

FINAL REPORT

Student name: Irene Zorzan

Cycle: XXX

Curriculum: Scienza e Tecnologia dell'Informazione

Supervisor name: Professor Maria Elena Valcher

Thesis title (final): On the Stability, Stabilizability and Control of Certain Classes of Positive Systems

PART 1 - COURSES, CONFERENCES AND MOBILITY

Courses for Ph.D. students

- Applied Functional Analysis
- Computational Inverse Problems
- Applied Linear Algebra
- Statistical Methods

Summer schools, short courses, tutorials

- SIDRA Summer School (Bertinoro, July 13-18 2015) on the themes "Robot Control" and "Underwater Robotics"
- SIDRA Summer School (Bertinoro, July 11-16 2016) on the themes "Robust and constrained control" and "Distributed Control and its applications"
- SIDRA Summer School (Bertinoro, July 3-8 2017) on the themes "Formal methods for the control of large-scale networked nonlinear systems with logic specifications" and "Port-Hamiltonian modelling and passivity-based control of physical systems. Theory and applications"

Seminars

- See the attached file.

Participation to International Conferences and Workshops

- 54th IEEE Conf. on Decision and Control, Osaka, Japan, December 15-18, 2015
- 2016 American Control Conference, Boston, MA, USA, July 6-8, 2016
- Process Control Workshop, Lund University, Lund, Sweden, September 28-30, 2016

Other learning activities

- Tutor Junior for the course "Systems and models" (course coordinator Professor Gianna Maria Toffolo) for the Bachelor Degree in Information Engineering, Academic Year 2015-2016
- Peer Tutoring for first year students of the Bachelor Degree in Biomedical Engineering, Academic Year 2015-2016 (project coordinator Lorenza Da Re)

Mobility periods

- September 20th, 2016 – June 29th, 2017: research period on the topic "Optimal Control of Positive Bilinear Systems", under the supervision of Professor Anders Rantzer at the Department of Automatic Control of Lund University

PART 2 - RESEARCH ACTIVITY

Research activity mainly focused on the study of stability, stabilizability and other control issues for certain classes of positive systems. In particular, the main problems addressed are briefly described as follows:

- *Stability analysis for Compartmental Switched Systems:* for the class of positive switched systems with autonomous compartmental subsystems both stability under arbitrary switching and stability under dwell time switching have been investigated. It has been proved that, differently from the general class of positive switched systems, Hurwitz stability of all the subsystem matrices is enough to guarantee asymptotic convergence to zero of all the state trajectories, independently of the positive initial condition and of the switching function. In addition, for the case when one at least of the subsystem matrices is not Hurwitz, classes of switching functions that drive to zero the state trajectory independently of the positive initial condition have been identified.
- *Stabilizability of Compartmental Switched Systems:* first, for Compartmental Switched Systems with autonomous subsystems, the problem of assessing the existence, for every positive initial condition, of a stabilizing switching function has been addressed and proved to be equivalent to the existence of a Hurwitz convex combination of the subsystem matrices. Secondly, for the class of Compartmental Switched Systems with single-input subsystems, state-feedback and output-feedback stabilizability have been completely characterized in terms of the nonzero patterns of the matrices involved in the system description.
- *Stabilization of Multi-Input Compartmental Systems:* for Multi-Input Compartmental Systems the problem of designing a state-feedback matrix that preserves the compartmental property of the resulting closed-loop system, meanwhile achieving asymptotic stability has been investigated. Differently from the single-input case, problem solvability depends not only on the nonzero patterns of the matrices involved in the system description but also on their specific entries. An algorithm that allows to verify, through the solution of a sequence

of very simple Linear Programming problems, when the problem is solvable, and to produce a possible solution has been proposed.

- *Positive Consensus Problem*: for a homogeneous group of positive single-input agents, solving the positive consensus problem means determining a common state-feedback law that each agent can individually implement in such a way that consensus is achieved and the positivity of the overall system is preserved. Under the assumption that mutual interactions among agents are cooperative, conditions that are either necessary or sufficient for the problem solvability have been provided. Special conditions either on the system description or on the Laplacian of the communication graph have been identified that allow to obtain necessary and sufficient conditions for the problem solvability.
- *Optimal Control of Positive Bilinear Systems*: focusing on a particular class of Positive Bilinear Systems that is used to design drugs concentration for HIV treatment, the problem of determining an optimal constant input that stabilizes the system while maximizing its robustness against the presence of the external disturbance has been addressed. Specifically, when considering the L1-norm of the transfer function matrix as robustness measure, a convex formulation for the optimal control problem has been provided. For the case when the H-infinity norm of the system transfer matrix is taken as robustness measure, an algorithm based on the iterative solution of a convex feasibility problem that approximates an H-infinity optimal controller with arbitrary accuracy has been proposed.
- *Stabilization via periodic switching of Positive Switched Systems for traffic modelling*: stabilization via periodic switching has been investigated for a particular class of Positive Switched Systems associated with triangular and quadrangular junctions governed by traffic lights. In particular, stabilizing periodic switching sequences have been characterized in terms of system parameters describing the rates at which vehicles tend to accumulate at red lights and queues tend to zero at green lights. The problem is currently under investigation.

Another research topic, not directly connected to positive systems, is represented by consensus under arbitrarily switching for a homogeneous multi-agent system with switching communication topology. Under the assumption that each agent is described by a general (not necessarily positive) single-input stabilizable state-space model, and that the communication graph is connected at every time-instant, it has been proved that consensus can always be achieved. In addition, an algorithm to construct a constant state-feedback controller that makes the agents reach consensus has been proposed.

PART 3 - PUBLICATIONS

List of publications on international journals

- J1. M.E. Valcher, and I. Zorzan "Stability and stabilizability of continuous-time compartmental switched systems", IEEE Transactions on Automatic Control, vol. 61, issue 12, pp. 3885-3897, 2016. DOI: 10.1109/TAC.2016.2525016

- J2. M.E. Valcher, and I. Zorzan "On the consensus of homogeneous multi-agent systems with positivity constraints", IEEE Transactions on Automatic Control, DOI: 10.1109/TAC.2017.2691305
- J3. M.E. Valcher, and I. Zorzan "On the consensus of homogeneous multi-agent systems with arbitrarily switching topology", Automatica (Brief Paper), vol.84, pp. 79-85, October 2017. <https://doi.org/10.1016/j.automatica.2017.07.011>
- J4. M.E. Valcher, and I. Zorzan "State-feedback stabilization of multi-input compartmental systems", submitted to Systems and Control Letters, 2017

List of publications on conference proceedings

- C1. M.E. Valcher, and I. Zorzan "On the stabilizability of continuous-time compartmental switched systems", Proceedings of the 54th IEEE Conf. on Decision and Control, Osaka, Japan, pp. 4246-4251, December 15-18, 2015.
- C2. M.E. Valcher, and I. Zorzan "On the consensus problem with positivity constraints", Proceedings of the 2016 American Control Conference, pp. 2846-2851, July 6-8, Boston, MA, 2016
- C3. M.E. Valcher, and I. Zorzan "New results on the solution of the positive consensus problem", Proceedings of the 55th IEEE Conf. on Decision and Control, pp. 5251-5256, Las Vegas, Nevada, December 12-14, 2016.
- C4. M.E. Valcher, and I. Zorzan "On the state-feedback stabilisation of compartmental systems", (accepted) to be presented at the 56th IEEE Conf. on Decision and Control, Melbourne, Australia, December 12-15, 2017.
- C5. I. Zorzan, and A. Rantzer "L1 and H-infinity Optimal Control of Positive Bilinear Systems", (accepted) to be presented at the 56th IEEE Conf. on Decision and Control, Melbourne, Australia, December 12-15, 2017.

List of other publications (books, book chapters, patents)

- B1. M.E. Valcher, and I. Zorzan "Positive consensus problem: the case of complete communication", (plenary paper at 5th International Symposium on Positive Systems, September 14-16, 2016), in Positive Systems, Lecture Notes in Control and Information Sciences, Filippo Cacace, Lorenzo Farina, Roberto Setola and Alfredo Germani Eds., Chapter 19, pp. 239-252, 2017, ISBN 978-3-319-54210-2
- B2. M.E. Valcher, and I. Zorzan "Continuous-time Compartmental Switched Systems", (invited paper at 5th International Symposium on Positive Systems, September 14-16, 2016) in Positive Systems, Lecture Notes in Control and Information Sciences, Filippo Cacace, Lorenzo Farina, Roberto Setola and Alfredo Germani Eds., Chapter 10, pp. 123-138, 2017, ISBN 978-3-319-54210-2

26-09-2017

Student signature

Diego Zorzan

Supervisor signature

Marco Di Val

Talks/Seminars attended

1. 13/11/14: Florian Dörfler, *ETH Zürich*
“Plug and Play Operation of Microgrids”
Automatica Group Seminars
2. 14/11/14: Josè A. Cobos, *Technical Univ. Madrid*
“Power Supply Systems for Energy Efficiency”
DEI Distinguished Lecture
3. 17/11/14: Arthur Krener, *Univ. California Davis*
“Filtering of Boundary Value Discrete Time Linear Systems”
Automatica Group Seminars
4. 27/11/14: Luigi Colangeli, *European Space Agency (ESA)*
“Rosetta rendez-vous with the 67P/Churyumov-Gerasimenko comet”
DEI Distinguished Lecture
5. 28/11/14: Bruno Chiarellotto, *Univ. Padova*
“Il lavoro e la vita di Alexander Grothendieck”
Colloquia Patavina
6. 13/03/15: Michele Pavon, *Univ. Padova*
“On the geometry of maximum entropy problems”
Automatica Group Seminars
7. 23/03/15: Walter Snoeys, *PH department, CERN*
“How chips helped discover the Higgs boson at CERN”
DEI Distinguished Lecture
8. 08/04/15: Ulrich Oberst, *Univ. Innsbruck*
“Weakly exponentially stable linear time-varying differential behaviors”
Automatica Group Seminars
9. 24/04/15: Luigi Palopoli, *Univ. Trento*
“When multimedia meets control: use of soft real-time techniques for control design”
Automatica Group Seminars

10. 28/04/15: Martin Grötschel, *Zuse Institute, Technical Univ. Berlin*
"Polyhedra: Their Description and Use"
Colloquia Patavina
11. 29/04/15: Gianluca Pollastri, *UC Dublino*
"Deep architectures and deep learning in chemoinformatics: the prediction of properties and activities of drug-like molecules"
DEI Seminars
12. 15/05/15: Alessandro Farinelli, *Univ. Verona*
"Recent advances on coordination in Multi-Robot Systems"
DEI Seminars
13. 29/05/15: Tryphon T. Georgiou, *Univ. Minnesota*
"The Hilbert metric and Schrödinger bridges"
Workshop: New challenges in reciprocal processes, Schrödinger bridges...
14. 29/05/15: Francesco Ticozzi, *Univ. Padova*
"A walk to symmetrization via a Schrödinger bridge"
Workshop: New challenges in reciprocal processes, Schrödinger bridges...
15. 03/06/15: Mérouane Debbah, *Huawei France R&D Center*
"Mathematical Scientific Challenges of 5G"
DEI Distinguished Lecture
16. 09/06/15: Ivar Ekeland, *Univ. Paris Dauphine*
"Are people rational?"
Colloquia Patavina
17. 17/06/15: Michel Verhaegen, *Univ. Delft*
"Nuclear Norm identification for lumped and distributed systems"
Automatica Group Seminars
18. 18/06/15: Rodolphe Sepulchre, *Univ. Cambridge*
"Do brains compute?"
DEI Distinguished Lecture
19. 07/07/15: Davide Piovesan, *Univ. Gannon*
"Human Arm Mechanics: from system identification to neural control"
DEI Colloquia
20. 09/07/15: Luca Scardovi, *Univ. Toronto*
"From Synchronization Analysis to Synchronization Control of Cellular Networks"
Automatica Group Seminars

21. 24/09/15: Kahori Kita, *Univ. Chiba*
“Development of sensory feedback system for stroke patients with sensory disturbance and neural basis of musicians dystonia”
DEI Seminars
22. 25/09/15: Pratap Pattnaik, *IBM*
“Bitcoin, an attempt at a separation of money and state”
DEI Distinguished Lecture
23. 28/09/15: Blaz Zupan, *Univ. Lubiana*
“Large-scale data fusion”
DEI Seminars
24. 30/09/15: Pierluigi Crescenzi, *Univ. Firenze*
“Fast and Simple Computation of Top-k Closeness Centralities”
DEI Seminars
25. 06/11/15: Fabrizio Luccio, *Univ. Pisa*
“Arithmetic for Rooted Trees”
DEI Seminars
26. 18/01/2016: Alessandro Abate, *Univ. Oxford*
“Formal verification of complex control systems”
Automatica Group Seminars
27. 02/02/2016: ,
“Neuroscience Day”
DEI Workshop
28. 27/04/2016: Alexandr Aravkin, *Univ. Washington*
“Conjugate Interior Point Method for Large-Scale Problems”
Automatica Group Seminars
29. 17/05/2016: Marino Gatto, *Politecnico di Milano*
“Matematica ed ecologia: le nuove frontiere della modellistica”
Colloquia Patavina
30. 20/05/2016: Kim Listmann, *ABB*
“Interactive Control & Learning for Robots - What we need and why!”
Automatica Group Seminars
31. 23/05/2016: Luca Zaccarian, *Univ. Trento*
“Static input allocation for reaction wheels desaturation using magnetorquers”
Automatica Group Seminars

32. 25/05/2016: Ananda Chowdhury, *Univ. Jadavpur (India)*
 “Matching, Cut, Connectivity: Graph-theoretic Solutions for Biomedical Image Analysis”
DEI Seminars
33. 20/06/16: Michael I. Jordan, *Univ. Berkeley (CA)*
 “Computational Thinking, Inferential Thinking and Data Science”
DEI Distinguished Lecture
34. 27/06/2016: Reza Arghandeh, *Florida State University*
 “CyPhy Detective: Learning Based Events Detection in Power”
Automatica Group Seminars
35. 20/07/2016: Subhrakanti Dey, *Uppsala University (Sweden)*
 “Sensor Scheduling in Variance Based Event Triggered Estimation with Packet Drops”
Automatica Group Seminars
36. 21/07/2016: Enrico Lovisari, *Volvo Cars (Goteborg, Sweden)*
 “Traffic networks: modelling and control”
Automatica Group Seminars
37. 24/10/2016: Li Qiu, *Hong Kong University of Science and Technology*
 “Projected-Spectrahedral-Cone-Invariant (PSCI) Realizations of Nonnegative Impulse Responses”
LCCC Seminar
38. 24/10/2016: Daria Madjidian, *MIT*
 “Emulating Batteries with Flexible Energy Demand”
LCCC Seminar
39. 18/11/2016: John Hedengren, *Brigham Young University*
 “Multi-echelon Control, Scheduling, and Design”
LCCC Seminar
40. 28/11/2016: Pontus Nordfeldt, *Vaderstad AB*
 “Agricultural control systems”
LCCC Seminar
41. 2/02/2017: Rodolphe Sepulchre, *Cambridge University*
 “Excitable behaviors”
LCCC Seminar
42. 3/02/2017: Luc N. Muhirwa, *TU Kaiserslautern*
 “Sub-moments of linear time-delay systems: model order reduction”
LCCC Seminar

- 43. 6/02/2017: Mikael Lindberg, *Axis Communications*
"Image completion using deep convolutional generative adversarial networks and tensorflow"
LCCC Seminar
- 44. 30/05/2017: Yong Sheng Soh, *Caltech*
"Learning regularizers from data"
LCCC Seminar
- 45. 1/06/2017: Alexander Gasnikov, *Moscow Institute of Physics and Technology*
"Unified view on accelerated randomized methods"
LCCC Seminar
- 46. 1/06/2017: Zhou Su, *TU Delft*
"Multi-Level Scenario-based Model Predictive Control for Optimal Maintenance Planning of Railway Networks"
LCCC Seminar
- 47. 2/06/2017: Ross Boczar, *UC Berkeley*
"Active Measurement for Neuroscience"
LCCC Seminar
- 48. 5/06/2017: Cesar A. Uribe, *University of Illinois*
"Distributed learning for cooperative inference"
LCCC Seminar
- 49. 5/06/2017: Soomin Lee, *Georgia Tech*
"Communication-efficient decentralized and stochastic optimization"
LCCC Seminar
- 50. 13/06/2017: Adrien Taylor, *UC Louvain*
"Analysis and Design of First-order Optimization Methods using the Performance Estimation Framework"
LCCC Seminar
- 51. 13/06/2017: Tryphon Georgiou, *UC Irvine*
"Density flows and optimal mass transport"
LCCC Seminar
- 52. 15/06/2017: Stephen Boyd, *Stanford University*
"Convex optimization with abstract linear operators"
LCCC Seminar

- 53. 15/06/2017: Madeleine Udell, *Cornell University*
"Sketchy Decisions: Convex Low-Rank Matrix Optimization with Optimal Storage"
LCCC Seminar
- 54. 15/06/2017: Amir Beck, *Technion*
"Primal and dual predicted decrease approximation methods"
LCCC Seminar
- 55. 15/06/2017: Russell Luke, *University of Gottingen*
"A Globally Linearly Convergent Method for Large-Scale Pointwise Quadratically Supportable Convex-Concave Saddle Point Problems"
LCCC Seminar
- 56. 15/06/2017: Laurent Lessard, *University of Wisconsin-Madison*
"Robust control for the analysis and design of large-scale optimization algorithms"
LCCC Seminar
- 57. 15/06/2017: Pontus Giselsson, *Lund University*
"Optimal and long-step feasibility algorithms"
LCCC Seminar
- 58. 15/06/2017: Christian Grussler, *Lund University*
"Low-rank inducing norms with optimality interpretations"
LCCC Seminar
- 59. 16/06/2017: Anders Rantzer, *Lund University*
"A Unified Analysis of Stochastic Optimization Methods Using Jump System Theory and Quadratic Constraints"
LCCC Seminar
- 60. 20/06/2017: Philipp Braun, *University of Bayreuth*
"(Nonsmooth) Control Lyapunov Functions"
LCCC Seminar
- 61. 20/06/2017: Anton Shiriaev, *NTNU, Trondheim, Norway*
"The "Butterfly" robot: challenges for motion planning and control"
LCCC Seminar
- 62. 27/06/2017: Rene' Schneider, *EPFL Lausanne*
"Real-time optimization under uncertainty: accelerated and distributed modifier-adaptation schemes"
LCCC Seminar

- 63.** 22/09/2017: Chris Van Hoof, *Holts Centre/ IMEC, The Netherlands*
“Personal Behavioral Technology - Wearables Can Become an Active Contributor to
Your Wellbeing”
DEI Distinguished Lecture

