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 **

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

General information

This Ph.D. research position in Automatic control will take place with the *project IMPACTS "Implicit port Hamiltonian control systems"* (funded by the French National Research Agency under the number ANR-21-CE48-0018). 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 located at the Research Unit LAGEPP of the University Lyon 1 in Lyon (France) and 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 and the context of process engineering. The candidate will also benefit from a regular collaboration and joined supervision with FEMTO-ST in Besançon and the participation to 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.

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 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 recently has been 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 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 of 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.

3 Cooperation, prospects, applications

This Ph.D. research will be an essential part of a collaborative research project on Implicit port-Hamiltonian control systems (IMPACTS), funded by the French national research agency (ANR), involving the LCIS lab (Valence), FEMTO-ST (Besançon), ISAE-Supaero (Toulouse) and the LAGEPP (Lyon). Therefore, its results will be regularly presented to and discussed with the project partners. It will be conducted in close cooperation between 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" (www.epc.ed.tum.de/en/rt/doctoral-college/), including graduate schools, workshops and funding for research mobility.

References

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