Constructive Architectures for Digital Controllers of Continuous Time

Systems (Kottenstette)

We have recently demonstrated how to interconnect either a linear or non-linear interior-conic continuous time systems (in which passive systems are a special case) to an appropriately con-strained conic digital controller in which continuous time stability (Lm2-stability) can be guaranteed in spite of time varying delay. The key to achieving a stronger result and further weaken our initial passivity assumptions of the continuous time system is to explicitly consider the resulting conic-system properties resulting from the feed-back loops created from our use of wave-variables. Initial results demonstrate improved rejection of high-frequency noise which can be effectively filtered with multi-rate passive samplers (PS:MTs) and passive hold devices (PH:M Ts) while achieving better performance over traditional sample-and-hold digital control systems. As a result, we can now control the position of robotic-arm-manipulators using direct position feedback instead of indirect velocity feedback. In addition we have shown that the inner-product-equivalent-sampler and zero-order-hold (IPESH) not only preserves passivity properties of a given system but preserves the more general interior-conic system properties as well. The implication is that like the bilinear-transform which preserves both passivity and stability properties when mapping a continuous linear time invariant (LTI) system to a discrete LTI system, the IPESH in general preserves stability for non-linear interior conic systems such that if the IPESH is applied to a continuous interior conic system which is inside the sector [a,b] then the resulting discrete-time system whose output is scaled by (1/Ts) remains inside the sector [a,b]. These results should extend to those related to control over power-junction-networks.

Some of our past reported work related to control over power-junction-networks will appear in IJSCC’s Special Issue on Progress in Networked

Control Systems. However new results involving these control networks continue to be discovered. We have demonstrated that a simplified linear-power- junction-network can be used in distributed deployment of point-mass systems whose inertial position control system closely resembles that used to control position for our quad-rotor aircraft. Furthermore a resilient-power-junction-network has also been demonstrated to allow a single plant to be reliably controlled by many redundant digital controllers in order to better withstand both denial-of-service (DOS) attacks and even safely handle certain compromises of the redundant controllers. The linear-power-junction-network appears to be a good candidate for networked control of quad-rotor aircraft as well as fixed-wing aircraft.

In order to better study formation control of fixed wing aircraft for a potential aerial refueling scenario posed at our 2009 review we had to develop an inertial control system and model of a fixed wing aircraft. Therefore we developed and verified an advanced Simulink-based fixed-wing model of the Cessna A-37 whose velocity flight-path and heading angles were maintained by a resilient backstepping control law. The backstepping control law was derived using a simplifying small-angle assumption involving the angle of attack and bank angle while maintaining the side-slip angle near zero. It achieves performance close to its adaptive counterparts while al-lowing for system model verification. In addition we demonstrated that if we filter one of the feedback terms typically required to achieve asymptotic stability results for our backstepping controller then we could better withstand discrete time wind gusts. In general we proved our backstepping control law can be applied not only to the control of fixed-wing aircraft but other non-linear systems which posses triangular structures and invertible controller affine terms. Finally, we demonstrated that a classical anti-windup compensator can be applied to the velocity control system when subject to control thrust saturation which can occur during aggressive maneuvers. Using the small angle assumption allowed us to significantly simplify our backstepping control law for our fixed-wing aircraft, however, the quad-rotor aircraft control system was still much less complicated. Although both systems share the same kinematic equations of motion, the fixed-wing aircraft dynamics depend heavily on the wind velocity vector. As a result it is not clear how to exploit the passivity like subsystems related to the kinematics in order to simplify the control design as was done for the quad-rotor aircraft. However, one technique to simplify controller design which looks promising is Interconnection Damping Assignment Passivity Based Control (IDA-PBC).

IDA-PBC attempts to derive control laws which attempt to exploit the passivity like proper-ties of a system in order to derive a dissipative structure which achieves asymptotic stability. Unlike backstepping control laws, IDA-PBC is not as an aggressive method in attempting to cancel non-linear terms in the system in order to make it appear as a cascade of integrators. As a result the IDA-PBC control laws are typically less computationally intensive and possess more linear feed-back terms similar to those seen with our quad-rotor control system. Therefore, we have studied, implemented and refined an IDA-PBC control algorithm initially presented by Johnsen & Allgower related to the control of a four-tank process. We have developed preliminary tools to automatically generate IDA-PBCs while providing improved integrator anti-windup compensators. Furthermore we determined that the bilinear-transform works quite well in implementing low-sampling rate (possibly non-linear) integrator terms in theses IDA-PBCs. Furthermore IDA-PBC allows us to determine explicit gain and trajectory constraints to apply to our controller implementation in order to further improve system resilience.

Publications

1. Kottenstette, N., Hall, J., Koutsoukos, X., Antsaklis, P., and

Sztipanovits, J., “Digital control of multiple discrete passive plants over networks”, International Journal of Systems, Control and Communications (IJSCC), (Special Issue on Progress in Networked Control Systems (To Appear)) URL:

<http://www.isis.vanderbilt.edu/sites/default/files/tr_power_junction_revised_8_2009.pdf>.

2. Kottenstette, N. and Antsaklis, P.J. “Relationships between positive real, passive dissipative, & positive systems”, in American Control Conference – ACC2010, 1–8., Baltimore, Maryland, USA.

3. Kottenstette, N., "Constructive non-linear control design with applications to quad-rotor and fixed-wing aircraft", Technical Report, Nashville, TN, Institute for Software Inte-grated Systems, Vanderbilt University, 01/2010.

4. Kottenstette, N., Porter, J., "Backstepping Control Design with Applications to Fixed-Wing Aircraft", (under review CDC 2010).

5. Kottenstette, N., G. Karsai, and J. Sztipanovits, "A Passivity-Based Framework for Resilient Cyber Physical Systems", ISRCS 2009 2nd International Symposium on Resilient Control Systems, Idaho Falls, ID, IEEE, 08/2009.

6. Kottenstette, N., Porter, J., Karsai, G. and Sztipanovits, J., “Discrete-Time IDA-Passivity Based Control of Coupled Tank Processes Subject To Actuator Saturation”, 3rd International Symposium on Resilient Control Systems (ISRCS 2010), Under Review.

7. LeBlanc, H., Eyisi, E., Kottenstette, N., Koutsoukos, X., and Sztipanovits, J., "A passivi-ty-based approach to deployment in multi-agent networks." In Proceedings of the 7th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2010). SciTePress, Funchal, Madeira - Portugal. URL: <http://www.isis.vanderbilt.edu/sites/default/files/ICINCO_2010_265_CR_press.pdf>.

8. Kottenstette, N., H. LeBlanc, E. Eyisi, and X. Koutsoukos, "Multi Rate Networked Control of Conic Systems", Technical Report, Nashville, TN, Institute for Software Integrated Systems, Vanderbilt University, 09/2009 (revised and under review CDC 2010): <http://www.isis.vanderbilt.edu/sites/default/files/tr_quantization_revised_4_2010.pdf>.

Participation/presentations at meetings, conferences, seminars

1. HCDDES Review Meeting, December, 2009, Berkeley. Nicholas Kottenstette presented “Constructive Non-linear Control Design with Applications to Quad-Rotor and Fixed-Wing Aircraft”.

2. 7th IEEE International Conference on Control and Automation, December, 2009, Christ-church, New Zealand. Nicholas Kottenstette presented “Digital Passive Attitude and Altitude Control Schemes for Quad-rotor Aircraft” while chairing the session on Aircraft Control and Aerodynamical Systems.

3. 1st IFAC Workshop on Estimation and Control of Networked Systems (NecSys 2009), Venice, Italy. Nicholas Kottenstette presented “Lm2-Stable Digital-Control Networks for Multiple Continuous Passive Plants”.

4. 2nd International Symposium on Resilient Control Systems (ISRCS

2009), Idaho Falls, ID. Nicholas Kottenstette presented "A Passivity-Based Framework for Resilient Cyber Physical Systems".

5. SIAM Conference on Control and its Applications (CT09), Denver, CO. Nicholas Kottenstette Chaired the Session on Constructive Methods for High Confidence Networked Control Systems: <http://meetings.siam.org/sess/dsp_programsess.cfm?SESSIONCODE=8532>.

6. Dynamics & Control Program Review (July 2009) Washington, D.C. Nicholas Kottenstette presented on “Frameworks and Tools for High-Confidence Design of Adaptive, Distributed Embedded Control Systems” with contributions from Bruce Krogh & Gabor Karsai.