

# 036087 Hybrid Dynamics in Mechanical Systems

Winter Semester, 2023-2024

Lecturer: Assoc. Prof. Yizhar Or, [izi@technion.ac.il](mailto:izi@technion.ac.il)

Lectures are on Tuesday 14:30-17:30 room 430, Lady Davis Building.

Office hours: will be announced in the course's Moodle page.

Grading assistant: Alon Shirizly, [alon.shirizly@campus.technion.ac.il](mailto:alon.shirizly@campus.technion.ac.il)

The lectures will be given **in English**, jointly for the Technion's International Program in Mechanical Engineering with Israeli students in both undergraduate and graduate studies. (Except for exams, all written material will be posted in English only. Submission of solutions in Hebrew is allowed)

The course deals with dynamics of mechanical and robotic systems under constraints, and specifically kinematic constraints of contact with friction. Motion of such systems is typically described by a hybrid dynamical system with non-smooth solutions due to transitions between different contact states and impact at the contacts. These systems are useful for motion analysis and control design of robotic systems for object grasping and manipulation, as well as legged mobile robots and wheeled or tracked vehicles. The class discusses basic topics in addition to phenomena which are unique to hybrid systems, as well as advanced research problems.

## **Topics:**

Lagrange's equations, formulating the dynamics of mechanical systems with holonomic and non-holonomic constraints, with mechanical and/or kinematic inputs. Contact kinematics and contact forces. Friction, Coulomb's model, planar multi-contact statics – graphical and computational analysis. Dynamics under different contact states, Painlevé paradox and dynamic jamming. Impact models with and without friction, Zeno phenomenon, simple models of dynamic walking, Poincaré map, stability of periodic orbits in hybrid systems.

**Text Books:** (some are available in electronic format online or via Technion's library)

1. M. T. Mason, "Mechanics of robotic manipulation", MIT Press 2001  
[LINK](#) to Mason's class lecture notes at CMU
2. R. M. Murray, Z. Li, S. Sastry, "Mathematical Introduction to Robotic manipulation", CRC press 1994. [LINK](#) to author's online printout.
3. B. Brogliato, "Nonsmooth Mechanics: models, dynamics, and control", Springer 1999
4. E. R. Westervelt, J. W. Grizzle, C. Chevallereau, J. H. Choi, and B. Morris, "Feedback Control of Dynamic Bipedal Robot Locomotion", CRC Press 2007

**Credits:** 3.0 points. **Pre-requisites:** Dynamics, Linear Systems, Introduction to Control

## **Grading policy:**

Mandatory homework assignment – **50%**, final project assignment – **20%**.

Submission in pairs is done electronically via the course's MOODLE webpage.

Oral defense on submitted assignments may be required and weighted in grades.

Mid-exam – **30%** mandatory. Will take place on 28/3/2024 (session A) and 30/4/2024 (session B).