ADVANCES IN FLIGHT CONTROL SYSTEMS

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Preface

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 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 14 contributions are grouped in six categories, corresponding to six parts of the book.

The first part of the book is a collection of four chapters (1, 2, 3, 4) dedicated to the adaptive flight control.

In Chapter 1 the purpose is to introduce the technical community to some of the adaptive flight control mechanisms and structures which have either lead directly to or actually flown in various classes of missiles, munitions and unhabited aircraft. Although many programs are not open for publication, glimpses of a select flow have made it to the public arena at various level. This chapter is centered on airing several supersystem-level advances to flight-proven missiles, munitions and UAVs. Toward that end, basic models were used to lay out proof-of-concept flight hardware which was then fabricated, bench and/or ground tested and incorporated in flight vehicles. In the early years the adaptive aircraft were often simply flown, just to prove the concept worked. More recently, aircraft using adaptive flight control mechanisms have been flown off against conventional benchmark aircraft so as to demonstrate systematic superiority, thereby proving that flight control systems employing adaptive aerostructures result in some combination of lower power consumption, higher bandwidth, reduction in total aircraft empty weight, greater flight-speed, shock resistance, lower part count, lower cost etc. On normal occasions, adaptive aerostructures have ever been shown to be “enabling” that is, the aircraft class would not be able to fly without them.

In Chapter 2 an integrated, though cascaded Lyapunov-based adaptive backstepping approach is taken and used to design a flight path controller for nonlinear high-fidelity

F-16 model. Adaptive backstepping allows assuming that the aerodynamic force and moment models may not be known exactly, and even that they may change in flight due to causes as structural damage and control actuator failness. To simplify the mathematical approximation partition the flight envelope into multiple connecting operating regions, called hyperboxes, is proposed. In each hyperbox a locally valid linear-in-parameters nonlinear model is defined. The coefficients of these local models can be estimated using the update laws of the adaptive backstepping control laws. The number and size of the hyperboxes should be based on a priori information on the physical properties of the vehicle on hand, and may be defined in terms of state variables as Mach number, angle of attack and engine thrust. To interpolate between the local models to ensure smooth model transitions B-spline neural networks are used. Numerical simulations of various maneuvers with aerodynamic uncertainties in the model and actuator failures are presented. The maneuvers are performed at several flight conditions to demonstrate that the control laws are valid for the entire flight envelope.

In Chapter 3 a hybrid adaptive flight control method as another possibility to reduce the effect of high-gain control, is investigated. The hybrid adaptive control blends both direct and indirect adaptive control in a model inversion flight control architecture. The blending of both direct and indirect adaptive control is sometimes known as composite adaptation. The indirect adaptive control is used to update the model inversion controller by two parameter estimation techniques: 1) an indirect adaptive law based on the Lyapunov theory and 2) a recursive least-squares indirect adaptive law. The model inversion controller generates a command signal using estimates of the unknown plant dynamics to reduce the model inversion error. This directly leads to a reduced tracking error. Because the direct adaptive control only needs to adapt to a residual uncertainity, its adaptive gain can be reduced in order to improve stability robustness. Simulations of the hybrid adaptive control for a damaged generic transport aircraft and a pilot-in-loop flight simulator study show that the proposed method is quite effective in providing improved command tracking performance for a flight control system.

In Chapter 4 the purpose is to design a compensator using an evolutionary computing technique (i.e. generic algorithms) to compensate the interaction between control allocation and actuator dynamics.

The interaction of first order actuator dynamics and control allocation and the structure of the compensator is established for first order and second order actuator dynamics. The tuning of the compensator parameters using generic algorithm is described. Simulation and results for tuned compensator are shown for a range of first and second order actuator dynamics. At the end conclusions are established.

The second part of this book consists on four chapters (5, 6, 7, 8) dedicated to the fault tolerant flight control.

In Chapter 5 a physical modular approach, where focus is placed on the use of mathematical representation based on flight dynamics., is used. All variables and quantities which appear in the model have a physical meaning and thus are interpretable in this approach, and on avoids so called black and grey box models, where the content has no clear physical meaning. Besides the fact that this is a more transparent approach, allowing the designers and engineers to interpret data of each step, it is assumed that these physical models will facilitate certification for eventual future real life applications, since monitoring of data is more meaningfull. Adaptive nonlinear dynamic inversion is selected as the preferred adaptive control method in this modular or indirect approach. The advantage of dynamic inversion is the absence of any need for gain scheduling and an input-output decoupling of all control channels. Adaptation of the controller is achieved by providing up-to-date aerodynamic model information which is collected in a separate identification module.

In Chapter 6 an intelligent flight control system is presented that can discriminate between faults and natural disturbances in order to evaluate and deal with the situation. In the control system, an evaluator of flight conditions is designed on the basis of the dynamics of a controlled object. Moreover, to deal with the situation adaptively, a new flight-path-planning generator is introduced on the basis of the evaluation. In the study each system is designed by neural network. The learning based systematical design method is developed that uses evaluation functions for the subsystems. A six-degree-of-freedom nonlinear simulation is carried out.

In Chapter 7 a nonlinear UAV model, which allows simulating asymmetrical control surface failures is presented. In fault-free mode, a nominal control law based on an Eigenstructure assignment strategy is designed. As the control surface positions are not measured, a diagnosis system is performed with a bank of observers able to estimate the unknown inputs. However, as the two ailerons offer redundant effects, isolating a fault on these actuators requires an active diagnosis method. In the last part, a pre-computed F.T.C. strategy, dedicated to accommodate for a ruddervator failure, is depicted.

In Chapter 8 a scheme of a fault-tolerant flight control system is proposed. It is composed by the core control laws, based on the DAMF technique, to achieve both robustness and reconfiguration capabilities and the CA system, based on the active set method, to properly allocate the control effort on the healthy actuators. Numerical results of a case study with a detailed model of a large transport aircraft are reported to show the effectiveness of the proposed fault-tolerant control scheme.

The third part of this book consists on one chapter (9) dedicated to the acceleration based flight control.

In Chapter 9 the manoeuvre autopilot solution presented moves away from the more mainstream methods, recently reported in the literature and instead returns to the concept of acceleration control which has been commonly used in missile applications, and to a limited extent in aircraft applications, for a number of decades. However, whereas acceleration control has traditionally been used within the framework of linearized flight control (the aircraft or missile dynamics are linearized, typically about a straight and level flight condition), the algorithms and mathematics presented in this chapter extend the fundamental acceleration controller for operate equally effectively over the entire 3D flight envelope. The result of this extension is that the aircraft then reduces to a point mass with a steerable acceleration vector from a 3D guidance perspective. This abstraction which is now valid over the entire flight envelope is the key to significantly reducing the complexity involved in solving the manoeuvre flight control problem.

The fourth part of this book consists on three chapters (10, 11, 12) dedicated to helicopter flight control.