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Mechanics and Model Based Control

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Keywords: Mechanics. Model based control. Structures, robots and machines. Reduced order approximation. Multi-physics actuation and sensing. Structural control and health monitoring. Geometric modelling of distributed parameter physical networks. Integrated control loop design. Parameter identification for non-linear systems.

Abstract. The present contribution gives an overview on own research that has been performed from 2008 to 2011 in Area 2, *Mechanics and Model Based Control*, of the COMET K2 Austrian Center of Competence in Mechatronics (ACCM), which is situated at the Science Park of the Johannes Kepler University of Linz. Area 2 is motivated by the fact that mechanics and control both are rapidly expanding scientific fields, which share demanding mathematical and/or system-theoretic formulations and methods. The goal of Area 2 has been to utilize and extend these relations, with special emphasis on solid mechanics and control methods based on physical models. Some corresponding results will be reviewed subsequently with respect to the mechanical modelling of structures, robots and machines, and with respect to the corresponding model based control as linear/non-linear lumped/distributed parameter systems. Due to limitations in space, the present review restricts itself to work of Area 2 that has been directly performed at the University of Linz. The review contains 118 references to works on mechanics and model based control.

Introduction

The COMET K2 Austrian Center of Competence in Mechatronics (ACCM) is a peer-reviewed research center funded by the Austrian government, which is located at the Science Park of the Johannes Kepler University of Linz, Austria, and in which scientific and industrial partners from Austria and abroad are jointly performing mechatronics research in multi-firm and strategic research projects, grouped into six interconnecting Areas. One of these, Area 2, *Mechanics and Model Based Control*, is motivated by the fact that mechanics and control both are rapidly expanding scientific fields, which share demanding mathematical and/or system-theoretic formulations and methods. The main goal of Area 2 is to utilize and extend these relations, with special emphasis on *solid mechanics* and *control methods based on physical models* for *structures*, *robots* and *machines*, see www.accm.eu/en/research-innovation/research-areas/mechanics-model-based-control.html

The research work of ACCM started in 2008. A recent international evaluation has lead to a prolongation of the funded research until 2017. From 2008 to 2009, Area 2 has been co-ordinated by H. Irschik and K. Schlacher, and afterwards by M. Krommer and K. Schlacher. These three persons have prepared the subsequent partial review on the research work that was conducted in Area 2 from 2008 to 2011.

A main demand of the Austrian government in the COMET K2 program has been to increase the international visibility of the conducted research. Therefore, scientists in Area 2 have extensively tried to contribute to international conferences. In order to mention a view activities only, we recall the organization of mini-symposia on *industrial applications in mechatronics*, on *sensor systems for structural and health monitoring*, and on *multibody system dynamics with control* at the 4th European Conference on Structural Control [1], on *smart structure theories motivated by continuum physics formulations* at the 10th International Conference on Computational Structures Technology (CST2010) [2], on the *application of the Rayleigh-Ritz Method in rotordynamics* at the 8th IFToMM International Conference on Rotordynamics [3], as well as on *advances in mechatronics* and on *advances in structural control* at the 5th World Conference on Structural Control and Monitoring [4]. International workshops, the contributions of which were published as books, were organized in Linz on topics related to mechanics and model based control, see [5] – [7]. A large number of papers have been contributed to these and several other international conferences, as well as published in international journals and books. However, due to the limitation in space we subsequently restrict to work that has been performed directly at the Johannes Kepler University of Linz. The following topics will be treated:

- *Mechanical modelling of structures, robots and machines*: Model based reduced order approximation; piezoelectric actuation and sensing; health monitoring; structural control.
- *Model based control for linear/non-linear lumped/distributed parameter systems*: Geometric modelling of distributed parameter physical networks; integrated control loop design; parameter identification for non-linear systems.

Note that the above classification is not a strict one, however. Many of the contributions to mechanical modelling include control aspects also, and most of the control papers refer to advanced mechanical modelling. For some corresponding works of our group prior to 2008, see [8].

Mechanical Modeling of Structures, Robots and Machines

Model Based Reduced Order Approximation. Model reduction in structural mechanics represents an important prerequisite for an efficient computer simulation and for the design of algorithms for controlling structures, robots and machines. The main work in this field was concerned with complex multi-body dynamic systems, and with their components. Non-linear problems in beam-type components have been treated in [9]-[15]. The absolute-nodal-coordinate formulation in multi-body dynamics was studied in [16]-[22]. A comprehensive direct Ritz approach for elastic multibody dynamics was presented in the book [23]. Several advanced reduced order rotordynamics and multi-body dynamics formulations were presented in [24]-[37]. Rigid-elastic robotic systems were studied in the book [38]. Solutions for the homogenization of structures consisting of a large number of sheets, as they occur e.g. in electric power transformers, were presented in [39]-[42]. Improved modal reduction formulations for contact problems by adding suitable mode bases, so-called joint interface modes, were presented in [43], [44]. An efficient topology optimization of large dynamic finite element systems using fatigue was performed in [45]. Special problems of the dynamics of structures and robots were treated in [46]-[49].

Piezoelectric Actuation and Sensing; Structural Health Monitoring. Improved mechanical models for smart structures containing piezoelectric elements were developed in several directions. The effect of lateral piezoelectric actuation and sensing on wide beam- and frame-type structures, which require a modelling in the framework of plate theory, was systematically treated in [50]-[56]. The advanced piezoelectric d_{15} shear response-based torsion actuation mechanism was studied in [57]-[59]. Continuum mechanics based formulations concerning non-linear effects in piezoelectric solids and structures were presented in [60]-[66]. Special emphasis was laid upon the development of novel sensor concepts, see [67] for a review. Strain-type sensor networks that can measure structural entities, such as displacements or slopes, were presented in [68]-[70]. These formulations are particularly suitable for health monitoring. Extensions to piezoelectric sensing in the presence of large deformation were presented in [71]-[73].

Structural Control. Our works in these fields were concerned with extensions on own contributions before 2008, see [8] for a review. Remarkable success was obtained in developing discrete piezoelectric actuator and sensor networks for shape control and displacement tracking of beam- and frame-type structures, which can successfully replace the continuously distributed actuator and sensor distributions that follow from the exact solution of the problems in hand, and which do work for high-frequency excitation also, see [74]-[85] for various applications. Suppression of torsional vibrations by piezoelectric actuation was successfully treated in [86]-[91]. Novel concepts for shape control of piezoelectric beam-type structures with passive electric networks were developed in [92]-[95].

Model based control for linear/non-linear lumped/distributed parameter systems

In this field advanced automatic control methods and solutions were presented concerning the geometric modelling of structures, robots and machines as distributed parameter physical networks, for which integrated control loop design methodologies were developed. As a necessary prerequisite, parameter identification techniques for non-linear systems were also studied. The novel automatic control techniques under consideration were based, among others, on the notions of port-Hamiltonian systems and flatness-based control, see [96]-[118] for a list of theoretical contributions as well as for various successful applications, which give evidence for the appropriateness of the considered geometrical approaches.

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