Course Package

Biorobotics

MODULE	1A	15.0 EC
Biorobotics	First half of the first semester	

Required preliminary knowledge: Bachelor's level on Systems and Control, Dynamics, and Mechanics. *More information will be available shortly.*

191150480 **Human Movement Control (2A)**
Different neuromuscular systems are involved in the control of human movement. These systems include the different sensory systems (visual, proprioceptive, vestibular), the central nervous system and the muscles. This course discusses the role of the separate systems and their interactions in motor control with an emphasis on integration of sensory information, postural control and control and adaptation of reaching movements. Obtained knowledge can be applied in the development of treatments and assessment methods for diagnosis in neurology and (neuro)rehabilitation. In this course student will obtain knowledge about the physiological and computational mechanisms involved in movement control through lectures and self-study and will learn to make use of engineering skills/tools in assignments and a practical to better understand the importance of the different involved processes.

Elective (Choose 2 out of 3):

- 191561620 **Optimal Control (2A)**
  The purpose of this course is to familiarize the students with the principles of stability of dynamical systems and optimal control and the calculus of variations. Stability is an important issue in many applications. Loosely speaking, we call the solution of a differential equation stable if a small change of the initial condition results in a small change in the solution. Two approaches will be treated. The first is based on linearization. The second method is based on Lyapunov functions. The calculus of variations is concerned with the problem where the optimal value of a criterion that depends on an infinite dimensional quantity, such as a function, has to be found. A well known example of such a problem is the optimal shape of a rope that is hanging from two points at a ceiling. Optimal control is concerned with the problems like steering a system from a given state to a desired state with minimal cost. The cost can be fuel consumption, total work, money or time. We cover two approaches to optimal control. One is based on Pontryagin's maximum principle. This is a generalization of the Lagrange multiplier method for optimization of a function, subject to a constraint. The maximum principle is derived using the calculus of variations. The other method is based on dynamic programming. This is a recursive algorithm that starts at the final state of the system and solved backwards in time until the initial state is reached. The optimal control problem for linear systems with quadratic cost criterion also known as the LQ problem is treated in depth. Throughout the course motivating examples based on physical and economic problems will be given.

- 191131730 **Dynamics of Machines (2A)**
  Basic models and concepts of machine dynamics are presented using a non-linear finite element method. In this approach the machine or mechanism is modelled as an assembly of finite elements including hinges, beams, trusses or more specialized elements used to model joints and bearings. The influence of component compliances on accuracy and stability of machines is analysed.

In order to increase machine functionality and tracking - (positioning) accuracy of machines, intelligent control systems are incorporated in machines. Then the effects of the control system should be included in the dynamic simulation.

- 191131700 **System Identification and Parameter Estimation (2A)**

In system modelling the choice of the model structure plays an important role. This model structure specifies the mathematical expressions to describe the system and the parameters that are considered to be relevant . By setting correct values for the parameters, it is possible to optimise the agreement between the behaviour of the model and system.
Topics of this course are: The selection of the model structure, parameter estimation and the design of identification experiments for that purpose. One part is about so-called system identification, where mathematical models are used. Usually the parameters do not have a physical meaning. The focus is on a limited number of standard model structures for linear systems. In addition, attention will be paid to more general parameter estimates in time and frequency domain. Nonlinear systems are also tackled and the parameters usually have a physical meaning.

193810070 **Identification of Physiological Systems (2B)**

Motion disorders become manifest by spasm, rigidity, abnormal muscle tone, clones, etc. Abnormal motor control is expressed in ordinal clinical scales. A disadvantage of these clinical scales is that some of them are sensitive to how the clinical test is performed by the medical professional. The used clinical outcome measures are a reflection of the loss of function but do not identify the cause of the disorder. The clinician is perfectly able to see that something is wrong and can use available clinical scales to quantify the severity of the impairment or disability. However he is much less able to see what is wrong.
System identification techniques make it possible to characterize human motor control for various conditions in a standardized way. Moreover it makes it possible to look insight the motor control system and identify the underlying cause of motor control disorders. The advantages of the use of system identification techniques are: 1) a better standardized test; 2) exploiting motor control for a larger range of environmental conditions (motor control behavior is very adaptive); 3) detect what is wrong.
The methods and techniques can be applied to wide range of physiological and technical systems. In this course a physiological control model of the arm is used throughout the course to apply the methods and techniques. Collected experimental data from arm perturbations in healthy subjects and patients is also used to illustrate the methods. These models and data will be used by the students in the assignments.

In this course we will elaborate on the theories and techniques that have been introduced in the course Biomedical Signal Analysis. In this course we will emphasize practical issues. Topics that will be discussed are: the effect on how noise is modeled on the estimation of system dynamics; systems with multiple inputs and outputs; experimental design; model validation; parameter estimation; identification in a closed loop, the relation between the time-domain and frequency domain; comparison of parametric and non-parametric system identification; identification of time varying systems (optional).

201200133 **Biomechatronics (2B)**

The course Biomechatronics presents concepts for the support of the motor control function in persons with neuromuscular disorders. Topics include: clinical need, models and selection of actuation, sensor fusion, interaction control and stability, human machine interfaces, wearable exoskeletons, prosthesis, and rehabilitation robotics.

191210920 **Optimal Estimation in Dynamic Systems (2B)**

The course addresses the following problem: How to estimate the dynamic quantities in a physical process given the data from a sensory system? Although the applications are wide: (ranging from production processes, water management, orbit determination, telecommunication and so on), the course will concentrate on robotic applications: navigation and tracking. Especially, the SLAM problem will be addressed. SLAM = simultaneous localisation and mapping, e.g. a mobile robot that has to navigate within an unseen environment. The course will familiarise the student with methods for the estimation of state variables in dynamic systems. The course starts with an introduction of the topic 'parameter estimation' which is the fundament for state estimation. After that, the estimation paradigm will be embedded in a dynamic framework. For linear-Gaussian systems this leads to the well-known Kalman filter which is an online estimation method. An extension of the Kalman filter makes it applicable to offline estimation, and to prediction. For nonlinear dynamic systems, the so-called 'extended Kalman filter' is a suboptimal solution which only works well if the nonlinearities are not severe and the disturbances are Gaussian. Another estimation method is the 'particle filter'. This method is generally applicable, and is optimal, but it is computationally intensive. An important aspect of the course is bringing a theoretical concept to a practical solution. Students that attend this course will design an estimator for a given navigation process. Various estimation methods (e.g. Kalman, extended Kalman, particle filtering) will be tested and evaluated with a tracking and SLAM problem. Matlab is used as a development platform.