

Preface

The model based approach to fault detection and diagnosis has been the subject of continuing research for several decades. A number of monographs, several edited books, and many conference proceedings cover a multitude of aspects of two closely related important fields: fault diagnosis and fault tolerant control. This book addresses from a procedural point of view a basic aspect of these techniques: the synthesis of residual generators for fault detection and isolation. Although the need for specialized computational procedures has been earlier recognized by several authors, the computational aspects have been largely ignored in the existing literature or they are addressed only superficially without a clear understanding of the main numerical issues. Therefore, the aim of this book, to address the fault detection and isolation topics from a computational perspective, contrasts with most existing literature. This book is an attempt to close the gap between the existing well-developed theoretical results and the realm of reliable computational synthesis procedures.

The book addresses several important aspects which make it unique in the fault detection literature. A *first aspect* is the solution of standard synthesis problems in the most general setting. Consequently, the presented synthesis procedures can determine a solution to a specific problem whenever a solution exists in accordance with the stated general existence conditions. Although this feature is a legitimate goal when developing computational approaches, the existing literature still abounds with technical assumptions which, although they often facilitate establishing of particular theoretical results, are not necessary for the solution of the problems. A distinctive feature of the presented synthesis methods is their general applicability to both continuous- and discrete-time systems, regardless of whether the underlying system is proper or not.

The *second aspect* is the focus on the best suited numerical algorithms to solve the formulated filter synthesis problems. In contrast to the opinions of some authors that cultural aspects (e.g., familiarity with one approach or another) may influence the choice of appropriate algorithms, I firmly believe that only state-space description based algorithms are a viable choice when solving relatively high order problems. Therefore, I completely dismissed computational procedures based on

polynomial or rational matrix manipulations, and exclusively rely on state-space representation based numerically reliable computational methods. An extra bonus is the availability of a huge arsenal of numerically reliable linear algebra software tools that facilitate the implementation of dedicated robust numerical software.

The *third aspect* emphasized is the development of so-called integrated computational procedures, where the resulting filters are determined by successive updating of partial synthesis results addressing specific requirements. Since each partial synthesis may represent a valid fault detection filter, this approach is highly flexible when using or combining different synthesis techniques. A common feature of all synthesis methods is the use of the nullspace method as the first synthesis step to reduce all synthesis problems to a simple standard form that allows easy checking of solvability conditions and addressing least-order synthesis problems.

The *fourth aspect* is the provision of a comprehensive set of supporting software tools which accompany this book. This software allows the easy implementation of all synthesis procedures presented in the book and facilitates performing rapid prototyping experiments in the computational environment MATLAB¹. The software tools rely on numerically reliable algorithms for solving computational problems for systems in a generalized state-space form, also known as descriptor systems. The provided collection of MATLAB functions, called Descriptor System Tools, has been entirely implemented during the preparation of this book. There are also numerous MATLAB scripts which allow the recalculation of all worked examples and of several case studies. Since virtually all numerical results in the book can be reproduced by the readers using these scripts, this book is one of the first contributions to reproducible research in the field of fault detection.

Two alternative models are used in the book to describe systems with faults: an input-output description based on transfer function matrices, and state-space descriptions in standard or generalized (descriptor) forms. It is important to clarify from the beginning the roles of these two model types used in the book. The input-output models underlie the theoretical developments in the book to solve various fault detection problems. Therefore, they serve to formulate the specific fault detection problems to be solved, to establish algebraic existence conditions, and even to describe high level conceptual solution procedures. In this way, it is possible to hide in a first reading most of the involved computational details by focusing mainly on conceptual aspects. However, when entering the realm of developing reliable numerical algorithms, there is an exclusive reliance on the equivalent state-space representations. There are several important reasons for this decision. Firstly, state-space models are better suited to numerical computations than are the potentially highly sensitive polynomial based models. Second, state-space models allow the formulation of integrated algorithms, where successive steps are closely connected and structural features can be fully exploited. Finally, by developing explicit state-space representation based updating formulas, the resulting algorithms lead to minimal order filters, by implicitly performing all

¹MATLAB® is a registered trademark of The Mathworks, Inc.

hidden pole-zero cancelations. This significantly increases the reliability of computations and confers a sound numerical basis for all developed algorithms.

The treatment of fault detection problems is limited to linear time-invariant systems, for which both the theory and computational tools are well developed. Although the proposed linear synthesis methodologies offer satisfactory solutions for many practical applications, performance limitations (e.g., lack of sufficient robustness) may still occur when facing more complicated systems. Nevertheless, linear techniques are frequently used to address even problems where the underlying system models are nonlinear and parameter dependent. Besides providing guidance for problem solvability and performance limitations, linear synthesis approaches form the basis of complex gains-scheduling-based synthesis methodologies that are able to fully address robustness aspects. Also, using linear fault detection filters in conjunction with signal processing techniques for online identification of various types of faults often represents a viable approach to enhance the robustness of the fault detection and to provide useful information for control reconfiguration purposes. The considered case studies illustrate these aspects.

The book includes a substantial amount of background material on rational matrices, descriptor systems and computational algorithms. The presentation of theoretical backgrounds on rational matrices and descriptor systems exhibits a certain parallelism meant to ease introducing or recalling to readers the main theoretical concepts. The algorithmic details are presented only in the final chapter. This may help readers, especially those not familiar with or not interested in numerical aspects, to focus primarily on the main synthesis steps of the conceptual synthesis procedures, by blending out all non-essential technicalities. Nevertheless, the presentation of the underlying algorithms is a main part of this book, and the final chapter even includes several algorithmic improvements, which are presented for the first time here.

This book is primarily aimed at researchers and advanced graduate students in the areas of fault diagnosis and fault tolerant control. The Chaps. 1–6 and 8 fit well into an advanced fault diagnosis curricula relying on computer aided design tools. The Chaps. 7 and 10 will appeal to mathematicians with interests in control oriented numerics.

The present book is largely based on my own research, started in 2002, on developing reliable numerical methods for the synthesis of fault detection filters. Many colleagues working in the field of fault diagnosis recognized the need to develop efficient and reliable computational methods. This was a constant stimulus for me to understand all the subtleties of problem formulations, to discover the technical and numerical limitations of many of the existing computational approaches, and to pursue research to develop efficient and reliable algorithms which are able to provide a solution whenever one exists. A particular impulse came from the organizers of the SAFEPROCESS'2012 conference in Mexico City, Prof. Jan Lunze (Program Chair) and Prof. Cristina Verde (General Chair), who invited me to hold a semi-plenary lecture at this conference. In my talk I presented a systematic account of linear time-invariant synthesis techniques of fault detection filters. The underlying plenary paper was later published, in an extended and

revised form, in Annual Reviews in Control (ARC, 2013). This paper, which is simultaneously a survey of synthesis methods and a presentation of several new ideas and research results, laid the methodical foundation for this book. During its preparation, I realized the importance of the availability of numerical software suitable for the easy implementation of the presented synthesis methods. Therefore, implementing the free software tools that accompany this book was a natural extension of my original plans.

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