Supervisory Control of Nonlinear Systems

João P. Hespanha

`hespanhaece.ucsb.edu`

Center for Control Dynamical Systems and Computation
University of California, Santa Barbara

The control of nonlinear systems with large uncertainty is especially challenging. In spite of this, significant progress has been made in the area of multi-model supervisory control.

The most general results available for nonlinear processes relate to scenarios in which (i) all uncertainty is parametric with a known functional dependence of the state-space model with respect to the unknown parameter, and (ii) there is no measurement noise nor disturbances. Under this admittedly restrictive assumptions the results available are quite general. In [6] and related papers, a general procedure was outlined that allows the design of provably stable supervisory controllers for nonlinear systems. This procedure relies on nonadaptive techniques for control and estimation for which there is a wealth of results in the nonlinear control literature. In particular, one needs the following two ingredients:

1. For each possible value of the parameter, one needs to know how to design a (nonadaptive) controller that would stabilize the process if the parameter value was known. Such controller should be able to guarantee input-to-state stability with respect to an appropriately introduced disturbance.

2. For each value of the parameter, one needs to know how to design a (nonadaptive) output estimator for the process that would converge to the process output if the parameter value was known. This is a trivial matter when the whole state of the process can be measured, but can still be challenging for nonlinear systems for which the state cannot be measured.

When the parameter set in infinite, current results also require that the (nonadaptive) controllers exhibit some robustness with respect to small parameter variations, i.e., there must exist a small but positive constant ϵ such that the controller designed for the value p of the unknown parameter, stabilizes any process with parameter q in a ball of radius ϵ centered at p. This type of robustness generally comes for free when we have exponential stability and globally Lipschitz vector fields, but can disappear for weaker forms of stability or vector fields that are only locally Lipschitz.

The main challenge that remains open in the supervisory control of nonlinear systems is robustness with respect to noise/disturbances. Although, the algorithms appear to work well in the presence of noise, few stability results are available. This is perhaps not surprising in view of the fact that there are few systematic procedures to design controllers/estimators for nonlinear systems that are robust with respect to noise. In addition, there are also few results to analyze the closed-loop switched nonlinear systems that arise as one switches among different controllers.

We believe that, from the perspective of a stability analysis, addressing issues related to unmodeled dynamics will not be hard once one discovers how to deal with disturbances/noise. This expectation stems from the conjecture that proving robustness with respect to unmodeled dynamics will have to rely on small-gain arguments. This is also supported by the techniques used to address unmodeled dynamics in the linear context [7].

Finally, one should add that in spite of the theoretical difficulties, supervisory control has been successfully used in the context of several applications that exhibit strong nonlinearities. In our work, we used these techniques to control underactuated underwater vehicles [1], pH neutralization processes [2], field-oriented control of induction motors [3], unicycle robots [5], etc.

We refer the reader to the tutorial [4] for more details on linear and nonlinear supervisory control.

References

[1] A. P. Aguiar and J. P. Hespanha. Trajectory-tracking and path-following of underactuated autonomous vehicles with parametric modeling uncertainty. *IEEE Trans. on Automat. Contr.*, Sept. 2007. To appear.

[2] J. M. Böling, D. E. Seborg, and J. P. Hespanha. Multi-model adaptive control of a simulated pH neutralization process. *Contr. Eng. Practice*, 2007. To appear.

[3] G. Chang, J. P. Hespanha, A. S. Morse, M. Netto, and R. Ortega. Supervisory field-oriented control of induction motors with uncertain rotor resistance. *Int. J. of Adaptive Contr. and Signal Processing,* Special Issue on Switching and Logic, 15(3):353–375, May 2001.

[4] J. P. Hespanha. Tutorial on supervisory control. Lecture Notes for the workshop *Control using Logic and Switching* for the 40th Conf. on Decision and Contr., Orlando, Florida, Dec. 2001. Available at `http://www.ece.ucsb.edu/~hespanha/published`.

[5] J. P. Hespanha, D. Liberzon, and A. S. Morse. Logic-based switching control of a nonholonomic system with parametric modeling uncertainty. *Syst. & Contr. Lett.,* Special Issue on Hybrid Systems, 38(3):167–177, Nov. 1999.

[6] J. P. Hespanha, D. Liberzon, and A. S. Morse. Supervision of integral-input-to-state stabilizing controllers. *Automatica*, 38(8):1327–1335, Aug. 2002.

[7] A. S. Morse. Supervisory control of families of linear set-point controllers—part 2: robustness. *IEEE Trans. on Automat. Contr.*, 42(11):1500–1515, Nov. 1997.