Course name:

Modelling and Control of Robotic Systems

Course location:

Theoretical part (1 week): Partner Institution
Practical part (2 weeks): Johannes Kepler University Linz (Linz, Austria, Europe)

Description of the course:

In this course the students will learn the basics of modelling, simulation and control of robotic systems. The course will be divided into two parts. Both parts will be taught by staff of the Institute for Robotics which is located at the Johannes Kepler University Linz.

The first part, focusing on theoretical issues, will last for one week and will take place at the Partner Institution. The students will get an understanding of the theoretical fundamentals of robotic topics, as for example structure of robots, sensors and actors, kinematics, dynamics, trajectory planning and robot control.

Shorty after the theoretical input, there is a two-week lab course at the Johannes Kepler University in Linz. During these two weeks the main focus lies on the practical implementation of the theoretical issues, which were presented during the course at the Partner Institution and prepared as homework for the lab courses. The modelling and programming of real robots in combination with an intelligent controller design are the key aspects of this lab session. Students will work together in groups of two to three in order to solve the issues with the support of the Institute's scientists. Maple and Matlab/Simulink are used to derive the equations of motion, to simulate the received dynamics and to design intelligent controllers. The results are verified using the laboratory robots. Beside the classes in the lab, students will also get an understanding of several robotic systems that are available at the Institute.

Contents of the Course:	Hours
Theoretical Part: ***1. Introduction to Robotics*** *Course overview, lecture schedule* 1.1. Motivation *History of robotics, robotics applications, motivating examples.* 1.2. Classification of Robots *Mobile vs. stationary robots, serial vs. parallel kinematics, examples of different robot configurations.*	40 (CLASS)

2. Kinematics 2.1. Introduction and Notation *Introduction into vector and matrix calculus, problems of spatial description, minimal coordinates, degrees of freedom, holonom & nonholonom problems.* 2.2. Orientation and Rotation *Rotation representations, rotation matrix, Euler angles, singularities of the rotation representation, several examples* 2.3. Forward Kinematics *Introduction and examples.* 2.4. Homogeneous Transformations. *Introduction to homogeneous transformation, several examples.* 2.5. Velocities *Translational and angular velocities of a rigid body in several coordinate systems, velocity of the robot TCP, several examples.* 2.6. Accelerations *Translational and angular acceleration of a rigid body in several coordinate systems, acceleration of the robot TCP, several examples.* 2.7. Joint Space and Cartesian Space *Introduction to joint and cartesian space.* 2.8. Inverse Kinematics *Inverse kinematics calculations of a robot, different approaches (analytical vs. numerical), singularities of the inverse kinematics, Jacobian, simulations.* ***3. Dynamics*** 3.1. Kinetic and Potential Energy *Kinetic and potential energy of a rigid body,* 3.2. Lagrange Formalism *Derivation of the Lagrange equation of the second kind, Derivation of the vector of generalized forces* 3.3. Equations of Motion *Equations of motion in minimal representation, mass matrix, centrifugal and Coriolis forces, gravity terms, external forces Application of the Lagrange equation for several examples (single pendulum, pendulum on a cart, SCARA robot) in detail, transformation into state space representation, simulations* ***4. Trajectory Planning*** 4.1. Introduction *Joint space trajectories, operational space trajectories.* 4.2. Point-to-Point Paths	

Trapezoidal velocity and acceleration profile, minimum jerk trajectories, examples and simulations. 4.3. Continuous Differentiable Paths *Introduction to splines, cubic splines* ***5. Control*** 5.1. Introduction *Centralized vs. decentralized control, feedback vs. feedforward control.* 5.1. Decentralized Feedback Control *PD joint control, cascaded PD joint control, simulations.* 5.2. Centralized Feedback Control *Model-based Feedforward Control (Calculation of feedforward joint torques by the equations of motion), Passivity based control, Computed Torque control, introduction of Lyapunow theory, simulations, comparisons between different control schemes.*	
Practical Part: ***1. Introduction: Furuta Pendulum*** 1.1. Equations of Motion *Derivation of the equations of motion in MAPLE.* 1.2. Simulation Model *Transformation of the equations of motion into state space, generation of a simulation model, application of the kinetic model in MATLAB/Simulink.* 1.3. Verification of the Model *Comparison between simulation model and measurements from experimental setup (open loop).* 1.4. Control Design *Linearization of the equations of motion, controller design with pole placement (Ackermann) and linear quadratic regulator theory (LQR).* 1.5. Experimental Tests *Implementation of the controller on a real time system, comparison between experimental setup and simulation.* *2. Industrial Robot* 2.1. Forward and Inverse Kinematics *Derivation of the kinematic model in MAPLE* 2.2. Equations of Motion *Derivation of the equations of motion in MAPLE,* 2.3. Simulation Model *Transformation of the equations of motion into state space, generation of a simulation model, application of the kinetic model in MATLAB/Simulink* 2.4. Path Planning	80 (LABS)

Point-to-Point path, simulation 2.5. PD Joint Control *Implementation and simulation of a PD joint controller, derivation and implementation of a feed forward controller, simulations and experiments* 2.6. Passivity Based Control *derivation and implementation of a passivity based controller, simulations and experiments* 2.7. Computed Torque Control *derivation and implementation of a computed torque controller, simulations and experiments*	