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Modeling and analysis of nonlinear control systems using exterior differential systems

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13. ABSTRACT (Maximum 200 words)

This is a final report for the staff research grant for Dr. Linda G. Bushnell, which started 9/30/1996 and ended 9/30/2000, when Dr. Bushnell left the US ARO. This was the first staff research grant funded for Dr. Bushnell. The subject of the research work was on hybrid control systems. This work resulted in 10 journal papers (submitted and/or published) and 11 conference papers. One Ph.D. student, Octavian Beldiman, who was fully funded by ARO for his Ph.D. work at Duke University under this grant and the subsequent staff research grant, completed his MS degree in 1999 and Ph.D degree in March 2001. One NRC Research Fellow, Dr. David Niemann, also worked on this research grant. He completed his NRC fellowship in January 1999.

14. SUBJECT TERMS
Hybrid control systems, distributed control networks.

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Enclosure 1

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Statement of the Problem Studied

This research investigates hybrid systems as heterogenous dynamical systems characterized by interacting continuous and discrete dynamics. The high-profile and safety-critical nature of the application areas, such as air traffic control and automated manufactureing and chemical process control, has fostered a large and growing body of work on formal methods for hybrid systems: mathematical logics, computational models and methods, and computer-aided reasoning tools supporting the formal specification and verification of performance requirements for hybrid systems, and the design and synthesis of control programs for hybrid systems that are provably correct with respect to formal specifications. This work continues to provide original contributions to the use of switching systems in the analysis of hybrid systems, specifically in the area of hybrid controller synthesis problems. Recent work formulates and robustly solved a quite general class of hybrid controller synthesis problems, focusing on the switching control mechanism of a hybrid automaton. The robustness result is with respect to variations in the right hand sides of the differential equations that depend continuously on a parameter. A novel methodology for controller design and synthesis which uses multi-model and multi-controller is developed.

The second aspect of this research deals with the subject of networked control systems. The development of networks creates the opportunity to bring multiple-input, multiple-output control system technology to application areas where the prohibitive cost of point-to-point wiring had previously barred its use. The primary characteristic of a networked control system (NCS) is having the feedback loop closed through a network. This networked architecture has many advantages compared to the traditional point-to-point design, the most preeminent ones being low cost of installation, ease of maintenance and greater flexibility. Applications where such architecture is already used include manufacturing plants, automobiles, and aircraft. Many standards are based on the automotive networking technology Control Area Network (CAN) because it is supported in a wide variety of devices from micro-controllers like the 6805 or 8051 variants, to digital signal processors such as the TMS320C24X series.

Summary of the Most Important Results

Significant progress was made in two new areas of research, hybrid control systems and networked control systems. Many papers were written and one Ph.D. student completed his dissertation work on this area.

Peer-Reviewed Journal Publications

1. Y. Hong, G. Yang, L. Bushnell, and H. Wang, "Global finite time control: from state feedback to output feedback," submitted to *IEEE Trans. Automatic Control*.

2. Y. Hong, H. Wang, and L. Bushnell, "Adaptive finite time control of nonlinear systems," submitted to *Int. J. of Control.*

3. H. Wang, Yiguang Hong, and L. Bushnell, "Nonsmooth bifurcation control: from fractional power control to trumpet bifurcation," submitted to *Int. J. of Bifurcation and Chaos.*

4. H. O. Wang, D. S. Chen and L. Bushnell, "Dynamic feedback control of bifurcations," (to appear) LAARJ.

5. H. Wang, Y. Hong, and L. Bushnell, "Nonsmooth feedback control of rotating stall in axial flow compressors," (to appear) *IEEE Trans. Control Systems Technology.*

6. G. Walsh, O. Beldiman and L. Bushnell, ``Error encoding algorithms for networked control systems," (to appear) *IEEE Trans. On Automatic Control.*

7. G. Walsh, O. Beldiman and L. Bushnell, ``Asymptotic behavior of nonlinear networked control systems," (to appear) *Automatica.*

8. G. Walsh, H. Ye and L. Bushnell, ``Stability Analysis of Network Control Systems," *IEEE Control Systems Technology* (to appear).

9. J. Li, H. Wang, L. Bushnell, Y. Hong, and K. Tanaka, "A fuzzy logic approach to optimal control of nonlinear systems," *International Journal of Fuzzy Systems*, vol. 2, pp. 153-161, 2000.

10. J. Li, H. O. Wang, L. Bushnell, Y. Hong, and K. Tanaka, "A Fuzzy Logic Approach to Optimal Control of Nonlinear Systems," *International Journal of Fuzzy Systems,* Vol. 1, No. 3, September 2000.

Conference Proceedings

1. O. Beldiman, L. G. Bushnell, G. C. Walsh, H. O. Wang and Y. Hong, "Perturbations in Networked Control Systems," submitted to ASME Symposium on Networked Control Systems: Modeling, Analysis and Control (New York, NY) November 2001.

2. Y. Gu, H. O. Wang, K. Tanaka and L. G. Bushnell, "Fuzzy control of nonlinear time-delay systems: stability and design issues," *Proceedings American Control Conference*, (Washington, D.C.) June 2001.

3. Y. Hong, H. O. Wang and L. G. Bushnell, "Adaptive finite-time control of nonlinear systems," *Proceedings American Control Conference*, (Washington, D.C.) June 2001.

4. Y. Gu, H. O. Wang, Y. Hong and L. G. Bushnell, "A Predictive Congestion Control Algorithm for High Speed Communication Networks," *Proceedings American Control Conference*, (Washington, D.C.) June 2001.

5. Y. Hong, G. Yang, L. G. Bushnell and H. O. Wang "Global finite-time stabilization: From state feedback to output feedback," *Proceedings 39th IEEE Conference on Decision and Control*, (Sydney) December 2000.

6. H. Ye, G. Walsh and L. Bushnell, ``Wireless Local Area Networks in the Manufacturing Industry," *Proceedings American Control Conference*, (Chicago) June 2000.

7. O. Beldiman, L. Bushnell and G. Walsh, ``Observers for Networked Control Systems," *Proceedings American Control Conference*, (Chicago), June 2000.

8. G. Walsh, O. Beldiman and L. Bushnell, ``Error encoding algorithms for networked control systems," *Proceedings 38th IEEE Conference on Decision and Control*, (Phoenix) December 1999.

9. G. Walsh, O. Beldiman and L. Bushnell, ``Asymptotic Behavior of Networked Control Systems," *Proceedings 1999 IEEE Conference on Control Applications*, (Hawaii) August 1999.

10. G. Walsh, H. Ye and L. Bushnell, ``Stability Analysis of Network Control Systems," *Proceedings American Control Conference*, (San Diego) June 1999.

11. O. Beldiman and L. Bushnell, ``Stability, linearization and control of switched systems," *Proceedings American Control Conference,* (San Diego), June 1999.

Participating Personnel

Dr. Linda G. Bushnell, US ARO and Duke University
Prof. Hua Wang, Professor, Duke University
Dr. David Niemann, NRC Fellow, Duke University
Dr. Octavian Beldiman, Mitsubishi Electronics (graduated May 2001, Duke University)
Mr. Dong Chen, MS degree awarded May 1999, Duke University
Dr. Jing Li, IBM (graduated May 2001, Duke University)
Mr. Yongru Gu, graduate student, Duke University

Report of Inventions

None

Enclosure 2

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SUBMITTED FOR PUBLICATION TO (applicable only if report is manuscript):

Sincerely,

Linda Bushnell & Hua Wang
Duke University

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