

**Final Report of Parma's Research Unit on
High-performance Control Methods for Constrained Systems
Research Project supported by MIUR
(December 2006 – January 2009)**

Parma's team has devoted its research efforts to the following topics:

- *Optimal minimum-time feedforward control for systems with amplitude constraints on inputs and outputs* – Algorithms using Chebyshev polynomials for linear systems have been proposed in [1,2,3,23,28]. A geometric approach for nonlinear systems with convex accessibility set is exposed in [4,5].
- *Feedforward/feedback schemes for high-performance control systems* – An approach using generalized bang-bang control is presented [6]. Inversion-based control designs are reported in [7,8,9,10,11,29].
- *Dynamic inversion for the control of nonlinear systems* – A new method for nonlinear nonminimum-phase systems has been proposed for the control of VTOL models (vertical take-off and landing aircrafts) and for the control of a bi-dimensional inverted pendulum [12,13,14]. Homotopy methods for exact tracking have been proposed in [25,27,33,34,36]. A new polynomial-spline method for the motion planning of wheeled mobile robots has been presented in [15].
- *Path following for nonlinear nonminimum-phase systems* – A feedback controller to achieve path following of a PVTOL model (planar vertical take-off and landing aircraft) has been designed using the ideas of transverse feedback linearization, finite time stabilization and virtual constraints [32,35].
- *Applications* – A Plug&Control strategy for industrial controllers [16]. Bang-bang generalized control for mechatronic systems [17,26]. Minimum-time control of wheeled mobile robots [18]. Decentralized control in formations of wheeled mobile robots [19,20,21,22]. Advances on PID control [24,30,31,38]. Regulation of magnetic levitation systems [37].

Publications

1. S. Piccagli, A. Visioli, "Using a Chebyshev technique for solving the generalized bang-bang control problem", *IEEE International Conference on Decision and Control*, New Orleans (LA), pp. 4743-4748, December 2007.
2. S. Piccagli, A. Visioli, "Minimum-time feedforward plus PID control using a Chebyshev technique", *IEEE International Conference on Decision and Control*, New Orleans (LA), pp. 1795-1800, December 2007.
3. S. Piccagli, A. Visioli, "Minimum-time feedforward plus PID control for MIMO systems", *17th IFAC World Congress*, Seul (ROK), July 2008.
4. L. Consolini, O. Gerelli, "A geometric approach to minimum-time control based on convexity", *In Proc. of the European Control Conference*, pages 3379–3384, July 2007.
5. L. Consolini, O. Gerelli, "An algorithm for minimum-time feedforward control based on convexity", *In Proc. of the IEEE 2007 Conference on Decision and Control*, December 2007.
6. L. Consolini, A. Piazzzi, A. Visioli, "Minimum-time feedforward control for industrial processes", *In Proc. of the European Control Conference*, pages 5282–5287, July 2007.

7. A. Piazzzi, A. Visioli, "Combining H-infinity control and dynamic inversion for robust constrained set-point regulation", *International Journal of Tomography & Statistics*, Vol. 6, No. S07, pp. 63-68, 2007.
8. A. Visioli, A. Piazzzi, "A toolbox for input-output system inversion", *International Journal of Computers, Communication and Control*, Vol. 2, No. 4, pp. 375-389, 2007.
9. A. Piazzzi, A. Visioli, "An iterative approach for noncausal feedforward tuning", *American Control Conference*, New York (NY), pp. 1251-1256, July 2007.
10. A. Piazzzi, A. Visioli, "Iterative feedforward tuning for residual vibration reduction", *17th IFAC World Congress*, Seul (ROK), July 2008.
11. C. Carnevale, A. Piazzzi, A. Visioli, "A methodology for integrated system identification, PID controller tuning and noncausal feedforward control design", *17th IFAC World Congress*, Seul (ROK), July 2008.
12. L. Consolini, M. Tosques, "On the VTOL aircraft exact tracking with bounded internal dynamics via a Poincarè map approach", *IEEE Transaction on Automatic Control*, Vol. 52, No. 9, pp.1757-1762, 2007.
13. L. Consolini, M. Tosques, "On the existence of small periodic solutions for the 2-dimensional inverted pendulum on a cart", *SIAM Journal on Applied Mathematics*, Vol. 68, No. 2, pp. 486-502, 2007.
14. L. Consolini, M. Tosques, "A morphing method for exact tracking control of nonminimum phase non linear systems", *In Proc. of the IEEE 2007 Conference on Decision and Control*, December 2007.
15. A. Piazzzi, C. Guarino Lo Bianco, M. Romano, "Eta3-splines for the smooth path generation of wheeled mobile robots", *IEEE Transaction on Robotics*, Vol. 23, No. 5, pp. 1089-1095, October 2007.
16. A. Visioli, "Experimental evaluation of a time-optimal Plug&Control strategy", *ISA Transactions*, Vol. 46, pp. 519-525, 2007.
17. L. Consolini, O. Gerelli, C. Guarino Lo Bianco, A. Piazzzi, "Minimum-time control of flexible joints with input and output constraints", *In Proc. of the ICRA 2007 International Conference on Robotics and Automation*, pages 3811-3816, April 2007.
18. S. Piccagli, T. van den Boom, A. Visioli, "Minimum-time control of a two-wheeled differentially driven vehicle in the presence of slip", *17th IFAC World Congress*, Seul (ROK), July 2008.
19. F. Morbidi, L. Consolini, D. Prattichizzo, M. Tosques, "Leader-follower formation control as a disturbance decoupling problem", *In Proc. of the European Control Conference*, pages 1492-1497, July 2007.
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21. L. Consolini, F. Morbidi, D. Prattichizzo, M. Tosques, "Steering hierarchical multirobot formations of unicycle robots", *In Proc. of the IEEE 2007 Conference on Decision and Control*, December 2007.
22. L. Consolini, F. Morbidi, D. Prattichizzo, M. Tosques, "Leader-follower formation control of nonholonomic mobile robots with input constraints", *Automatica*, 44(5):1343-1349, 2008.
23. S. Piccagli, A. Visioli, "An optimal feedforward control design for the set-point following of MIMO processes", *Journal of Process Control*, in press, 2009.

24. M. Veronesi, A. Visioli, "Performance assessment and retuning of PID controllers", *Industrial and Engineering Chemistry Research*, Vol. 48, No. 5, pp. 2616-2623, 2009.
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32. C. Nielsen, L. Consolini, M. Maggiore, M. Tosques, "Path following for the PVTOL: A set stabilization approach", *In CDC 08, Control and Decision Conference*, pages 584-589, December 2008.
33. L. Consolini, M. Tosques, "On the exact tracking of the spherical inverted pendulum via an homotopy method", *In Control and Automation, 2008 16th Mediterranean Conference on*, pages 1077-1082, June 2008.
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35. L. Consolini, M. Maggiore, M. Tosques, C. Nielsen, "On the solution of the path following problem for the PVTOL aircraft", *In ACC 09, American Control Conference*, 2009, accepted.
36. L. Consolini, M. Tosques, "An homotopy method for exact tracking of nonlinear nonminimum phase systems: the example of the spherical inverted pendulum", *In ACC 09, American Control Conference*, 2009, accepted.
37. A. Di Fluri, A. Piazzzi, A. Visioli, "Feedforward/feedback control of a magnetic levitation apparatus", *In European Control Conference*, 2009, accepted.
38. M. Beschi, A. Piazzzi, A. Visioli, "On the practical implementation of a noncausal feedforward technique for PID control", *In European Control Conference*, 2009, accepted.