PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Davide Fiore

XXIX Cycle

Training and Research Activities Report – First Year

Tutor: Mario di Bernardo

1. Information

I received on 18/12/2014 the M. Sc. degree cum laude in Ingegneria dell'Automazione from University of Naples "Federico II". Currently I'm a PhD student of the XXIX cycle in ITEE.

Fellowship type: Fondo Sostegno ai Giovani - FSGDIS

Tutor: Prof. Mario di Bernardo

2. Study and Training activities

a. Courses

- "*Sistemi ad Eventi Discreti*" (6 CFU)
  Lecturer: Gianmaria De Tommasi
- "*Meccanica quantistica*" (3 CFU)
  Lecturer: Giovanni Miano
- *"Talks on Advanced Topics in Optimization"* (2 CFU)
  Lecturer: Stephen Boyd
- *"Theory and Applications of Piecewise Smooth Dynamical Systems"* (5 CFU)
  Lecturer: John Hogan
- *"Europrogettazione"* (3 CFU)
  Lecturer: Gianpaolo Varchetta

b. Seminars

- *"Opportunities and Challenges in Two Dimensional Magnetic Recording"*
  Lecturer: Jon Coker
  Date: 02.04.2014 - 2h
- *"Circuiti Quantistici"*
  Lecturer: Giovanni Miano
  Date: 04.04.2014 - 1h
- *"Bounded synchronization in resistive multi-terminal VSC-HVDC transmission systems"*
  Lecturer: Josep Olm
  Date: 08.04.2014 - 1h
- *"Terahertz response properties of carbon nanotubes and nanotube-based composite materials"*
  Lecturer: Sergey Maksimenko
  Date: 08.05.2014 - 2h
- *"Plasmon Resonances and Riemann Hypothesis"*
  Lecturer: Isaak Mayergoyz
  Date: 23.05.2014 - 1h
- *"Utilizzo di Reti di Petri per la diagnosi dei guasti e per la modellistica ed il controllo dei sistemi logistici"*
  Lecturer: Francesco Basile
  Date: 06.06.2014 - 2h
- *"Quantum Teleportation"*
  Lecturer: Giovanni Miano
  Date: 23.10.2014 - 1h
- *"Heterogeneities in temporal networks emerging from adaptive social interactions"*
  Lecturer: Takaaki Aoki
  Date: 14.11.2014 - 1h

- *"Caltech CDS@20: Education, depth, breadth, and futures"*
  Lecturers: John Doyle and Richard Murray
  Date: 14.12.2014 - 6h
- *"Differentially positive systems"*
  Lecturer: Rodolphe Sepulchre
  Date: 30.01.2015 - 1h
- *"Accounting for global physiological effects in the analysis of gene regulatory networks"*
  Lecturer: Hidde de Jong
  Date: 06.02.2015 - 1h
- *"Nonholonomic dynamics through friction"*
  Lecturer: Jaap Eldering
  Date: 13.02.2015 - 1h
- *"Computational Nonlinear Systems Analysis Using Sum-of-Squares Programming"*
  Lecturer: James Anderson
  Date: 20.02.2015 - 1h
- *"Coherent Lagrangian vortices: The KAM tori of turbulence"*
  Lecturer: George Haller
  Date: 27.02.2015 - 1h

3. Research activity

a. Title:

Incremental stability of Filippov systems via contraction theory

b. Research description:

Incremental stability has been established as a powerful tool to prove convergence in nonlinear dynamical systems [1]. It characterizes asymptotic convergence of trajectories with respect to one another rather than towards some attractor known a priori. Therefore it is a useful alternative to the traditional Lyapunov functions approach when such a steady state solution is not known. Popular control applications include tracking and regulation, observer design, coordination, and synchronization.
Several approaches to derive sufficient conditions for a system to be incrementally stable have been presented in the literature, among these contraction theory has been shown to be particularly effective [2], [3], [4]. A dynamical system is said to be contractive when the matrix measure of the Jacobian of the vector field is uniformly negative on the state space.

As the number of applications based on the use of switched and hybrid models increases, it is becoming increasingly important to characterize convergence and incremental stability of systems and networks modelled by ODEs with time-dependent or state-dependent discontinuities. Unfortunately, most of the results available in the literature on both incremental stability and contraction assume continuous differentiability of the system or network under investigation. Only few results deal with the problem of investigating incremental stability of piecewise-smooth (PWS), switched or hybrid dynamical systems.

Our research is aimed to systematically extend contraction theory to wider classes of state-dependent switching systems, particularly those modelled by ODEs with discontinuous right-hand sides (or Filippov systems), in order to analyse their incremental stability properties. Continuing the work presented in [5] for planar Filippov systems with sliding mode solutions, we generalized those results to the case of n-dimensional vector fields [6]. There we derived sufficient conditions for the incremental stability of Filippov systems by requiring firstly that the sliding region (the region of the discontinuity surface where sliding mode occurs) is globally attractive for the system trajectories and secondly that the sliding vector field is contracting. The latter condition was formulated using a local set of constrained coordinates

onto the discontinuity surface to remove the non-contracting orthogonal component of the sliding vector field from the analysis.

Further numerical analyses were conducted on simple relay systems to study their incremental properties showing that a weaker form of incremental stability occurs when the conditions in [6] are not completely fulfilled.

Currently, in collaboration with Prof. S.J. Hogan, using the regularization approach presented in [7] and based on the singular perturbation theory, we are investigating how stability properties of the vector fields of a bimodal Filippov system, such as contraction, are preserved in the sliding vector field when the system changes from a continuous one to discontinuous.

Moreover, in collaboration with Dr. M. Jeffrey, we are investigating how a contracting sliding vector field can be induced by the control input signals. The analysis is conducted using a more general convex combination to define the sliding vector field as described by Utkin in [8].

[1] D. Angeli, *"A Lyapunov approach to incremental stability properties",* IEEE Transactions on Automatic Control, vol. 47, no. 3, pp. 410-421, 2002

[2] W. Lohmiller, J.J.E. Slotine, *"On contraction analysis for nonlinear systems",* Automatica, vol. 34, no. 6, pp. 638-696, 1998

[3] G. Russo, M. di Bernardo, E.D. Sontag, *"Global entrainment of transcriptional systems to periodic inputs"*, PLoS computational biology, vol. 6, no. 4, p. e1000739, 2010

[4] W. Wang, J.J.E. Slotine, *"On partial contraction analysis for coupled nonlinear oscillators"*, Biological cybernetics, vol. 92, no. 1, pp. 38-53, 2005

[5] M. di Bernardo, D. Liuzza*, "Incremental stability of planar Filippov systems",* ECC2013, pp. 3706-3711, 2013

[6] M. di Bernardo, D. Fiore, *"Incremental stability of Filippov systems in R^n",* Proceedings of 2014 IEEE 53rd Annual Conference on Decision and Control (CDC), p. 4679-4684, 2014

[7] J. Sotomayor, M.A. Teixeira, *"Regularization of discontinuous vector fields",* International Conference on Differential Equations, Lisboa. 1996

[8] V.I. Utkin, *Sliding modes in control and optimization*, Springer-Verlag, Berlin, 1992

c. Collaborations:

- Prof. John Hogan
  Faculty of Engineering
  University of Bristol
- Dr. Mike Jeffrey
  Faculty of Engineering
  University of Bristol

4. Products

a. Publications

i. Already published:

- M. di Bernardo, D. Fiore, *"Incremental stability of Filippov systems in R^n"*, Proceedings of 2014 IEEE 53rd Annual Conference on Decision and Control (CDC), p. 4679-4684, 2014

ii. In preparation:

- M. di Bernardo, S.J. Hogan, D. Fiore, *"Contracting Filippov systems: a regularization approach"*

- M. di Bernardo, M. Jeffrey, D. Fiore, *"On contracting sliding vector fields"*

5. Conferences and Seminars

- IEEE 53rd Annual Conference on Decision and Control (CDC'2014)
  Los Angeles (California) – 14-17.12.2014
  One (1) conference paper was presented in the "Switched Systems I" session

Presentations made:

- IEEE International meeting on Analysis and Applications of Nonsmooth Systems (AANS'2014)
  Como (Italy) – 10-12.09.2014

6. Activity abroad

a. Period of research at the Department of Engineering Mathematics of University of Bristol (United Kingdom) to collaborate with Prof. S.J. Hogan and Dr. M. Jeffrey.
From 12.01.2015 to 01.03.2015

7. Tutorship

Assistant for exercises of the B.Sc. course "Controlli automatici" (Cod. 02826), held by Prof. Mario di Bernardo, 13 hours.

Student: Davide Fiore davide.fiore@unina.it

Tutor: Mario di Bernardo mario.dibernardo@unina.it

Cycle XXIX

								Credits year 2																		
	1	2	3	4	5	6			1	2	3	4	5	6			1	2	3	4	5	6			
	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	**Estimated**	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	**Estimated**	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	**Total**	**Check**
Modules	0	13	3	3	0	0	**19**	**12**							**0**								**0**	**19**	**30-70**
Seminars	1	1	0	0.2	1.4	1	**4.6**	**6**							**0**								**0**	**4.6**	**10-30**
Research	9	0	6	7	10	9	**41**	**42**							**0**								**0**	**41**	**80-140**
	10	13	9	10	11	10	**65**	**60**	0	0	0	0	0	0	**0**	**0**	0	0	0	0	0	0	**0**	**65**	**180**