ECMS'2006 – TRACK ON BOND GRAPH MODELING

INVITED LECTURE:

"BOND GRAPHS: AN ENGINEERING TOOL FOR INTEGRATED MODELING, ANALYSIS, DIAGNOSIS AND CONTROLLER SYNTHESIS OF PHYSICAL SYSTEMS"

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ABSTRACT: Three are the most important features that make of the bond graph methodology a powerful technique for graphical and mathematical modeling of physical systems: the representation of the power flow among components which stand for the basic energy phenomena in physics, the exhibition of the interconnection structure coupling these components, and the capture of the computational causality relating the system variables. Indeed, representing the energy exchange among components through power ports helps constructing modular models through coupling –a so-called object-oriented modeling approach–, procedure pretty much similar to the real construction of complex engineering systems. This modularity is supported by the structure of components and/or subsystem interconnection, which is explicitely displayed in the finished graphical model. Moreover, the assignment of computational causal relationships to the system variables allows for the derivation of mathematical models of the system, which are both of theoretical value as well as of practical interest to the aims of simulation of the system behavior.

The main subject of this lecture will be the exploitation of these three essential features of bond graphs, be it individually or in a combined manner, to the aims of the analysis of dynamic properties, the synthesis and design of control systems, and the diagnosis of physical systems.

Among the issues selected for the exposition are the derivation of other energy-based models like the classical Euler-Lagrange and Hamiltonian formalisms, as well as the so-called port-controlled Hamiltonian systems with dissipation, recently introduced in the domain of nonlinear control theory. Crucial to this aim is the use of the energy in the storages as a function of the states linked to the causal lecture of equations on the abstract representation of a generic bond graph through its decomposition in fields interconnected by a power-conserving junction structure.

Properties like the stability of equilibria and input-output passivity can be assessed also on bond graphs with the support of the information about the stored energy, the continuity of power flow, and the help of causality, which allows to apply the second method of Lyapunov directly on the graphical domain.

The previously mentioned results, in some cases coalesced with model decomposition techniques that exploit the information furnished by the BG interconnection structure, permit the synthesis of control laws (regulation, stabilizing, tracking controllers) for (possibly) nonlinear systems. Some of these synthesis methods proceed in a purely heuristic manner, while other can be systematically derived from, or put in close relation to well established methods supplied by the nonlinear control theory.

The obtention and application of input-output inverse models will also be reviewed. I/O-inverse models are essentially higher order differential equations relating system outputs to inputs. The main tool for derivation of inverse models is the celebrated bicausality technique. The synthesis of trajectory tracking controllers and the sizing of actuators are among the most important BG-applications of inverse models to be discussed in this talk. A particular choice of outputs allows for the full description of the system dynamics without the need of using any other internal variable. These particular output variables are called flat outputs. Recent studies and results on flatness of linear and, most important, nonlinear BGs models will be also addressed in this lecture, including results in control and diagnosis problems.

Fault detection and diagnosis (FDD) is an important domain of system automation. Some results on the application of FDD techniques on BGs, mostly the method of the analytical redundancy relationships, will be also presented.

From these and other results addressed in the lecture it is concluded that the bond graphs still constitute an important source of research for the BG-community, whose ripeness and consolidation will convert this technique into more than "just" a powerful modeling and simulation tool. Indeed, it is foreseen that the bond graph methodology will further evolve into a valuable integrated tool for modeling, simulation, analysis, diagnosis and control system synthesis of physical systems in engineering problems.