I2S doctoral school

Graduate course

Motion Planning & Motion Control for Underactuated Mechanical Systems

By

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Monday 01/07/2019	Tuesday 02/07/2019	Wednesday 03/07/2019	Thursday 04/07/2019	Friday 05/07/2019
Lecture 1	Lecture 2	Lecture 3	Lecture 4	Lecture 5
9:00 – 12:00	9:00 – 12:00	9:00 – 12:00	9:00 – 12:00	9:00 – 12:00

'Participants will get a credit of 15h'

For registration send an email to : "**chemori@lirmm.fr**"

Summary: The course helps students systematically explore several topics and research directions of modern robotics and nonlinear control theory focused on developing scalable methods for performing and analyzing agile movements of dynamically constrained robotic systems. Modeling, motion planning and motion control methods for such systems become important for describing problem settings for automating various labor-intensive tasks such as grasping, manipulating or handling of external objects performed nowadays in industry and service applications primarily by humans. Similarly physics and design driven constraints are known to dominate in developing aggressive maneuvers for flying machines or in searching and controlling gaits of walking robots etc.

In examples, most of dynamic constraints are case specific or linked to scenarios of work of mechanisms. Meanwhile, some constraints are generic and can be simultaneously present in describing behaviors of quite distant nonlinear mechanical systems. Constraints due to underactuation provide examples of such generic structural features. They appear due to system designs and literally mean an excess of a number of degrees of freedom of the system (representative for a searched movement) over a number of actuators available and used in the system (for performing the movement). For this situation, the dynamics of non-actuated variables portray dynamic constraint written as a continuum set of equalities, which a movement of the system must obey and which are parameterized by a time interval the motion is defined. These non-integrable relations can be irrelevant for some tasks. For instance, underactuation constraints might have a negligible effect in local regulating a steady-state position of a drone. Similarly, the constraint can be often ignored in process of planning and controlling of some of slow motions of a flying machine. Meanwhile, the constraints become dominant and should be taken into account in planning and performing its agile maneuvers.

The lectures provide introductory materials and problem settings to the subject exploiting generic arguments for modelling, representing and analyzing behaviors of nonlinear systems, which can be further extended and applied for controlled mechanical systems. The development is well illustrated by solving a number of comprehensive examples of increased complexity, where important math concepts and tools are emphasized and exemplified. The common thread of the lectures is put on formalization of motion planning, stabilization and stability analysis assignments and on approaches for solving the tasks, which are relevant and instrumental in engineering applications and practice.

Syllabus for lectures

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, Andronov theorem). Systems with dynamic constraints. Conceptual examples and assignments

1. Analysis of the Van der Pol oscillator, which are 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. Assignments to find solutions of the systems derived in Exercises 1-4 and analyze their stability, which are 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 a 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. Examples of choices of MG and steps in planning feasible behaviors of

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, where a part of computations is done in the class and a part is given as assignment for 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, where a part of computations is done in the class and a part is given as assignment for homework.