

ACTIVE FAILURE DETECTION: AUXILIARY SIGNAL DESIGN AND ON-LINE DETECTION

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Abstract

This paper describes an active approach for model identification and failure detection in the presence of quadratically bounded uncertainty. After developing the underlying geometry, two particular examples of this approach involving static and continuous models are described. Several examples are given.

1 Introduction

There are two general approaches to failure detection and isolation. One is a passive approach where a detector monitors input and outputs of the system and decides whether, and if possible what kind of, a failure has occurred. A passive approach is used for continuous monitoring. The detector has no way of acting upon the system.

In contrast, in an active approach the system is acted upon on a periodic basis or at critical times using a test signal (auxiliary signal) to exhibit abnormal behaviors. The decision of whether or not the system has failed should be made by the end of the test period. The active approach has the advantages that it can sometimes detect failures that are not detectable during the normal operation of the system. This is especially important for evaluating subsystem status before the subsystem's performance becomes crucial. An example would be evaluating the brakes



Figure 1: General system structure.

while moving but before a truck has to stop. An active approach also often permits quicker detection of a failure. Of course, it is usually important that the test signal be small in some sense in order to not interfere with normal operation.

In [2, 3, 4, 5] we have begun the investigation of a multi-model active approach for model identification and failure detection. These earlier papers have focused on the theory and computation for various special cases. As this work has progressed a general framework encompassing all of these cases and several additional ones has begun to become evident. This paper will discuss this general framework for the first time.

2 Geometry of the approach

The structure of the active failure detection method considered here is described in Figure 1. The system is acted on by both a control input u and the auxiliary signal v . The system is subject to noise v and there is an output y . The information available for

Auxiliary Signal Design For Failure Detection

Ilya Shmulevich, Edward R. Dougherty



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Auxiliary Signal Design for Failure Detection Stephen L. Campbell, Ramine Nikoukhah, 2004-02-15 Many industries such as transportation and manufacturing use control systems to insure that parameters such as temperature or altitude behave in a desirable way over time For example pilots need assurance that the plane they are flying will maintain a particular heading An integral part of control systems is a mechanism for failure detection to insure safety and reliability This book offers an alternative failure detection approach that addresses two of the fundamental problems in the safe and efficient operation of modern control systems failure detection deciding when a failure has occurred and model identification deciding which kind of failure has occurred Much of the work in both categories has been based on statistical methods and under the assumption that a given system was monitored passively Campbell and Nikoukhah's book proposes an active multimodel approach It calls for applying an auxiliary signal that will affect the output so that it can be used to easily determine if there has been a failure and what type of failure it is This auxiliary signal must be kept small and often brief in duration in order not to interfere with system performance and to ensure timely detection of the failure The approach is robust and uses tools from robust control theory Unlike some approaches it is applicable to complex systems The authors present the theory in a rigorous and intuitive manner and provide practical algorithms for implementation of the procedures **Auxiliary Signal**

Design for Failure Detection Stephen L. Campbell, Ramine Nikoukhah, 2015-11-03 Many industries such as transportation and manufacturing use control systems to insure that parameters such as temperature or altitude behave in a desirable way over time For example pilots need assurance that the plane they are flying will maintain a particular heading An integral part of control systems is a mechanism for failure detection to insure safety and reliability This book offers an alternative failure detection approach that addresses two of the fundamental problems in the safe and efficient operation of modern control systems failure detection deciding when a failure has occurred and model identification deciding which kind of failure has occurred Much of the work in both categories has been based on statistical methods and under the assumption that a given system was monitored passively Campbell and Nikoukhah's book proposes an active multimodel approach It calls for applying an auxiliary signal that will affect the output so that it can be used to easily determine if there has been a failure and what type of failure it is This auxiliary signal must be kept small and often brief in duration in order not to interfere with system performance and to ensure timely detection of the failure The approach is robust and uses tools from robust control theory Unlike some approaches it is applicable to complex systems The authors present the theory in a rigorous and intuitive manner and provide practical algorithms for implementation of the procedures *Fault Detection, Supervision and Safety of Technical Processes 2003 (SAFEPROCESS 2003)* Marcel Staroswiecki, Eva Wu, 2004-02-27 A three volume work bringing together papers presented at SAFEPROCESS 2003 including four plenary papers on statistical physical model based and logical model based approaches to fault detection and diagnosis as well as 178 regular papers Fault Detection

Supervision and Safety of Technical Processes 2006 Hong-Yue Zhang, 2007-03-01 The safe and reliable operation of technical systems is of great significance for the protection of human life and health the environment and of the vested economic value The correct functioning of those systems has a profound impact also on production cost and product quality The early detection of faults is critical in avoiding performance degradation and damage to the machinery or human life Accurate diagnosis then helps to make the right decisions on emergency actions and repairs Fault detection and diagnosis FDD has developed into a major area of research at the intersection of systems and control engineering artificial intelligence applied mathematics and statistics and such application fields as chemical electrical mechanical and aerospace engineering IFAC has recognized the significance of FDD by launching a triennial symposium series dedicated to the subject The SAFEPROCESS Symposium is organized every three years since the first symposium held in Baden Baden in 1991 SAFEPROCESS 2006 the 6th IFAC Symposium on Fault Detection Supervision and Safety of Technical Processes was held in Beijing PR China The program included three plenary papers two semi plenary papers two industrial talks by internationally recognized experts and 258 regular papers which have been selected out of a total of 387 regular and invited papers submitted Discusses the developments and future challenges in all aspects of fault diagnosis and fault tolerant control 8 invited and 36 contributed sessions included with a special session on the demonstration of process monitoring and diagnostic software tools

Test Signal Generation for Service Diagnosis Based on Local Structure Graphs Michael Ungermann, 2015-05-06 This work considers the problem of identifying the fault in a faulty dynamical system on the basis of the system's input and output signals only For this purpose a model based method for the design of diagnostic tests which consist of specific input signals and appropriate residual generators is developed The method extends the structure graph of dynamical systems in order to represent the couplings in a system which has been brought to a specific operating region The resulting local structure graph is used to determine specific residual generators which can distinguish between faults on the basis of the system's input and output signals in the corresponding operating region Algorithms to determine advantageous operating regions and input signals which drive the system into such operating regions are given The application of the method to determine diagnostic tests is demonstrated using a typical automotive system a throttle valve

Modeling and Monitoring of Pipelines and Networks Cristina Verde, Lizeth Torres, 2017-05-21 This book focuses on the analysis and design of advanced techniques for on line automatic computational monitoring of pipelines and pipe networks It discusses how to improve the systems security considering mathematical models of the flow historical flow rate and pressure data with the main goal of reducing the number of sensors installed along a pipeline The techniques presented in the book have been implemented in digital systems to enhance the abilities of the pipeline network's operators in recognizing anomalies A real leak scenario in a Mexican water pipeline is used to illustrate the benefits of these techniques in locating the position of a leak Intended for an interdisciplinary audience the book addresses researchers and professionals in the areas of mechanical civil and control

engineering It covers topics on fluid mechanics instrumentation automatic control signal processing computing construction and diagnostic technologies Surveys in Differential-Algebraic Equations III Achim Ilchmann,Timo Reis,2015-10-29 The present volume comprises survey articles on various fields of Differential Algebraic Equations DAEs which have widespread applications in controlled dynamical systems especially in mechanical and electrical engineering and a strong relation to ordinary differential equations The individual chapters provide reviews presentations of the current state of research and new concepts in Flexibility of DAE formulations Reachability analysis and deterministic global optimization Numerical linear algebra methods Boundary value problems The results are presented in an accessible style making this book suitable not only for active researchers but also for graduate students with a good knowledge of the basic principles of DAEs for self study

Modelling and Estimation Strategies for Fault Diagnosis of Non-Linear Systems Marcin Witczak,2007-04-05 This monograph presents a variety of techniques that can be used for designing robust fault diagnosis schemes for non linear systems The introductory part of the book is of a tutorial value and can be perceived as a good starting point for the new comers to this field Subsequently advanced robust observer structures are presented Parameter estimation based techniques are discussed as well A particular attention is drawn to experimental design for fault diagnosis The book also presents a number of robust soft computing approaches utilizing evolutionary algorithms and neural networks All approaches described in this book are illustrated by practical applications **Proceedings IECON.** ,1997 **Resilient Controls for Ordering**

Uncertain Prospects Khanh D. Pham,2014-09-05 Providing readers with a detailed examination of resilient controls in risk averse decision this monograph is aimed toward researchers and graduate students in applied mathematics and electrical engineering with a systems theoretic concentration This work contains a timely and responsive evaluation of reforms on the use of asymmetry or skewness pertaining to the restrictive family of quadratic costs that have been appeared in various scholarly forums Additionally the book includes a discussion of the current and ongoing efforts in the usage of risk dynamic game decision optimization and disturbance mitigation techniques with output feedback measurements tailored toward the worst case scenarios This work encompasses some of the current changes across uncertainty quantification stochastic control communities and the creative efforts that are being made to increase the understanding of resilient controls Specific considerations are made in this book for the application of decision theory to resilient controls of the linear quadratic class of stochastic dynamical systems Each of these topics are examined explicitly in several chapters This monograph also puts forward initiatives to reform both control decisions with risk consequences and correct by design paradigms for performance reliability associated with the class of stochastic linear dynamical systems with integral quadratic costs and subject to network delays control and communication constraints Modern Anti-windup Synthesis Luca Zaccarian,Andrew R. Teel,2011-07-11 This book provides a wide variety of state space based numerical algorithms for the synthesis of feedback algorithms for linear systems with input saturation Specifically it addresses and solves the anti windup problem presenting

the objectives and terminology of the problem the mathematical tools behind anti windup algorithms and more than twenty algorithms for anti windup synthesis illustrated with examples Luca Zaccarian and Andrew Teel s modern method combining a state space approach with algorithms generated by solving linear matrix inequalities treats MIMO and SISO systems with equal ease The book aimed at control engineers as well as graduate students ranges from very simple anti windup construction to sophisticated anti windup algorithms for nonlinear systems Describes the fundamental objectives and principles behind anti windup synthesis for control systems with actuator saturation Takes a modern state space approach to synthesis that applies to both SISO and MIMO systems Presents algorithms as linear matrix inequalities that can be readily solved with widely available software Explains mathematical concepts that motivate synthesis algorithms Uses nonlinear performance curves to quantify performance relative to disturbances of varying magnitudes Includes anti windup algorithms for a class of Euler Lagrange nonlinear systems Traces the history of anti windup research through an extensive annotated bibliography

Advanced and Intelligent Computations in Diagnosis and Control Zdzisław Kowalczyk, 2015-09-01 This book is devoted to the demands of research and industrial centers for diagnostics monitoring and decision making systems that result from the increasing complexity of automation and systems the need to ensure the highest level of reliability and safety and continuing research and the development of innovative approaches to fault diagnosis The contributions combine domains of engineering knowledge for diagnosis including detection isolation localization identification reconfiguration and fault tolerant control The book is divided into six parts I Fault Detection and Isolation II Estimation and Identification III Robust and Fault Tolerant Control IV Industrial and Medical Diagnostics V Artificial Intelligence VI Expert and Computer Systems

Stability and Control of Large-Scale Dynamical Systems Wassim M. Haddad, Sergey G. Nersisov, 2011-11-14 Modern complex large scale dynamical systems exist in virtually every aspect of science and engineering and are associated with a wide variety of physical technological environmental and social phenomena including aerospace power communications and network systems to name just a few This book develops a general stability analysis and control design framework for nonlinear large scale interconnected dynamical systems and presents the most complete treatment on vector Lyapunov function methods vector dissipativity theory and decentralized control architectures Large scale dynamical systems are strongly interconnected and consist of interacting subsystems exchanging matter energy or information with the environment The sheer size or dimensionality of these systems necessitates decentralized analysis and control system synthesis methods for their analysis and design Written in a theorem proof format with examples to illustrate new concepts this book addresses continuous time discrete time and hybrid large scale systems It develops finite time stability and finite time decentralized stabilization thermodynamic modeling maximum entropy control and energy based decentralized control This book will interest applied mathematicians dynamical systems theorists control theorists and engineers and anyone seeking a fundamental and comprehensive understanding of large scale interconnected dynamical systems and control

Mathematical Analysis of Deterministic and Stochastic Problems in Complex Media Electromagnetics G. F.

Roach, I. G. Stratis, A. N. Yannacopoulos, 2012-03-04 Electromagnetic complex media are artificial materials that affect the propagation of electromagnetic waves in surprising ways not usually seen in nature. Because of their wide range of important applications, these materials have been intensely studied over the past twenty-five years, mainly from the perspectives of physics and engineering. But a body of rigorous mathematical theory has also gradually developed, and this is the first book to present that theory. Designed for researchers and advanced graduate students in applied mathematics, electrical engineering, and physics, this book introduces the electromagnetics of complex media through a systematic state-of-the-art account of their mathematical theory. The book combines the study of well-posedness, homogenization, and controllability of Maxwell equations complemented with constitutive relations describing complex media. The book treats deterministic and stochastic problems both in the frequency and time domains. It also covers computational aspects and scattering problems among other important topics. Detailed appendices make the book self-contained in terms of mathematical prerequisites and accessible to engineers and physicists as well as mathematicians.

Diagnosis and Fault-Tolerant Control Mogens Blanke, Michel Kinnaert, Jan

Lunze, Marcel Staroswiecki, 2006-09-24 Fault-tolerant control aims at a graceful degradation of the behaviour of automated systems in case of faults. It satisfies the industrial demand for enhanced availability and safety in contrast to traditional reactions to faults that bring about sudden shutdowns and loss of availability. The book presents effective model-based analysis and design methods for fault diagnosis and fault-tolerant control. Architectural and structural models are used to analyse the propagation of the fault through the process to test the fault detectability and to find the redundancies in the process that can be used to ensure fault tolerance. Design methods for diagnostic systems and fault-tolerant controllers are presented for processes that are described by analytical models, by discrete event models, or that can be dealt with as quantised systems. Five case studies on pilot processes show the applicability of the presented methods. The theoretical results are illustrated by two running examples used throughout the book. The second edition includes new material about reconfigurable control, diagnosis of nonlinear systems, and remote diagnosis. The application examples are extended by a steering-by-wire system and the air path of a diesel engine, both of which include experimental results. The bibliographical notes at the end of all chapters have been updated. The chapters end with exercises to be used in lectures.

Fault-tolerant Flight Control and Guidance Systems Guillaume J. J. Ducard, 2009-05-14 This book offers a complete overview of fault-tolerant flight control techniques. Discussion covers the necessary equations for the modeling of small UAVs, a complete system based on extended Kalman filters, and a nonlinear flight control and guidance system.

Mathematical Methods in Elasticity Imaging Habib Ammari, Elie Bretin, Josselin Garnier, Hyeonbae Kang, Hyundae Lee, Abdul

Wahab, 2015-04-06 This book is the first to comprehensively explore elasticity imaging and examines recent important developments in asymptotic imaging modeling and analysis of deterministic and stochastic elastic wave propagation.

phenomena It derives the best possible functional images for small inclusions and cracks within the context of stability and resolution and introduces a topological derivative based imaging framework for detecting elastic inclusions in the time harmonic regime For imaging extended elastic inclusions accurate optimal control methodologies are designed and the effects of uncertainties of the geometric or physical parameters on stability and resolution properties are evaluated In particular the book shows how localized damage to a mechanical structure affects its dynamic characteristics and how measured eigenparameters are linked to elastic inclusion or crack location orientation and size Demonstrating a novel method for identifying locating and estimating inclusions and cracks in elastic structures the book opens possibilities for a mathematical and numerical framework for elasticity imaging of nanoparticles and cellular structures **Totally**

Nonnegative Matrices Shaun M. Fallat, Charles R. Johnson, 2022-12-13 Totally nonnegative matrices arise in a remarkable variety of mathematical applications This book is a comprehensive and self contained study of the essential theory of totally nonnegative matrices defined by the nonnegativity of all subdeterminants It explores methodological background historical highlights of key ideas and specialized topics The book uses classical and ad hoc tools but a unifying theme is the elementary bidiagonal factorization which has emerged as the single most important tool for this particular class of matrices Recent work has shown that bidiagonal factorizations may be viewed in a succinct combinatorial way leading to many deep insights Despite slow development bidiagonal factorizations along with determinants now provide the dominant methodology for understanding total nonnegativity The remainder of the book treats important topics such as recognition of totally nonnegative or totally positive matrices variation diminution spectral properties determinantal inequalities Hadamard products and completion problems associated with totally nonnegative or totally positive matrices The book also contains sample applications an up to date bibliography a glossary of all symbols used an index and related references Genomic Signal Processing Ilya Shmulevich, Edward R. Dougherty, 2014-09-08 Genomic signal processing GSP can be defined as the analysis processing and use of genomic signals to gain biological knowledge and the translation of that knowledge into systems based applications that can be used to diagnose and treat genetic diseases Situated at the crossroads of engineering biology mathematics statistics and computer science GSP requires the development of both nonlinear dynamical models that adequately represent genomic regulation and diagnostic and therapeutic tools based on these models This book facilitates these developments by providing rigorous mathematical definitions and propositions for the main elements of GSP and by paying attention to the validity of models relative to the data Ilya Shmulevich and Edward Dougherty cover real world situations and explain their mathematical modeling in relation to systems biology and systems medicine Genomic Signal Processing makes a major contribution to computational biology systems biology and translational genomics by providing a self contained explanation of the fundamental mathematical issues facing researchers in four areas classification clustering network modeling and network intervention Hidden Markov Processes M. Vidyasagar, 2014-08-24 This book explores

important aspects of Markov and hidden Markov processes and the applications of these ideas to various problems in computational biology. The book starts from first principles so that no previous knowledge of probability is necessary. However, the work is rigorous and mathematical, making it useful to engineers and mathematicians even those not interested in biological applications. A range of exercises is provided, including drills to familiarize the reader with concepts and more advanced problems that require deep thinking about the theory. Biological applications are taken from post-genomic biology, especially genomics and proteomics. The topics examined include standard material such as the Perron-Frobenius theorem, transient and recurrent states, hitting probabilities and hitting times, maximum likelihood estimation, the Viterbi algorithm, and the Baum-Welch algorithm. The book contains discussions of extremely useful topics not usually seen at the basic level, such as ergodicity of Markov processes, Markov Chain Monte Carlo (MCMC), information theory, and large deviation theory for both independent and Markov processes. The book also presents state-of-the-art realization theory for hidden Markov models. Among biological applications, it offers an in-depth look at the BLAST (Basic Local Alignment Search Technique) algorithm, including a comprehensive explanation of the underlying theory. Other applications such as profile hidden Markov models are also explored.

Unveiling the Magic of Words: A Overview of "**Auxiliary Signal Design For Failure Detection**"

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