PhD research position:
Control of Implicit Port Hamiltonian Systems with implicit definition of the energy

Supervisor: Prof. B. Maschke *, co-supervisor: Prof Y. Le Gorrec **

May 2, 2022

* LAGEPP, University Lyon 1, bernhard.maschke@univ-lyon1.fr
** FEMTO-ST, UBFC ENSMM, Besançon, France

General information

This Ph.D. research will be an essential part of the collaborative research project on Implicit port-Hamiltonian control systems (*project IMPACTS*), funded by the French national research agency (ANR-21-CE48-0018), involving the LCIS lab (Valence), FEMTO-ST (Besançon), ISAE-Supaero (Toulouse) and the LAGEPP (Lyon). It will be conducted in close cooperation between and under the co-supervision of *LAGEPP* in Lyon and *FEMTO-ST* in Besançon with yearly research visits. The Ph.D. student will also benefit from the European research network on PHS, and more particularly of the *French-German Doctoral College* "Port-Hamiltonian Systems: Modeling, Numerics and Control", including graduate schools, workshops and funding for research mobility.

1 Scientific context, positioning

Energy-based approaches brought constructive solutions to many nonlinear control problems. First derived from generalized circuit-like models, the *Port Hamiltonian Systems* (PHS) approach is one of them [12, 2]. It is based on the explicit representation of multiphysics macroscopic systems, through a set of balance equations (for first principle models) and a set of, generally non linear, closure (or constitutive) equations. This underlying physical structure has been used to develop quite general nonlinear control designs, such as Control by Interconnection (CbI), Interconnection & Damping Assignment Passivity-Based Control (IDA-PBC) [7, 6] and the like. Those control designs have been succesfully applied to a wide variety of problems in mechanics and robotics, smart materials, power engineering, electrical networks [2, 8].

For systems with highly nonlinear constitutive relations however, as they arise in systems taking account for the thermodynamical potentials such as the internal energy, entropy and the exergy, for instance in chemical engineering, biological systems, material science for micro-robotic applications or when the control objective accounts for energy control, the dynamical systems have to be described as a set of algebraic and differential relations.

Such systems are known in linear control as *descriptor systems* and has been recently applied to Port Hamiltonian Systems [1, 5, 9]. In this setting the energy is no more described as a function but as a reciprocal relations between variables. For nonlinear Port Hamiltonian Systems, most work on control systems with an implicit definition of an energy has been based on concepts of irreversible thermodynamics where the energy is described by Gibbs' equations: the state space is then defined as a submanifold of an embedding space, for instance the Thermodynamic Phase Space of higher dimension [3, 4, 10].

Recently an alternative definition of nonlinear Port Hamiltonian Systems with implicit definition of the energy has been given [11] wich combines the geometric structure of Port Hamiltonian Systems defined with respect to a Dirac structure [12, 8], which may be associated with a network interconnection structure, with the implicit definition of the energy by reciprocal relations defining the state space as a Lagrangian submanifold of Phase Space [11]. The aim of this thesis is to analyse the system-theoretic properties of these systems, define some subclasses associated with particular engineering domains for instance chemical engineering or active materials based micro mechatronic applications and generalize the control design methods using their structure and their passivity properties.

2 PhD subject and objectives

The aim of this thesis is to develop a *novel design of passivity-based control for nonlinear Port Hamiltonian Systems with implicit definition of the Hamiltonian function.*

The first objective is to characterize this class in terms of physical models, in particular the relation with the Port Hamiltonian formulation of mechanical systems with constraints, Thermodynamic systems defined on the Thermodynamic Phase Space. Furthermore its various coordinate representations will be detailed, the index of the constraints and the projection to an explicit representation will be investigated. Finally its system-theoretic properties such as passivity, cyclo-passivity, observabiliuty and controllability will be analyzed.

The second objective is to develop and generalize the control design techniques such as the Control by Interconnection (CbI), Interconnection & Damping Assignment Passivity-Based Control (IDA-PBC) to these systems in order to shape in closed-loop their properties in terms of structure, dissipation and energy.

The third objective is to consider the structure preserving, model order reduction techniques in the light of these Port Hamiltonian Systems with implicit definition of the Hamiltonian and consider singular perturbation techniques.

Candidate profile

The candidates should have a MSc in automatic control, control system theory or equivalent and be motivated by a research project Ph.D. in control system theory. Prior knowledge in (port-)Hamiltonian systems, nonlinear control and an experience in numerical method programming will be appreciated. The expected period for the position is (approximately) October, 2022-September, 2025 (in total 36 months). The Ph.D. student will be co supervised by Prof. Bernhard Maschke (Univ. Lyon1, Lyon) and Prof. Yann Le Gorrec (ENSMM, Besançon). He will be mainly located at the Research Unit LAGEPP of the University Lyon 1 in Lyon (France) where he will benefit of an active research environment in nonlinear control, control of distributed parameter systems in the DYCOP (DYnamics Control and Observation of Processes) research group in the context of process engineering. He will spend some regular research periods as invited researcher at FEMTO-ST where he will benefit of an active research environment in nonlinear control, control of distributed parameter systems in the ROMOCO research group of AS2M Department in the context of micro mechatronics and micro robotics. The candidate will also take part in the *Doctoral College of the French-German University* on "Port Hamiltonian Systems: Modeling, Numerics and Control".

For application, a motivation letter and a C.V. should be sent to the supervisors: bernhard.maschke@univ-lyon1.fr, and yann.le.gorrec@ens2m.fr before June, 27th, 2022.

References

[1] C. Beattie, V. Mehrmann, H. Xu, and H. Zwart. Linear port-Hamiltonian descriptor systems. *Mathematics of Control, Signals, and Systems*, 30(4):17, Oct 2018.

[2] V. Duindam, A. Macchelli, S. Stramigioli, and H. eds. Bruyninckx. *Modeling and Control of Complex Physical Systems - The Port-Hamiltonian Approach*. Springer, Sept. 2009. ISBN 978-3-642-03195-3.

[3] D. Eberard, B.M. Maschke, and A.J. van der Schaft. An extension of Hamiltonian systems to the Thermodynamic space: towards a geometry of non-equilibrium Thermodynamics. *Reports on Mathematical Physics*, 60(2):175 – 198, 2007.

[4] A. Favache, D. Dochain, and B.M. Maschke. An entropy-based formulation of irreversible processes based on contact structures,. *Chemical Engineering Science*, 65:5204–5216, 2010.

[5] C. Mehl, V. Mehrmann, and M. Wojtylak. Linear algebra properties of dissipative Hamiltonian descriptor systems. *SIAM Journal on Matrix Analysis and Applications*, 39(3):1489–1519, 2018.

[6] R. Ortega, A. van der Schaft, F. Castanos, and A. Astolfi. Control by interconnection and standard passivity-based control of port-Hamiltonian systems. *IEEE Trans. on Automatic Control*, 53(11), 2008.

[7] R. Ortega, A.J. van der Schaft, I. Mareels, and B. Maschke. Putting energy back in control. *IEEE Control Systems Magazine*, 21(2):18– 32, April 2001.

[8] A. van der Schaft and D. Jeltsema. Port-Hamiltonian systems theory: An introductory overview. *Foundations and Trends in Systems and Control*, 1(2-3):173–378, 2014.

[9] A. van der Schaft and B. Maschke. Generalized Port-Hamiltonian DAE systems. *Systems & Control Letters*, 121:31–37, 2018.

[10] A. van der Schaft and B. Maschke. Geometry of Thermodynamic Processes. *Entropy*, 20(12):925–947, 2018.

[11] A. van der Schaft and B. Maschke. Dirac and Lagrange algebraic constraints in nonlinear Port-Hamiltonian systems. *Vietnam Journal of Mathematics*, 48(4):929–939, 2020.

[12] A.J. van der Schaft and B.M. Maschke. The Hamiltonian formulation of energy conserving physical systems with external ports. *Archiv für Elektronik und Übertragungstechnik*, 49(5/6):362–371, 1995.