Journal of Nonlinear Systems and Applications (2013) 86–91

http://www.watam.org/JNSA/

STOCHASTIC SWITCHING RELIABLE CONTROL FOR A CLASS OF STOCHASTIC HYBRID SYSTEMS WITH STATE DELAY

Mohamad S. Alwan, Xinzhi Liu, and Wei-Chau Xie *†‡

Abstract. This paper deals with the design of a switching reliable control for a class of stochastic hybrid system with constant delay and nonlinear lumped uncertainties having linear-growth-type bounds. Two sets of actuators are considered; namely, a set of operational actuators that never fail, and a set of actuators that are susceptible to failure. The main objective here is to design a state feedback controller for each system mode such that, for all admissible nonlinear uncertainties and actuator failures occurring in a pre-specified subset of actuators, the closed-loop modes are exponential stable in the mean square (m.s.). Moreover, to maintain the stability property of the switched system, a dwell-time-type switching rule and the technique of multiple Lyapunov function together with the Razumikhin methodology are used. This approach leads to solving a set of algebraic Riccati-like equations. Finally, a numerical example with simulations is presented to illustrate the usefulness of the proposed control design.

Keywords. Reliable control, stochastic switching systems, time delay, multiple Lyapunov functions, Razumikhin methodology.

References

[1] J. Ackremann, *Sampled-Data Control Systems*. Springer-Verlag, New York, 1985.

[2] M.S. Alwan, X.Z. Liu, and W.-C. Xie, Robust reliable control for uncertain stochastic impulsive systems with time delay, *Proceedings of the International Conference on Dynamic Systems and Applications*, **6**, In press.

[3] M.S. Alwan, X.Z. Liu, and W.-C. Xie, On input-to-state stability of nonlinear stochastic hybrid systems, *Dynamics of Continuous, Discrete and Impulsive Systems-Series A*, **19**, pp 513-533, 2012.

[4] M.S. Alwan and X.Z. Liu, On stability of weakly nonlinear switched systems with time delay. *Mathematical and Computer Modelling*, **48**, pp. 1150-1157, 2008.

[5] X.-M. Cheng, W.-H. Gui, and Z.-J. Gan, Robust reliable control for a class of time-varying uncertain impulsive systems. *J. Cent. South University Technol.*, **12**, No. 1, pp. 199-202, 2005.

[6] C. De Persis, R. De Santis, and A.S. Morse, Switched nonlinear systems with state-dependent dwell-time. *Systems and Control Letters*, **50**, pp. 291-302, 2003.

*Mohamad S. Alwan and Xinzhi Liu are with Department of Applied Mathematics, University of Waterloo, Canada. E-mails: malwan@uwaterloo.ca, xzliu@uwaterloo.ca

†Wei-Chau Xie is with Department of Civil and Environmental Engineering, University of Waterloo, Canada. E-mail: xie@uwaterloo.ca

‡Manuscript received September 2012; revised August 2013.

[7] D.D. Driver, *Ordinary and Delay Differential Equations*. Springer-Verlag, New York, 1977.

[8] J. Gao, B. Huang, Z. Wang, and D.G. Fisher, Robust reliable control for a class of uncertain nonlinear systems with time-varying multistate time delays. *International Journal of Systems Sciences*, **32**, No. 7, pp. 817-824, 2001.

[9] T.C. Gard, *Introduction to Stochastic Differential Equations*, Marcel Dekker, 1988.

[10] K. Gopalsamy, *Stability and Oscillations in Delay Differential Equations of Population Dynamics*. Kluwer Academic Puplisher, Netherlands, 1992.

[11] A. Halanay, *Differential Equations: Stability, Oscillations, Time Lags*. Academic Press Inc., New York, 1966.

[12] J.K. Hale, *Functional Differential Equations*. Springer-Verlag, New York, 1971.

[13] J.K. Hale and S.M.V. Lunel, *Introduction to Functional Differential Equations*. Springer-Verlag, New York, 1993.

[14] R.Z. Hasminskii, *Stochastic Stability of Differential Equations* (Translated by D. Louvish). Sijthoff and Noordhoff, Netherlands, 1980.

[15] J.P. Hespanha and A.S. Morse, Stability of switched systems with average dwell-time. *Proceeding of the* 38^{th} *IEEE Conference on Decision and Control*, Phoenix, AR, pp. 2655-2660, 1999.

[16] B. Hu, X. Xu, A.N. Michel, and P.J. Antsaklis, Stability analysis for a class of nonlinear switched systems. *Proceeding of the* 38^{th} *IEEE Conference on Decision and Control*, Phoenix, AR, pp. 4374-4379, 1999.

[17] Y. Kuang, *Delay Differential Equations and Applications in Population Dynamics*. Academic Press Inc, CA, 1993.

[18] X. Luo, L. Yang, H. Yang, and X. Guan, Robust reliable control for neutral delay systems. *Proceeding of the 6th World Congress on Intelligent Control and Automation*, June 21-23, Dalian, China, pp. 144-148, 2006.

[19] X. Mao, *Exponential Stability of Stochastic Differential Equations*, Marcel Dekker, 1994.

[20] X. Mao, *Stochastic Differential Equations and Applications*. Horwood Publishing Limited, England, 2008.

[21] A.S. Morse, Supervisory control of families of linear set-point controllers-part I: exact matching. *IEEE Transactions on Automatic Control*, **41**, No. 10, pp. 1413-1431, 1996.

[22] C.-J. Seo, and B.K. Kim, Robust reliable H_∞ control for linear systems with parameter uncertainty and actuator failure. *Automatica*, **32**, pp. 465-467, 1996.

[23] R.J. Veillette, J.V. Medanic, and W.R. Perkins, Design of reliable control systems, *IEEE Transactions on Automatic Control*, **37**, No. 3, pp. 290-304, 1992.

[24] R.J. Veillette, Reliable state feedback and reliable observers, *Proceedings of the 31st Conference on Decision and Control*, Tucson, AZ, pp. 2898-2903, 1992.

[25] Z. Wang, B. Huang, and H. Unbehauen, Robust reliable control for a class of uncertain nonlinear state-delayed systems. *Automatica*, **35**, pp. 955-963, 1999.

[26] Z. Wang, B. Huang, and K.J. Burnham, Stochastic reliable control of a class of uncertain time-delay systems with unknown nonlinearities. *IEEE Transactions on Circuits and Systems-1: Fundamental Theory and Applications*, **48**, No. 5, pp. 646-650, 2001.

[27] Z. Wang, H. Shu, and X. Liu, Reliable stabilization of stochastic time-delay systems with nonlinear disturbance, *International Journal of General Systems*, **34**, No. 5 pp. 523-535, 2005.

[28] J. Wang, and H. Shao, Delay-dependent robust and reliable H_∞ control for uncertain time-delay systems with actuator failurs, *Journal of the Franklin Institute*, **337**, pp. 781-791, 2000.

[29] G.-H. Yang, J.L. Wang, and Y.C. Soh, Reliable H_∞ control design for linear systems, *Automatica*, **37**, pp. 717-725, 2001.