Aircraft Safety: Control Upset Management

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Jorge L. Aravena, PI, Louisiana State University
Kemin Zhou, co-PI, Louisiana State University
Fahmida N. Chowdhury, co-PI, University of Louisiana, Lafayette
Xiong Rong Li, co-PI, University of New Orleans

Highlights of Year One

The first year of activity has been productive.

- We list a total of 21 papers published or submitted by members of the research team and that have been partially supported by our sponsors.
- We attended the annual SAAP-Industry meeting on March 5 – 7, 2002, in Hampton, VA.
- Langley's FOSS laboratory has generated data on strain tests that is being used as test bed for some fault signature techniques. And, in an exciting new twist, it is pointing to a new blind identification technique for fault detection.
- We have received a complete mathematical model of a B747 that is being used by all the SAAP partners.

The second year should prove even more successful. We have smoothed out the wrinkles in our collaboration methods; we have common experimental models. And we are preparing our first Louisiana Workshop on System Safety.

Sensor Fault Detection

For the problem of sensor fault detection, currently we are developing multiple-model algorithms with a variable structure that can intelligently detect and isolate fault and provide some early warning of deteriorated situations. One particular algorithm in this class, called expected-mode augmentation, has been developed over this past year. A brief description of this algorithm and its performance evaluation are given in [1]. A more extensive version of the description is being prepared for journal publication. We are actively seeking ways to improve the performance of several variable-structure multiple-model algorithms, as reported in [2, 3]. An important topic in multiple-model approach is the design of the model set. Along this line, we have developed several methods for the model set design that is described in [4, 5,6]. Another important topic is online adaptation of the model set. Several such adaptation schemes have been proposed or refined. We also started the task of "Implementing optimal decision rules for optimal use of hardware redundancy by advanced data fusion techniques" and also starting work on "Wald's sequential probability ratio test". First, we have conducted a fairly thorough literature search for change point detection, including those reported in [7] for target tracking, and tentatively identified that the solution techniques should most likely be based on the sequential statistical procedures we developed before for target detection, as described in [R1, R2, R3]. These procedures are based in turn on Wald's sequential probability ratio test.

REFERENCES CITED

[R1] A. G. Tartakovsky, X. R. Li, and G. Yaralov, “Sequential detection of targets in multichannel systems,” to appear as a regular paper in IEEE Transactions on Information Theory, 2002-2003.
[R2] A. G. Tartakovsky, X. R. Li, and G. Yaralov, “Sequential detection of targets in distributed systems,” Proc. 2001 SPIE Conf. Signal Processing, Sensor Fusion, and Target Recognition, Vol. 4380, Orlando, FL, April 2001.
[R3] A. G. Tartakovsky, X. R. Li, and G. Yaralov, “Invariant sequential detection and recognition of targets in distributed systems,” Proc. 2001 International Conf. Information Fusion, Montreal, QB, Canada, August 2001, pp. WeA3-11–WeA3-18.

Fault Early Warning

Research in Fault Early Warning has concentrated in the development of fault indicators using Signal Processing Techniques (DSP) and Residual-based techniques. In the DSP approach we have designed filters banks that decompose a given signal into any number of equal bands. The filters have been used on faulty data created by computer-simulated airplanes. Preliminary results appeared in [8]. There is an effort to use simulation and simplified models to estimate the sensitivity that can be achieved with a given filter bank. We are also analyzing the issue of false alarms that could be induced by external signals. The design method needs to be improved to create filters that can operate efficiently in real time. We are also developing enhanced signatures using pseudo power signatures [9]. One effort is directed to enhanced signatures using continuous wavelet transform and a frequency domain formulation. Partial results will appear in [10]. We are in the process of developing the necessary computational tools for this method.

Research on Residual-based techniques has focused on the design of dual loop identification schemes for aircraft. The concept was outlined in [11]. We have developed and successfully tested (via computer simulations) a dual-loop system-identification scheme for general dynamic systems. Of the two identification loops, one is based on neural networks (see [12], [13]) and the other, time-varying linear systems. Another enhancement of the dual-loop identification technique has been achieved: that of directly obtaining a state-space model from the experimental input-output data [14]. We have successfully implemented this model (estimated by a time-lagged neural network using back propagation through time) on the F-14 aircraft simulator.

Fault Tolerant Control

In the task of developing fault tolerant control algorithms, we have made some preliminary investigations into the robust and fault tolerant control system design using the proposed control architecture. Our numerical simulations and some simple experimental tests have shown significant improvement of the system performance over the conventional robust control design techniques. We have also tested some simple switching techniques that seem to be working well. These results are reported in [15, 16]. Further investigation of closed-loop system stability issues will be taken up in the next stage of research. However, we have noted that the switching techniques used in our framework are fundamentally different from the switching techniques used in adaptive control and other nonlinear control setups. Hence the stability due to switching appears not to be an issue in most cases. In addition to the control system design using the proposed architecture, we have also made significant progress in many other fronts of developing robust and fault tolerant control system design frameworks. We have developed a fast approach to construct the robustness degradation function due to model uncertainties, which describes quantitatively the relationship between the proportion of systems guaranteeing the robustness requirement and the radius of uncertainty set. This function can be applied to predict whether a controller design based on an inexact mathematical model will perform satisfactorily when implemented on the true system. This result is reported in [17]. We have also proposed a decentralized H_∞ control design technique through approximation [18]. We have shown that a decentralized H_∞ control problem as well as any fixed structured H_∞ control problem can be (conservatively) converted into a model approximation problem. We then propose some explicit parameterizations of the decentralized controllers and the final decentralized controllers are obtained through some convex optimization. Finally, we have developed a set of parametric optimization techniques that can effectively design stable H_2 and H_∞ controllers for MIMO systems, which are very critical in fault tolerant control system design, and solve multi-objective or mixed $L_1/H_2/H_\infty$ optimization problems [19, 20, 21]. Examples show the performance improvements of these algorithms over methods already presented in the literature.

Team Publications Partially Supported by Sponsor

[1] X. R. Li, V. P. Jilkov, J.-F. Ru, and A. Bashi, "Expected-mode augmentation algorithms for variable-structure multiple-model estimation," to appear in Proc. 2002 IFAC Congress, Barcelona, Spain, July 2002.

[2]X. R. Li, V. P. Jilkov, and L. Lu, "Performance enhancement of IMM estimation by smoothing," appear in *2002 International Conference on Information Fusion*, Annapolis, MD, July 2002.

[3] V. P. Jilkov and X. R. Li, "Bayesian estimation of transition probabilities for Markovian jump systems," Submitted to *IEEE Transactions on Signal Processing,* Feb 2002

[4] X. R. Li, "Model-set design for multiple-model estimation—part I," to appear in *2002 International Conference on Information Fusion*, Annapolis, MD, July 2002.

[5] X. R. Li, Z.-L. Zhao, P. Zhang, and C. He, "Model-set design for multiple-model estimation—part II: examples," to appear in *2002 International Conference on Information Fusion*, Annapolis, MD, July 2002.

[6] X. R. Li, Z. Zhao, P. Zhang and C. He, " Model-set design, choice and comparison for multiple-model approach to hybrid estimation." *Proc. Workshop on Signal Processing, Communications, Chaos and Systems*." Newport, RI, June 2002.

[7] X. R. Li and V. P. Jilkov, "A survey of maneuvering target tracking—Part V: decision-based methods," to appear in *Proc. 2002 SPIE Conf. Signal and Data Processing of Small Targets*, Vol. 4728-60, Orlando, FL, April 2002.

[8] J. L. Aravena and F. N. Chowdhury, "Fault Detection of Flight Critical Systems" Proc. 20th Digital Avionics Systems Conference in October 2001.

[9] J. L. Aravena, "Detecting Change Using Pseudo Power Signatures," in Proc. 2002 IFAC Congress, Barcelona, Spain, July 2002.

[10] Min Luo and J. L. Aravena, "Pseudo Power Signatures for Aircraft Fault Detection and Identification" in Proc. 21th Digital Avionics Systems Conference in October 2002.

[11] F. N. Chowdhury, "System Identification: Resolving the Conflict Between Fault Detection and Control," submitted to IEEE Transactions on Control System Technology, 2002.

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[13] F. N. Chowdhury, " A New Approach to Real-time Training of Dynamic Neural Networks," submitted to Int'l Journal Aut. Cont. Sys.

[14] F. N. Chowdhury, K. N. Rao, V. G. Siddhanti, "Obtaining Neural Networks Based State Space Models Using Time-Lagged Neurons," to be presented at Conference on Control Applications, Sept 2002.

[15] X. Chen, K. Zhou, and J. L. Aravena, Fast Construction of Robustness Degradation Function," submitted to IEEE Conference on Decision and Control, 2002.

[16] L. Li and K. Zhou, ``An approximation approach to decentralized H_∞ control," to appear in the 4th World Congress on Intelligent Control and Automation, Shanghai, China, June 10-14, 2002.

[17] D. U. Campos-Delgado and K. Zhou, ``Reconfigurable Fault Tolerant Control Using GIMC Structure," submitted to IEEE Transactions on Automatic Control, November 2001.

[18] K. Zhou and X. Chen, ``Are the Tradeoffs between Performance and Robustness Intrinsic for Feedback Systems," submitted to Systems and Control Letters, November 2001.

[19] D.U. Campos-Delgado and K. Zhou,``H_∞ and H_2 Strong Stabilization by Numerical Optimization,'' to be presented in IFAC, July 2002.

[20] D.U. Campos-Delgado and K. Zhou, ``A Parametric Optimization Approach to H_∞ and H_2 Strong Stabilization,'' Submitted to Automatica, September 2001.

[21] D. U. Campos-Delgado and K. Zhou, ``Mixed $L_1/H_2/H_\infty$ Control Design: Numerical Optimization Approaches," submitted to International Journal of Control, February 2002.