Syllabus for lectures

Part I.

Lecture 1: Nonlinear dynamic systems. Concepts of stability of a motion. Stable cycles of nonlinear systems. Tools for analysis (Lyapunov lemma, Poincare first return map, small parameter and Krylov-Bogolyubov methods for approximate integration, Andronov theorem). Systems with dynamic constraints. Conceptual examples and assignments

1. Analysis of the Van der Pol oscillator (partly done in the class and partly given as homework);
2. Introduction to the restricted three-body problem.

Lecture 2: Nonlinear mechanical systems with constraints. Classification of constraints. Stability of nonlinear mechanical systems with constraints. Examples and assignments:

1. Deriving a point mass dynamics subject to a holonomic constraint and the gravity;
2. Deriving two point masses dynamics subject to a holonomic and non-holonomic constraints and the gravity;
3. Deriving a cart-pendulum system dynamics;
4. Deriving dynamics of non-holonomic rolling of a coin on a table;
5. Searching behaviors of the systems derived in Exercises 1-4 and to analyze their stability (partly done in the class and partly given as homework).

Lecture 3: Problem formulations and settings for motion (trajectory) planning for constrained controlled mechanical systems. Examples and solutions for:

1. Searching feasible behaviors of three degrees of freedom underactuated ship model for moving along a straight line;
2. Searching feasible behaviors of a three degrees of freedom underactuated ship model for moving along a circle;
3. Representing behaviors of the cart-pendulum system shaped by a constant force;
4. Searching forced behaviors of the cart-pendulum system to pass over a wall (vertical obstacle). The assignment is partly done in the class and partly given as homework.

Lecture 4: Concepts of a motion generator (MG) and its dynamics for mechanical systems. A nested representation of motion candidates for underactuated mechanical systems. Properties of the dynamics of a MG derived based on the nested representation of a feasible behavior of an underactuated mechanical system. Choices of MG and steps in planning feasible behaviors for

1. A cart-pendulum system with one passive degree of freedom;
2. A spherical pendulum on a puck with two passive degrees of freedom;
3. A rolling a passive solid disc on a robot hand (computations are partly done in the class and partly are given as homework).

Lecture 5: Concepts of transverse dynamics, moving Poincare sections, transverse coordinates and their linearization developed for controlling a motion of mechanical system. Examples of related computations for a motion of

1. A mathematical pendulum and a cart-pendulum system;
2. A rolling a passive solid disc on a robot hand (computations are partly done in the class and partly are given as homework).

Lecture 6: Concepts of transverse dynamics and methods for analysis of stability and for stabilization of movements of hybrid mechanical systems. Examples of computations in searching gaits and feedback stabilization for

1. A passive compass biped walker on an inclined floor;
2. An underactuated compass biped walker with one passive degree of freedom;
3. An underactuated compass biped walker with torso having two passive degrees of freedom.

Part II.

Lecture 7: Introduction to the Butterfly robot. Choices for coordinates appropriate for representing unilateral and non-slipping constraints. Dynamics of the Butterfly robot in alternative sets of excessive coordinates. Assumptions and uncertainties in system's parameters. Organization and running experiments for identification of parameters (a friction in the actuated joint and of an inertia of the robot hand).

Lecture 8: Steps in planning perpetual rotations of a passive disc on the actuated hand of the Butterfly robot. Nested representation of motions. Choices for a motion generator and for parametric sets of synchronization functions in searching feasible rotations. Steps in computing the dynamics of the motion generator and in qualitative analysis of its phase portrait for planning movements consistent with the unilateral constraint, non-slipping conditions, external torque limits, and characteristics of sensing devices. Reformulation of trajectory planning assignment as a geometrical optimization task.

Lecture 9: Control system architecture of the Butterfly robot. Developing algorithms for controlling the robot hand. Developing model based and model free estimates and observers for coordinates and velocities. Testing and validating algorithms in simulations and on the robotic set-up.

Lecture 10: Transverse dynamics and transverse coordinates in a vicinity of the nominal rolling of a passive disc on the hand of the Butterfly robot. Transverse linearization and its robust stabilization. Nonlinear controller designs for orbital stabilization of the nominal movement. Experimental verification. Adaptivity and learning in performing non-prehensile manipulations.