Course Title: Systems identification	**Units:** 1
SSD: ING-INF/04	**CFU:** 6

Course aims:
Providing both a theoretical and practical skills to apply optimization and identification tools to synthesize control systems for different kind of processes, with an emphasis on estimation and control in presence of uncertainty.

Course Description:
Dynamical Optimization:_Multi-stage optimization problems and dynamical constraints: definition and meaning of the objective function and solution of the problem using a variational approach. Adjoint system and necessary conditions for optimality.Optimal control problem for discrete-time systems. Multi-stage decision. The linear-quadratic (LQ) case. State-feedback solution and the Riccati equation. Solution of the LQ regulator in open and closed loop._Bellman's Principle of Optimality and Dynamic Programming (DP). Solution of the optimal control problem using the DP algorithm. Application to the LQ problem. Asymptotic solution of the optimal control problem and stability of the closed-loop system._Dynamical Optimization in Presence of Uncertainty:Brief overview on probability and statistics. Static optimization in presence of uncertainty: certainty equivalence and stochastic programming.Decisions in presence of uncertainty. Modeling uncertainty: measurement and process noises. White gaussian noise and noise propagation through a discrete-time dynamical system. Multi-stage decision problem in presence of uncertainty. Uncertain objective functions. The value of information on the state and closed-loop solutions. Solution of the linear-quadratic-gaussian (LQG) problem via DP._State Filtering and Prediction:
State estimation in an uncertain linear dynamical system. Kalman predictor/corrector/filter. Filter optimality. The extended Kalman filter for nonlinear systems. Optimal control with estimated state feedback. Matlab/Simulink implementation of the state-feedback optimal control and of the asymptotic Kalman filter. Numerical examples in applications. Estimation Theory: *Parametric estimation.*Data generating process. Modeling uncertainty. Estimators and estimates. Properties of estimators. Least squares and Gauss-Markov estimates. Quality of the least squares estimate. Orthogonality between the estimate and the prediction error. Recursive least squares estimator. Issues in the numerical implementation. Forgetting factor in recursive least squares estimation.
Minimum-variance unbiased estimator, and linear minimum-variance unbiased estimator. Maximum likelihood estimator. *Bayesian Estimation* The Bayesian estimation problem. Minimization of the conditional least squares. Properties of the Bayesian estimator. Bayesian estimator in presence of correlated information sources. Linear Bayesian estimator: properties. Kalman filter as Bayesian estimator. A priori prediction, correction and estimate update. Relation between recursive parametric estimation and optimal state filtering. Numerical application of estimation theory with Matlab/Simulink implementation. Identification Models for identification. Overview on the state-space and input-output representations of a dynamical systems. Polynomial representation using the *z*-operator. Model and equation errors. ARMAX models. Identification problem. Model and parameter identification. Model accuracy and complexity. Validation of the identified model and residuals analysis. Stochastic models of time series: AR, ARX, MA, ARMAX. Correlation analysis and spectral analysis. Predictions of times series models. Formulation of the parameter identification problems as a parameter estimation problem. Efficiency of least square estimates. Structural and experimental identifiability. Order estimation and model validation.

Assumed Background:

Assessment methods: oral exam