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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 described. The main part including Chapters 4–9, covers the traditional topics in fault diagnosis and FTC; it is structured according to the model types which can be used to describe a system. The remaining part of the book, i.e. Chapter 10, constitutes the third part in which applications are described.

The book starts with a dissertation on the general concepts and ideas which are introduced in Chapter 1. In particular the authors answer to very simple, but useful questions such as: which kind of faults are considered? How does the fault affect the system? What are the main ideas and the aims of fault diagnosis and FTC? etc. This chapter is of prime interest for those students or engineers who are interested in applying the methods addressed in the book. It is also to be noticed that the general organization of the book is presented here, thus providing advices to those who would prefer to focus on a particular topic. In Chapter 2, two examples which will be also used all along the book for illustration purposes are presented. The first one (two tanks system) can be considered as an academic illustration while the other (ship navigation and steering) can be seen as complex problem closer to real life applications. Both examples, relevant to the category of continuous dynamic systems are clearly explained and well documented. Chapter 3 deals with systems modelling in view of fault tolerant control. Modelling the nominal behaviour of the system as well as modelling of faulty operating conditions are developed here. Different kind of models are discussed, from the basic differential equation to the discrete events systems. Modelling of hybrid system is also introduced in this chapter, but only a reduced size paragraph is reserved here to this topic which is of prime importance in FTC since FTC systems usually based on control reconfiguration are hybrid by nature.

In Chapters 4 and 5, several tools for a preliminary analysis of systems subject to faults are introduced. In Chapter 4, generic components models are the basic elements used to describe the system architecture from a formal point of view. The systematic approach presented in the book provide means to categorise the faults with respect to their effect, to study how faults propagate and affect the different components of the system and to manage the transition from an operating mode to another in reaction to the faults. In Chapter 5, redundancies among the system variables are described using structure graphs, thus making it possible to analyse the redundancies. This chapter also investigates important features of FTC systems such as system reconfigurability and existence of a fault tolerant controller.

The main concepts of model-based fault diagnosis of continuous-variable systems are presented in Chapter 6 following a traditional way. FD implies design residuals that are close to zero in fault-free situations and deviate from zero in the presence of faults. The residual must possess the ability to discriminate between all possible modes of faults, explaining the use of the term isolation. The solutions which are presented in the book rely on the parity space or equivalent approaches. One may regret that the design based on the use of detection filters having directional properties in response to particular faults, are not described in the book. Such a design represents an attractive way for enhancing fault isolability. Methods for fault estimation are also described in Chapter 6. The remaining part of the chapter is devoted to residual evaluation. This is developed in the stochastic case reducing the decision process to a change detection in the mean of the residual, assuming that is a random sequence normally distributed.

Chapter 7 which discusses FTC methodologies represents in my view one of the key innovative contribution of the book, in particular due to the lack of a framework of FTC technology, based on which a systematic design of FTC systems could be carried out. In that sense, this book can be seen as an overview of the available FTC theory and methods. In this chapter several methods for fault accommodation and control reconfiguration are introduced. Readers of the book will appreciate the elegant formalism used in this chapter which can be seen as an attempt to propose a unified formalism for the design of an FTC system. It makes use of the triple $\langle O, C, U \rangle$ where O, C and U are respectively the control objectives, the set of constraints and set of admissible control laws. Fault tolerance is achieved by system and/or controller reconfiguration, in which the overall system performance will be recovered by a reconfiguration of parts of the control system, after faults are identified and a reduction of the system performance is observed. In this framework, Chapter 7 introduces several methods for fault accommodation and control reconfiguration for continuous variable plants.

Although, Chapters 8 and 9 are very unique compared to many other textbooks dealing with FD and FTC, the topics addressed here are presented in a natural way. Discrete-event systems and quantized systems in which both continuous and discrete time phenomena have to be taken into account are studied in these chapters. It is not usual in the control literature to find textbooks where both theories of discrete event systems and continuous variable system are treated at the same level. But, it is fully justified in the engineering practice. Despite the fact that for many of those who will read the book, it could appear far from their main concern, it is clear that the ideas in Chapters 8 and 9 to develop methods for FD similar to those classical observer-based solutions used in classical model based FDI are very attractive. But, it is to be noticed that only merely preliminary results are presented here to deal with the reconfiguration problem.

Finally, the book ends with a chapter of case studies for FTC in industry and pilot plants drawn from concrete experience. In addition to the two tanks system and the ship steering control problem introduced in Chapter 2, two other examples, both from process industry, are used to illustrate the methods developed in the book. These well documented examples are investigated in detail, thus providing useful guidelines for complete solutions to deal with real life situations.

FTC represents an emerging area in control. Even if more and more attention has been recently paid to this topic by the control community, only few books have been published on it; actually, in the last decade, the book referenced [8] seems to be the only one fully dedicated to FTC. This new book by Blanke *et al.* recently published is warmly welcomed not only as a valuable reference in the field but also as a source for advancement in control systems. Results in the book make a great contribution to the important research area that represent Fault diagnosis and FTC. Nevertheless, several other important aspects [9] of FDI and FTC are not addressed in the book, but it was not the goal of the authors to be exhaustive. In particular, among these topics one may list: advanced FDI and FTC methods for nonlinear and uncertain systems, integrated design of FDI and reconfiguration mechanisms, analysis of switched behaviour between two different configurations and development of switching schemes, implementation of reconfiguration mechanism under real time condition and the related constraints, etc.

The primary interest in this book will be for the practitioners in control system engineering that would benefit from the problem formulation and methodologies presented in the book, in particular thanks to the intensive use of application examples and case studies. It is likely that the book will be found to be useful as a teaching text at the graduate level. The book provides solid foundations for advanced courses. It could also represent a valuable book for those researchers who are interested in reading a state of the art in FTC. This book makes it possible for researchers in control to get into the topics more quickly without spending to much time searching in the vast amount of the literature [9].

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