Fault Tolerant Flight Control And Guidance Systems Practical Methods For Small Unmanned Aerial Vehicles Advances In Industrial Control

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.

The research is concerned with developing a new approach to enhancing fault tolerance of flight control systems. The original motivation for fault-tolerant control comes from the need for safe operation of control elements (e.g. actuators) in the event of hardware failures in high reliability systems. One such example is modem space vehicle subjected to actuator/sensor impairments. A major task in flight control is to revise the control policy to balance impairment detectability and to achieve sufficient robustness. This involves careful selection of types and parameters of the controllers and the impairment detecting filters used. It also involves a decision, upon the identification of some failures, on whether and how a control reconfiguration should take place in order to maintain a certain system performance level. In this project new flight dynamic model under uncertain flight conditions is considered, in which the effects of both ramp and jump faults are reflected. Stabilization algorithms based on neural network and adaptive method are derived. The control algorithms are shown to be effective in dealing with uncertain dynamics due to external disturbances and unpredictable faults. The overall strategy is easy to set up and the computation involved is much less as compared with other strategies. Computer simulation software is developed. A serious of simulation studies have been conducted with varying flight conditions. Song, Yong D. and Gupta, Kajal (Technical Monitor) Armstrong Flight Research Center

The objective of this thesis is to optimize the use of redundant actuators for a transportation aircraft once some actuators failure occurs during the flight. Here, the fault tolerant ability resulting from the redundant actuators is mainly considered. Different classical concepts and methods related to a fault tolerant flight control channel are first reviewed and new concepts useful for the required analysis are introduced. The problem which is tackled here is to develop a design methodology for fault tolerant flight control in the case of a partial actuator failure which will allow the aircraft to continue safely the intended maneuver. A two stages control approach is proposed and applied to both the remaining maneuverability evaluation and a fault tolerant control structure design. In the first case, an offline handling qualities assessment method based on Model Predictive Control is proposed. In the second case, a fault tolerant control structure based on Nonlinear Inverse Control and online actuator reassignment is developed. In both cases, a Linear Quadratic

(LQ) programming problem is formulated and different failure cases are considered when an aircraft performs a classical maneuver. Three numerical solvers are studied and applied to the offline and online solutions of the resulting LQ problems.

Fault Detection and Fault-tolerant Control Using Sliding Modes is the first text dedicated to showing the latest developments in the use of sliding-mode concepts for fault detection and isolation (FDI) and fault-tolerant control in dynamical engineering systems. It begins with an introduction to the basic concepts of sliding modes to provide a background to the field. This is followed by chapters that describe the use and design of sliding-mode observers for FDI using robust fault reconstruction. The development of a class of sliding-mode observers is described from first principles through to the latest schemes that circumvent minimum-phase and relative-degree conditions. Recent developments have shown that the field of fault tolerant control is a natural application of the well-known robustness properties of sliding-mode control. A family of sliding-mode control designs incorporating control allocation, which can deal with actuator failures directly by exploiting redundancy, is presented. Various realistic case studies, specifically highlighting aircraft systems and including results from the implementation of these designs on a motion flight simulator, are described. A reference and guide for researchers in fault detection and fault-tolerant control, this book will also be of interest to graduate students working with nonlinear systems and with sliding modes in particular. Advances in Industrial Control aims to report and encourage the transfer of technology in control engineering. The rapid development of control technology has an impact on all areas of the control discipline. The series offers an opportunity for researchers to present an extended exposition of new work in all aspects of industrial control.

The problem of fault diagnosis and reconfigurable control is a new and actually developing field of science and engineering. The subject becomes more interesting since there is an increasing demand for the navigation and control systems of aerospace vehicles, automated actuators etc. to be more safe and reliable. Nowadays, the problems of fault detection and isolation and reconfigurable control attract the attention the scientists in the world. The subject is emphasized in the recent international congresses such as IF AC World Congresses (San Francisco-1996, Beijing-1999, and Barcelona-2002) and lMEKO World Congresses (Tampere-1997, Osaka-1999, Vienna-2000), and also in the international conferences on fault diagnosis such as SAFEPROCESS Conferences (Hull-1997, Budapest-2000). The presented methods in the book are based on linear and nonlinear dynamic mathematical models of the systems. Technical objects and systems stated by these models are very large, and include various control systems, actuators, sensors, computer systems, communication systems, and mechanical, hydraulic, pneumatic, electrical and electronic devices. The analytical fault diagnosis techniques of these objects have been developed for several decades. Many of those techniques are based on the use of the results of modem control theory. This is natural, because it is known that fault diagnosis process in control systems is considered as a part of general control process. xxii In organization of fault diagnosis of control systems, the use of the concepts and methods of modem control theory including concepts of state space, modeling, controllability, observability, estimation, identification, and filtering is very efficient.

Fault Tolerant Flight Control, a Physical Model Approach.

This project focused on investigating the potential of on-line learning 'hardware-based' neural approximators and controllers to provide fault tolerance capabilities following sensor and actuator failures. Following a phase of simulation studies a set of selected architectures for neural estimators and neural controllers were flown on a semi-scale YF-22 aircraft model. The YF-22 model was designed, built, and flown at research facilities at West Virginia University. Additionally, a customized electronic payload featuring these fault tolerant schemes was designed, built, tested and interfaced with the YF-22 flight control system. A series of 33 flight tests were conducted with the aircraft; the flight data confirmed the potential of neural estimators and controllers for fault tolerance purposes. Another research objective was to start addressing system requirements leading to the problem of software validation and verification for this new class of algorithms for fault tolerant flight control systems.

Avionics Design for a Sub-Scale Fault- Tolerant Flight Control Test-Bed.

Written by leading experts in the field, this book provides the state-of-the-art in terms of fault tolerant control applicable to civil aircraft. The book consists of five parts and includes online material.

Safety is one of the major concerns in the aviation community for both manned aircraft and unmanned aerial vehicles (UAVs). The safety issue of manned aircraft, such as commercial aircraft, has drawn great attentions especially after a series of disasters in recent decades. Safety and reliability issues of UAVs have also attracted significant attention due to their highly autonomous feature towards their future civilian applications. Focusing on the improvement of safety and reliability of aircraft, a fault-tolerant control (FTC) system is demanded to utilize the configured redundancy in an effective and efficient manner to increase the survivability of aircraft in the presence of faults/failures. This thesis aims to develop an effective FTC system to improve the security, reliability, and survivability of the faulty aircraft: manned aircraft and UAVs. In particular, the emphases are focused on improving the on-line fault-tolerant capability and the transient performance between faults occurrence and control re-configuration. In the existing fault-tolerant literature, several control approaches are developed to possess fault-tolerant capability in recent decades, such as sliding mode control (SMC), model reference adaptive control (MRAC), and model predictive control (MPC), just as examples. Different strategies have their specific benefits and drawbacks in addressing different aspects of fault-tolerant problems. However, there are still open problems in the fault-tolerant performance improvement, the transient behavior management, consideration of the interaction between FTC and fault detection and diagnosis (FDD), etc. For instance, MPC is recognized as a suitable inherent structure in synthesizing a FTC system due to its capability of addressing faults via solving constraints, reforming cost function, and updating model on-line. However, this on-line FTC capability introduces further challenges in terms of fault problem formulation, on-line computation, transient behavior before reconfiguration is triggered, etc. Designing an efficient FDD is also a challenge topic with respect to time response speed, accuracy, and reliability due to its interaction with a fault-tolerant controller. In the control design framework based on linear quadratic (LQ) cost function formulation, faults can be accommodated in both passive and active way. A passive FTC system is synthesized with a prescribed degree of stability LQ design technique. The state of the post-fault system is obtained through state-augmented extended Kalman filter (SAEKF), which is a combined technique with state and parameter estimation. In terms of reconfiguration capability, MPC is considered as a favorable active FTC strategy. In addition to MPC framework, the improvement of on-line computational efficiency motivates MPC to be used to perform fault-tolerant flight control. Furthermore, a Laguerre-function based MPC (LF-MPC) is presented to enhance the on-line fault-tolerant capability. The modification is based on a series of Laguerre functions to model the control trajectory with fewer parameters. In consequence, the computation load is reduced, which improves the real-time fault-tolerant capability in the framework of MPC. The FTC capability is further improved for accommodating the performance degradation during the transient period before the control reconfiguration. This approach is inspired by exponentially increasing weighting matrix used in linear quadratic regulator (LQR). Two platforms are used to perform the evaluation of the designed FTC system. A quadrotor UAV, named the Qball-X4, is utilized to test FTC designed with exponentially increasing weighing matrix LQ technique and FDD designed with SAEKF. The evaluation is conducted under the task of trajectory tracking in the presence of loss of control effectiveness (LOE) faults of actuators. The modified MPC is utilized to synthesize an active FTC system to accommodate the elevator stuck fault of a Boeing 747-100/200 benchmark model. The exponentially increasing weighing matrix LQ technique is further implemented in LF-MPC framework to improve the fault-tolerant capability before the control reconfiguration. A time delayed FDD is integrated into the evaluation process to present the effectiveness of the proposed FTC strategies. The designed FTC system is evaluated under the emergency landing task in the event of failure of elevators.

Fault Tolerant Flight ControlA Benchmark ChallengeSpringer Science & Business Media

Safety, reliability and acceptable level of performance of dynamic control systems are the major keys in all control systems especially in safety-critical control systems. A controller should be capable of handling noises and uncertainties imposed to the controlled process. A fault-tolerant controller should be able to control a system with guaranteed stability and good or acceptable performance not only in normal operation conditions but also in the presence of partial faults or total failures that can be occurred in the components of the system. When a fault occurs in a system, it suddenly starts to behave in an unanticipated manner. Thereby, a fault-tolerant controller should be designed for being able to handle the fault and guarantee system stability and acceptable performance in the presence of faults/damages. This shows the importance and necessity of Fault-Tolerant Control (FTC) to safety-critical and even nowadays for some new and non-safety-critical systems. During recent years, Unmanned Aerial Vehicles (UAVs) have proved to play a significant role in military and civil applications. The success of UAVs in different missions guarantees the growing number of UAVs to be considerable in future. Reliability of UAVs and their components against faults and failures is one of the most important objectives for safety-critical systems including manned airplanes and UAVs. The reliability importance of UAVs is implied in the acknowledgement of the Office of the Secretary of Defense in the UAV Roadmap 2005-2030 by stating that, ?Improving UA [unmanned aircraft] reliability is the single most immediate and long-reaching need to ensure their success?. This statement gives a wide future scenery of safety, reliability and Fault-Tolerant Flight Control (FTFC) systems of UAVs. The main objective of this thesis is to investigate and compare some aspects of fault tolerant flight control techniques such as performance, robustness and capability of handling the faults and failures during the flight of UAVs. Several control techniques have been developed and tested on two main platforms at Concordia University for fault-tolerant control techniques development, implementation and flight test purposes: quadrotor and fixedwing UAVs. The FTC techniques developed are: Gain-Scheduled Proportional-Integral-Derivative (GS-PID), Control Allocation and Re-allocation (CA/RA), Model Reference Adaptive Control (MRAC), and finally the Linear Parameter Varying (LPV) control as an alternative and theoretically more comprehensive gain scheduling based control technique. The LPV technique is used to control the quadrotor helicopter for fault-free conditions. Also a GS-PID controller is used as a fault-tolerant controller and implemented on a fixedwing UAV in the presence of a stuck rudder failure case.

Fault Tolerant Flight Control Techniques with Application to a Quadrotor UAV Testbed.

Fault Diagnosis and Fault-Tolerant Control and Guidance for Aerospace demonstrates the attractive potential of recent developments in control for resolving such issues as flight performance, self protection and extended-life structures. Importantly, the text deals with a number of practically significant considerations: tuning, complexity of design, real-time capability, evaluation of worst-case performance, robustness in harsh environments, and extensibility when development or adaptation is required. Coverage of such issues helps to draw the advanced concepts arising from academic research back towards the technological concerns of industry. Initial coverage of basic definitions and ideas and a literature review gives way to a treatment of electrical flight control system failures: oscillatory failure, runaway, and jamming. Advanced fault detection and diagnosis for linear and linear-parameter-varying systems are described. Lastly recovery strategies appropriate to remaining actuator/sensor/communications resources are developed. The authors exploit experience gained in research collaboration with academic and major industrial partners to validate advanced fault diagnosis and fault-tolerant control techniques with realistic benchmarks or real-world aeronautical and space systems. Consequently, the results presented in Fault Diagnosis and Fault-Tolerant Control and Guidance for Aerospace, will be of interest in both academic and aerospatial-industrial milieux.

Nonlinear problems in flight control have stimulated cooperation among engineers and scientists from a range of disciplines. Developments in computer technology allowed for numerical solutions of nonlinear control problems, while industrial recognition and applications of nonlinear mathematical models in solving technological problems is increasing. The aim of the book Advances in Flight Control Systems is to bring together reputable researchers from different countries in order to provide a comprehensive coverage of advanced and modern topics in flight control not yet reflected by other books. This product comprises 14 contributions submitted by 38 authors from 11 different countries and areas. It covers most of the currents main streams of flight control researches, ranging from adaptive flight control mechanism, fault tolerant flight control, acceleration based flight control, helicopter flight control, comparison of flight control systems and fundamentals. According to these themes the contributions are grouped in six categories, corresponding to six parts of the book.

The book describes the state of the art and latest advancements in technologies for various areas of aircraft systems. In particular it covers wide variety of topics in aircraft structures and advanced materials, control systems, electrical systems, inspection and maintenance, avionics and radar and some miscellaneous topics such as green aviation. The authors are leading experts in their fields. Both the researchers and the students should find the material useful in their work.

The history of flight control is inseparably linked to the history of aviation itself. Since the early days, the concept of automatic flight control systems has evolved from mechanical control systems to highly advanced automatic fly-by-wire flight control systems which can be found nowadays in military jets and civil airliners. Even today, many research efforts are made for the further development of these flight control systems in various aspects. Recent new developments in this field focus on a wealth of different aspects. This book focuses on a selection of key research areas, such as inertial navigation, control of unmanned aircraft and helicopters, trajectory control of an unmanned space re-entry vehicle, aeroservoelastic control, adaptive flight control, and fault tolerant flight control. This book consists of two major sections. The first section focuses on a literature review and some recent theoretical developments in flight control systems. The second section discusses some concepts of adaptive and fault-tolerant flight control systems. Each technique discussed in this book is illustrated by a relevant example.

Systematic approaches for designing robust and fault tolerant aircraft control systems are presented. The robust control design approaches include a robust LQG control system based on the technique presented by McFarlane and Glover, and also a weighted sensitivity H[subscript infinity] control system design. These methods allow the designer to increase the robustness of an aircraft control system to parametric uncertainties that are within the aircraft model due to either modelling errors or unmodelled dynamics. The results presented in this work show good time response performance while increasing the robustness to parametric uncertainties substantially. The second part of the work presents an H[subscript infinity] control design methodology to account for control surface faults in an aircraft. An uncertainty model is formed for a specific fault condition using an additive loop around the model's input matrices. In this work a controller is formulated for the case of a simultaneous lock-in-place failure of both the ailerons and the rudder control surfaces. Through simulation it is shown that the fault tolerant controller design is able to stabilize the aircraft both with and without the presence of the faults while maintaining acceptable performance.

The key attribute of a Fault Tolerant Control (FTC) system is its ability to maintain overall system stability and acceptable performance in the face of faults and failures within the feedback system. In this book Integral Sliding Mode (ISM) Control Allocation (CA) schemes for FTC are described, which have the potential to maintain close to nominal fault-free performance (for the entire system response), in the face of actuator faults and even complete failures of certain actuators. Broadly an ISM controller based around a model of the plant with the aim of creating a nonlinear fault tolerant feedback controller whose closed-loop performance is established during the design process. The second approach involves retro-fitting an ISM scheme to an existing feedback controller to introduce fault tolerance. This may be advantageous from an industrial perspective, because fault tolerance can be introduced without changing the existing control loops. A high fidelity benchmark model of a large transport aircraft is used to demonstrate the efficacy of the FTC schemes. In particular a scheme based on an LPV representation has been implemented and tested on a motion flight simulator.