STUDIES ON PARAMETER ESTIMATION AND CONTRACTION BASED CONTROLLER DESIGN OF AIRCRAFT SYSTEM

by

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Certificate

This is to certify that the thesis entitled "**Studies on Parameter Estimation and Contraction Based Controller Design of Aircraft System**" being submitted by **Majeed M.** to the Department of Electrical Engineering, Indian Institute of Technology Delhi, for the award of the degree of Doctor of Philosophy is the record of the bonafide research work carried out by him under my supervision. In my opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree.

The results contained in this thesis have not been submitted either in part or full to any other university or institute for the award of any degree or diploma.

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Abstract

System Identification is the process of determining an adequate mathematical model of physical system, with unknown parameters which have to be determined from measured data. The knowledge of unknown parameters is very essential for controlling the behavior of system. Main motivation of the work presented in this thesis is to relook the established results in the field of parameter estimation and contraction theory analysis, and to explore their applications to aircraft systems. The challenge in parameter estimation to flight control is accurate estimation of flight control and stability parameters from noisy flight data. The estimation problem is difficult because of flight measured quantities available from airdata systems are erroneous due to uncertain environment, and poor quality of measured data. Following estimation problems, related to aircraft system, are addressed in the thesis.

1. Aircraft flow angles in airdata system are calibrated from the simulated data with wind and turbulence effects. The results are compared for various sensor fusion methods using Extended Kalman Filter (EKF) / Unscented Kalman Filter (UKF) algorithms.

2. Adaptive UKF is applied to flight test data for the estimation of aircraft aerodynamic parameters. The efficacy of the Adaptive UKF is compared with standard UKF. It was found that adaptive UKF is superior to standard UKF in the context of time varying noise characteristics.

3. Aerodynamic derivatives of flexible aircraft are identified by the incorporation of aeroelastic model in estimation algorithm, and selection of excitation input. Moreover, an attempt has also been made to identify the structural modes of aircraft from noisy measurements of differential accelerometers.

Finally, stochastic nonlinear observer is presented for the aircraft system using contraction theory. This theory provides a basic framework to analyze the stability of nonlinear systems

in an alternative way to the traditional Lyapunov based analysis. Along with that, this theory offers many significant advantages particularly in establishing exponential stability of stochastic dynamic system. In this connection, a frequency estimator is designed based on the stochastic contraction theory. An upper bound in estimation error is also derived in case of noisy measurements. In addition to this, attempt is also made to derive control law for an aircraft model in contraction framework. The control law is realized through the design of a stochastic observer. The contraction property of the overall closed loop system is proved. The efficacy of the various results presented in this thesis has been validated through the simulation studies.

Contents

3. Sensor fusion based approach for the calibration of flow angles in airdata systems

4. Adaptive UKF based recursive aerodynamic parameter estimation from flight data

5. Identification of aerodynamic derivatives of a flexible aircraft

8. Conclusions and further scope of the work

Appendix