# energy-based modeling for control of physical systems

## lecturers

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## objectives

This course presents a variety of modeling techniques that uses energy as a starting point. Apart from the fact that energy is a fundamental concept in physics, there are several motivations for adopting an energy-based perspective in modeling physical systems. First, since a physical system can be viewed as a set of simpler subsystems that exchange energy among themselves and the environment, it is common to view dynamical systems as energy-transformation devices. Secondly, energy is neither allied to a particular physical domain nor restricted to linear elements and systems. In fact, energies from different domains can be combined simply by adding up the individual energy contributions. Thirdly, energy can serve as a lingua franca to facilitate communication among scientists and engineers from different fields. Lastly, the role of energy and the interconnections between subsystems provide the basis for various control strategies.

## contents

First we start with the basic concepts of port-based network modeling, where complex lumped- parameter multiphysics systems are systematically modeled as networks of ideal components linked by energy-flow. We show how this immediately leads to a differential equation representation that is in generalized Hamiltonian form, including the standard conservative Hamiltonian systems based on the exchange of energy between different energy storages; e.g., in the mechanical domain between potential and kinetic energy. Furthermore, we discuss how the port-Hamiltonian representation leads to other useful representations such as the Brayton-Moser equations. We show how port-Hamiltonian models not only reflect the energy flow in the system, but also capture the other basic physical conservation laws, such as conservation of momentum or charge. This will be amply illustrated on a number of applications stemming from mechanics, mechatronics, hydraulic systems, MEMS, and power systems. We also show how distributed-parameter (partial-differential equation) components are incorporated in this broadly applicable modeling approach to nonlinear multi-physics systems.

## schedule

Week 1: General introduction to port-based modeling.
Week 2: Port-Hamiltonian systems.
Week 3: Distributed-parameter systems and other extensions..

## course material

• A.J. van der Schaft, "Port-Hamiltonian differential-algebraic systems", pp. 173--226 in Surveys in

Differential-Algebraic Equations I (eds. A. Ilchmann, T. Reis), Differential-Algebraic Equations Forum, Springer, 2013.
• D. Jeltsema and J.M.A. Scherpen, "Multi-domain modeling of nonlinear networks and systems: energy- and power-based perspectives", in August edition of IEEE Control Systems Magazine, pp. 28-59, 2009.
• A.J. van der Schaft, A comprehensive introduction to port-Hamiltonian systems, to be written.
• Hand-outs. To be distributed during the course.

## prerequisites

Calculus and linear algebra. Elementary physics. Some knowledge of systems theory is helpful, but not required.

## examination

Two case studies will be handed out during the course. The average grade of these two assignments determines the final grade. There is no final exam.