3	
Exam Period	Exam by appointment	
Course Language	English	
Expected prior knowledge	Control and system theory (undergraduate level), linear algebra,differential equations, stochastic processes.	
Course Contents	Discrete-time stochastic systems, distributions and invariant measures. Stochastic realization. Control with complete observations, optimal control theory, dynamic programming for finite and infinite horizons. Kalman filtering and special cases of filtering of stochastic systems. Control with partial observations, separation property. Elementary game and team problems, decentralized control.	
Study Goals	Students will be able to explain the fundamental concepts of stochastic systems. They will be able to solve elementary optimal control problems of stochastic systems by dynamic programming. They will understand the derivation of the Kalman filter. Finally, they will be able to explain the control of stochastic systems with partial observations.	
Education Method	Lectures/exercises	
Literature and Study Materials	Notes for this course can be obtained from the instructor.	
Assessment	Oral exam based on lecture notes and on home work sets. Home work sets cannot be redone. The oral exam can be done only once. disclaimer: information may change depending on the developments around the coronavirus.	
Elective	Yes	
Tags	Mathematics Signals and Systems Stochastics	

WI4226	Advanced System Theory	6
Responsible Instructor	Dr. J.W. van der Woude	
Contact Hours / Week x/x/x/x	0/0/4/0 hc	
Education Period	3	
Start Education	3	
Exam Period	Exam by appointment	
Course Language	English	
Expected prior knowledge	The BSc course Mathematical System Theory TW2530 (new code AM2503), or an equivalent course, and a good knowledge of basic mathematics.	
Course Contents	Part I In part I of this course the connection of linear system theory and convex optimization is illustrated. One of the key ingredients are the so-called Linear Matrix Inequalities, LMIs for short. LMIs can be treated efficiently by means of semi-definite programming techniques coming from convex optimization. It turns out that many properties of linear systems, like stability, controllability, observability, etc., can be formulated in terms of LMIs. Also the design of controllers satisfying stability and other constraints can be done efficiently using semi-definite programming and LMIs. The first part of part I starts by recalling basic knowledge from linear system theory and placing it in the frame work of LMIs. A second topic in part I will be LQ optimal control and the introduction of dissipativity. Both topics are of crucial importance for system theory. LQ optimal control has a long and rich history, but is still important and applicable. Dissipativity also has a long history, but its applicability has increased in recent years by the event of new efficient algorithms to solve semi-definite programming problems. The last topic in part I are system norms and the design of a controller such that the combined system behaves in a desired way specified in terms of its norm. To that end, the H-infinity and the H2 norm will be introduced. Also methods will be treated by which it can be investigated whether a certain desired norm can be achieved, and how this then actually can be done by means of state or output feedback. Part II Subject to change, depending on the prior knowledge and the interest of the students. Either a number of lectures on the principles behind the so-called behavioral approach of linear systems will be discussed. This approach offers an alternative for the input-output point of view on linear systems. Or a short introduction to general optimal control theory, containing stability issues for nonlinear systems, calculus of variations, the maximum principle, and so on. Both, the behavioral approach and the general optimal control theory, will be something new, completely different from part I and other system theory courses. The remaining time of part II will be reserved to study a paper that sheds an alternative light on traditional approaches and methods that are mostly treated in regular system theory courses. For instance, alternative proof methods and algorithms of the celebrated pole placement theorem. The students are requested to study a relevant paper and write a report on it. The paper and topic can be different each year.	
Study Goals	Advance system theory deals with the extensions in/of linear system theory. After the course the student will be familiar with the following topics. Convex optimization and linear matrix inequalities LQ optimal control and dissipativity Controller design and the H_inf norm/H_2 norm The following topics are tentative and may be subject to changes. Behavioral system theory or introduction to general optimal control theory. Alternative proofs and algorithms related to well-known results and theorems in system theory	
Education Method	Lectures, take home exercises, self study in a small project on research paper	
Literature and Study Materials	Lecture notes will be made available at the beginning of the teaching period through Brightspace. Homework sets and slides used during the lectures, become available during the teaching period.	
Assessment	Grade for course will be weighted average of both written exams (2 x 20%), the average of all homework exercises (1 x 40%) and the grade for the report (1 x 20%), where both written exams should have a grade of at least 5.0. A resit over the two written term exams will scheduled on an individual basis. disclaimer: information may change depending on the developments around the coronavirus.	
Remarks	Although a starting point, the above Course Contents may be adapted slightly during the course depending on the knowledge of the students. The second part of the Course Contents and the last topics mentioned as Study Goals are tentative and may be subject to change. Also the setup of the second part may be subject to changes.	

WI4260TU	Scientific Programming for Engineers	3
Responsible Instructor	Prof.dr.ir. H.X. Lin	
Practical Coordinator	Ir. C.W.J. Lemmens	
Contact Hours / Week x/x/x/x	0/0/2/0 + lab	
Education Period	3	
Start Education	3	
Exam Period	none	
Course Language	English	
Course Contents	The course tries to bring students to a level where they are able to change algorithms from e.g. numerical analysis into efficient and robust programs that run on a simple computer. It comprises: 1. Introduction to programming in general; 2. Floating point number rounding-off errors and numerical stability; 3. (Numerical) Software design; 4. Data Structures; 5. Testing, debugging and profiling; 6. Efficiency issues in computing time and memory usage; 7. Optimization and dynamic memory allocation; 8. Scientific software sources and libraries. P.S. This is not a general introductory course to learn how to write a computer program. Furthermore, the course concentrates mainly on sequential programming and only briefly introduces parallel programming (MPI and OpenMP). More advanced topics like threads or parallel (MPI/GPU) programming on supercomputers are not covered by this course (they are covered by other courses).	
Study Goals	1. Learn how to program in a high level programming language; 2. Learn about the problems related to the use of floating-point numbers in scietific computing; 3. Can make the transition from scientific model to a structured program; 4. Obtain basic knowledge about Optimization, Debugging and Profiling of these programs.	
Education Method	Weekly there are 2-hour lectures and 2-hour lab sessions.	
Books	Textbook: Writing Scientific Software - A guide to good style, by Suely Oliveira and David Stewart, Cambridge University Press, ISBN-13 978-0-521-67595-6	
Assessment	The grade is determined through a 3-hours exam that consists of theory and practical (lab) questions. disclaimer: information may change depending on the developments around the coronavirus.	

Year	**2020/2021**
Organization	**Mechanical, Maritime and Materials Engineering**
Education	**Master Systems and Control**

S&C YEAR 2	
Program Coordinator	Dr.ir. A.J.J. van den Boom

Year	**2020/2021**
Organization	**Mechanical, Maritime and Materials Engineering**
Education	**Master Systems and Control**

S&C Graduation Project Obligatory (45 ECTS)	
Responsible Program Employee	Dr.ir. A.J.J. van den Boom

SC52010	S&C Literature Research	10
Responsible Instructor	Dr.ir. A.J.J. van den Boom	
Contact Hours / Week x/x/x/x	x/x/x/x	
Education Period	1	
Start Education	1	
Exam Period	none	
Course Language	English	
Course Contents	The literature study is typically the initial phase of an MSc Thesis project (SC52045), with the purpose to get acquainted with the scientific publications within the realm of the MSc-thesis project, and to prepare for the specific topics to be investigated. The student will need to search for recent publications (i.e. articles, theses, books) that are relevant for the particular thesis project. It is important to be very careful in judging the literature, since not everything written even in high-standard journals is useful - or even correct. In other words, one should be very critical and selective of which publications to use, and one should try to fully understand those that are relevant. See also http://www.dcsc.tudelft.nl/Education/--> Graduation Guide for guidelines to perform literature searches. Moreover the student needs to identify the current issues in his research area in order to avoid performing research on questions that have already been resolved in the literature. Once some well-motivated choices have been made on what is planned to be to investigated, these are summarized in a report. This will then form the basis for the subsequent MSc-project work.	
Study Goals	The study goals of the literature study are: o The student is able to search for/identify publications that are relevant to a specific research question o The student is able to create an accurate overview of the state of the art for a specific research question o The student is able to write a report "in his own words", referring to the correct sources where necessary, and without any form of plagiarism.	
Education Method	The literature study is a self study, under supervision of your thesis supervisor.	
Assessment	The literature report is assessed by the thesis supervisor. Important aspects that are taken into consideration are the contents, the organization and clarity in writing and also the process in which the study is performed. An evaluation form is available from the DCSC website.	
Remarks	Old course code: SCP4510-11	
Department	3mE Department Delft Center for Systems and Control	

SC52135	S&C MSc Thesis	35
Responsible Instructor	Dr.ir. A.J.J. van den Boom	

Year	**2020/2021**
Organization	**Mechanical, Maritime and Materials Engineering**
Education	**Master Systems and Control**

S&C Elective Courses

Responsible Program Employee	Dr.ir. A.J.J. van den Boom

SC52055	Research Assignment	10
Responsible Instructor	Dr.ir. A.J.J. van den Boom	
Contact Hours / Week x/x/x/x	x/0/0/0	
Education Period	1	
Start Education	1	
Exam Period	none	
Course Language	English	
Assessment	Assignments	
Department	3mE Department Delft Center for Systems and Control	

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