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BOOK REVIEWS

FLOW CONTROL BY FEEDBACK: STABILIZATION AND MIXING, Ole Morten Aamo and Miroslav Krstic, Springer-Verlag: London, U.K., 2003

The book *Flow Control by Feedback* by Ole Morten Aamo and Miroslav Krstic is probably the first introductory monograph on flow control using digital control systems. It is an excellent book for its coverage of topics as well as for its clear presentation. The book contains a comprehensive survey of feedback algorithms for flow control that are currently available. The content structure also suits a course module on flow control or as supplementary reading on fluid dynamics and infinite dimensional systems courses.

Flow control is the technology of controlling a flow using passive or active devices to bring about desirable changes in the flow. Such changes are, for instance, delaying or advancing transition from laminar to turbulent flow, suppressing or enhancing turbulence and preventing or provoking separation. There are many important prospective applications for the aerospace, chemical and other areas of industry where drag reduction is needed for higher throughput to reduce energy consumption. In aerospace applications drag reduction, lift enhancement can result in considerable fuel savings. Mixing processes are frequently found in applications where the quality of the resulting mixture directly affects the quality of the end product. This is the case, for instance, in combustion, where the quality of the fuel air mixture is essential for power generation. In the process industries the quality of various mixtures affect chemical reaction rates.

The emergence of flow control is facilitated by breakthroughs in MEMS (micro-electromechanical systems) and related technologies, on which the book contains a brief account. The instrumentation of fluid flows on extremely short length and short time scales requires control algorithms with provable performance guarantees. Dedicated to this problem, this book brings together controller design and fluid mechanics expertise in an exposition of the latest research results. After an introduction the book contains chapters on differential equations of fluid mechanics, on the most relevant control techniques, on stabilization problems, on mixing and on sensors and actuators for flow control.

Chapter 1 sets the engineering context of flow control. A detailed account is given on why flow control is important in many applications, even beyond aerospace applications and mixing, as drag reduction is potentially relevant in many other technical areas. The scope of the book is defined as stabilization of prototype flows such as 2D and 3D channel flows, pipe flow, cylinder flow in 2D and also the development of controllers to enhance mixing.

Chapter 2 provides a concise introduction into the governing partial differential equations (PDEs) of fluid mechanics. The conservation of mass, conservation of momentum, and the Navier–Stokes equations are formulated both in Cartesian and cylindrical co-ordinates. For perturbation analysis the linearized Navier–Stokes equations are derived. The PDEs for three prototypes flows of the 3D channel flow, the 3D pipe flow, 2D channel/pipe flow and the 2D cylinder flow are given. For simulation purposes spatial discretization of the Navier–Stokes equations is also discussed. Spectral methods, the Fourier–Galerkin method, the Chebyshev collocation method are briefly introduced.

Chapter 3 is devoted to the control theoretic preliminaries and methods that can be used in flow control. For linear time invariant systems the classical Nyquist stability is recalled, LQG control is briefly explained with the separation theorem. H_2 optimal control is presented as a generalization of LQG control. For H_∞-control a solution is outlined for the sub-optimal control problem that is easy to implement in flow stabilization. For non-linear systems Lyapunov stability and related asymptotic stability concepts are defined. The method of integrator backstepping is outlined to obtain globally asymptotically stabilizing controllers for non-linear systems.

Chapter 4 addresses the stabilization problems in flow control where many of the author's own contributions can be found. Bringing the linearized Navier–Stokes equations into the form of a linear time invariant system constitutes the major part of working out a stabilizing solution. The 2D channel flow problem is analysed with LQG and classical control. Linear control is also applied to 3D channel flow. Control actuation is applied in the form of wall transpiration on both walls. A comparative study is presented for H_2, H_∞ and proportional controllers under two different Reynolds numbers. The possibility of localized control instead of a centralized digital controller is argued for, based on spatial invariance. An interesting Lyapunov stability analysis shows the stability of parabolic equilibrium profiles for 2D and 3D pipe and channel flows. The analysis provides surprisingly simple control laws that are linear and decentralized, despite the non-linear flow dynamics. Both wall-normal and wall-tangential distributed actuation is considered and numerical demonstrations are provided. Regularity of solutions of the controlled channel flow are proven and numerical simulations are used to illustrate the results. The 3D channel flow and 3D pipe flow are analysed in detail. Finally, the last section of the chapter examines vortex shedding for cylinder flow and stabilization by state feedback is presented in theory and simulation.

Chapter 5 first reviews selected results on the diagnostics of mixing based on dynamical systems theory. Chaotic advection, stirring protocol and particle transport in the mixing region of the oscillating vortex pair flow are outlined. The section on diagnostics tools introduces Lagrangian coherent structures, material lines and surfaces and analyses their stability properties and detection of boundaries. For enhanced destabilization of 2D channel flow active feedback control of the boundary of the flow is proposed instead of traditional stirring and numerical simulations illustrate the effectiveness of the method. Optimal mixing in 3D pipe flow is discussed: sensing and actuation, measures of mixing, energy analysis, optimal control and detectability of mixing. Numerical simulations are presented with measurements of mixing and actuator distribution and bandwidth. Finally practical dispersion in bluff body wakes is discussed in the closing section of the chapter.

Chapter 6 provides a brief introduction into the principles of sensors and actuators that can be most useful in flow control. To control small-scale features microelectro mechanical systems (MEMS) are reviewed and some existing devices are presented.

The book also comes with a list of 136 references on flow control, with 13 of the author's own contributions, that can provide plenty of further reading for researchers and students of this exciting and relatively new technological area.

Finally, a review cannot be complete without mentioning some related books [1,2], a review [3] and edited volumes [4–6]. The publication [3] is a review paper on flow control covering a good cross section of the methodologies, the book [1] was written from the hardware (actuators, sensors) and fluid mechanics point of view and does not deal with the issues of feedback control, whereas References [4,5] are collections of papers on early efforts in mathematical techniques for optimal control of Navier–Stokes equations. The edited book [6] focuses on fluid mechanics and actuation, not on feedback control. The book [2] came out after the Aamo–Krtic one and it is on numerical and mathematical issues associated with optimization in Navier–Stokes systems. These still leave the book by Aamo and Krstic in a comfortable unique position as the one that also deals with digital feedback control of fluid flow.

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DIAGNOSIS AND FAULT-TOLERANT CONTROL
M. Blanke, M. Kinnaert, J. Lunze and M. Staroswiecki, Springer-Verlag: Berlin, 2003, 571 pp, ISBN 3-540-01056-4

Performances of closed loop controlled systems can be altered by the occurrence of abrupt or incipient faults which can cause serious damages to the system. One way to prevent system deteriorations is to develop controller having some capabilities to accommodate for faults.

Associated with rapidly increasing demands for higher system performance, product quality, productivity and cost efficiency, fault diagnosis (FD) and fault-tolerant control (FTC) become key issues in product development and system design, and therefore have received much attention in the academic community as well as in industry. It is well known that increasing plant availability and reliability may have an impact on improving economic efficiency even larger than improving process operation.

The task to be tackled in achieving fault-tolerance is the design of a controller with suitable structure to guarantee satisfactory performance, not only when all control components are operational; but also in the case when instruments are operating under a faulty mode. In this context, the aim of the present book is to introduce the main ideas of fault diagnosis and FTC and also to survey recent methods for fault handling.

Fault diagnosis is a relatively well documented topic and there are several books on this subject (see for example References [1–4]). Model-based FD relies on a well established and structured theory and classification of the methods used for fault diagnosis is something which is now widely accepted in the FD research community. But, on the other hand, fault tolerant control is a more recent research topic. In the past years, a number of FTC approaches were reported, but most of them were developed for particular applications, mainly relevant to flight control or aerospace [5,6]. FTC has not reached its full maturity and it is still an open methodology [7]. That is within the framework of FTC there are many ways to achieve fault tolerance in the design of a controller. Actually, FTC concepts can be separated into 'passive' and 'active' approaches. The key difference between them consists in that the active FTC system includes an FDI system and the fault handling is carried out based on information on faults delivered by the FDI system, while in a passive FTC system the system components and controllers are designed in such a way that they are robust to possible faults to a certain degree.

The book addresses the main topics of FD and FTC in a logical way, considering the following items:

- Modelling of systems subject to the fault,
- Analysis of fault propagation and fault effects,
- Fault detection and isolation,
- Re-design of the controller.

The book consists of 10 Chapters and six appendices. As the authors claim, the 10 Chapters can be grouped into three parts. The first part consists of Chapters 1–3 in which the main problems encountered in FDI and FTC are introduced and the resulting concepts are

