



ABCDE



## Scientific Report

First name / Family name  
Nationality  
Name of the *Host Organisation*  
First Name / family name of the  
*Scientific Coordinator*  
Period of the fellowship

Florin STOICAN  
ROMANIA  
NTNU  
Morten HOVD

01/11/2011 to 31/10/2012



## I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

My research activities were organized in the interval 01.11.2011-31.10.2012 at NTNU in the Engineering Cybernetics Department (ITK) under the supervision of Prof. Morten Hovd.

During my fellowship I have concentrated mainly on Model Predictive Control (MPC) and related set theoretic issues. The most important directions of research were:

- soft constraints in MPC and exact penalty functions
- geometrical insights in the structure of the constraints resulting from an MPC problem
- zonotopic sets (a particular case of convex sets which is well-adapted to efficient algorithms)
- description of non-convex regions through a mixed integer representation
- fault tolerant control within a set-theoretic framework

The ability to handle constraints is often cited as the most important advantage of MPC when compared with other strategies. Still, hard constraints may lead to problems by making the optimization problem infeasible. To avoid this, it is common to use soft constraints (which can be violated but at a cost). The difficulty is to make the soft-constrained MPC equivalent with its hard-constrained counterpart (i.e., the original constraints are violated only when there is no solution verifying them). This is accomplished by designing an exact penalty term in the cost function. The “exactness” directly depends on the values taken by the Lagrangian multipliers of the KKT problem.

By studying the underlying structure of the MPC problem we have observed that the constraint matrices have a specific shape (lower block triangular). Using this, we were able to provide a better characterization of the sets of active constraints from the KKT problem. This in turn has permitted to describe a more efficient construction of the penalty term in the soft-constrained formulation.

Lately, the “curse of dimensionality” has become apparent as a troubling shortcoming of polyhedral sets (ie, the numerical implementations scale unreasonably fast with the space dimension and/or they become prone to numerical errors). Subsequently, as a generalization of the earlier interval arithmetic, the zonotopes (a subclass of polyhedral sets), have started to gain attention. Their symmetric shape, coupled with the flexibility inherited from the polyhedral class make them an appealing choice for higher dimensions (their particular representation permits extremely efficient algorithms and makes them almost impervious to the space dimension).

Thus, we have used their structure to reformulate MPC problems with zonotopic constraints, in a fault tolerant control construction and to provide an explicit description of the minimal robust positive invariant set characterizing dynamics with zonotopic disturbances.

It is often the case that optimization problems arising in control theory have to be solved over a non-convex feasible region. This issue arises naturally in many control engineering problems. Solving optimization problems over non-convex regions is not a new issue and it is well known that mixed integer (MI) formulations provide one of the best ways for dealing with this type of problems.

Using auxiliary notions (i.e., hyperplane arrangements) we have provided an efficient description of a non-convex region in the MI framework. Further advances were registered in the compact description of the feasible region. These results can and have been adapted for a variety of uses: multi-agent problems with collision and obstacle avoidance, obstacles described by zonotopic sets and even for the description of KKT problem.



## II – PUBLICATION(S) DURING YOUR FELLOWSHIP

- Conferences and book chapters

1. Ionela Prodan, **Florin Stoican**, Sorin Oлару, Cristina Stoica an Silviu-Iulian Niculescu. Mixed-Integer Programming Techniques in Distributed MPC Problems. *Accepted for apparition in “Distributed MPC Made Easy”, <http://distributedmpc.net/>.*
2. **Florin Stoican** and Morten Hovd. Some remarks upon the characteristics of the explicit representation of the MPC problem. In: *Proceedings of the 2012 IFAC Conference on Nonlinear Model Predictive Control, Noordwijkerhout, Netherlands, August 23-27, 2012.*
3. Giancarlo Marafioti, **Florin Stoican**, Robert R. Bitmead and Morten Hovd. Persistently Exciting Model Predictive Control for SISO systems. In: *Proceedings of the 2012 IFAC Conference on Nonlinear Model Predictive Control, Noordwijkerhout, Netherlands, August 23-27, 2012.*
4. **Florin Stoican** and Morten Hovd. Efficient solution of a qp optimization problem with zonotopic constraints. In: *Proceedings of the 2012 IEEE Multi-Conference on Systems and Control, Dubrovnik, Croatia October 3-5, 2012.*
5. **Florin Stoican**, Sorin Oлару and Morten Hovd. MPC techniques in fault tolerant control design. In: *Proceedings of the 17th Nordic Process Control Workshop, Lyngby, Denmark, January 26-27, 2012.*
6. Nikola Stankovic, **Florin Stoican**, Sorin Oлару and Silviu-Iulian Niculescu. Reference Governor Design with Guarantees of Detection for Delay Variation. In: *Proceedings of the 10th IFAC Workshop on Time Delay Systems, Boston, USA, June 22-24, 2012.*

- Submitted journal papers

1. Morten Hovd and **Florin Stoican**. On the design of exact penalty functions for MPC using mixed integer programming. Submitted to: Journal of Computers & Chemical Engineering.

- Submitted conference papers

1. **Florin Stoican**, Morten Hovd and Sorin Oлару. Explicit invariant approximation of the mRPI set for LTI dynamics with zonotopic disturbances. Submitted to: the 2013 American Control Conference, June 17 - 19, Washington, DC, US.
2. Feng Xu, **Florin Stoican**, Vicenc Puig, Carlos Ocampo-Martinez and Sorin Oлару. On the Relationship between Interval Observers and Invariant Sets in Fault Detection. Submitted to: the 2013 European Control Conference, July 17-19, Zurich, Switzerland.
3. **Florin Stoican**, Ionela Prodan and Sorin Oлару. Hyperplane Arrangements in Mixed-Integer Programming Techniques. Collision avoidance application with Zonotopic Sets. Submitted to: the 2013 European Control Conference, July 17-19, Zurich, Switzerland.

## III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

1. 1<sup>st</sup> ABCDE Seminar, Berlin, Germany, November 10-11, 2011
2. 17<sup>th</sup> Nordic Process Control Workshop Technical University of Denmark, Kgs Lyngby, Denmark, January 25-27, 2012
3. PROST Seminar, NTNU, Norway, March 21, 2012
4. 2012 IFAC Conference on Nonlinear Model Predictive Control, Noordwijkerhout, Netherlands, August 23-27, 2012
5. 2012 IEEE Multi-Conference on Systems and Control, Dubrovnik, Croatia, October 3-5, 2012



## IV – RESEARCH EXCHANGE PROGRAMME (REP)

1. Location: DTU, Denmark  
Duration: 24.01.2012–14.02.2012  
Contact: Prof. John Bagterp Jorgensen

The group coordinated by Prof. Jorgensen has an excellent reputation and was well suited to my topics of interest. In particular, I have discussed about optimization issues (box constraints and gradient projection methods) and about the use of fault tolerant control techniques in a set theoretic framework (in a discussion with Prof. Mogens Blanke which was facilitated by Prof. Jorgensen). I have also given a presentation of my work up to that point to an assembly of people from the department (<http://www.dtu.dk/centre/hea/English/news/calendar.aspx?guid=%7BFA493654-FA00-4086-A0F7-99FBD8B2D9FF%7D>).

2. Location: KUL, Belgium  
Duration: 01.07.2012–16.07.2012  
Contact: Prof. Moritz Diehl

The group coordinated by Prof. Diehl is well known for its interest in non-linear MPC, large scale problems and other difficult issues. As such, it was a very good opportunity for me to have the chance to meet and discuss with Prof. Diehl himself and with the people from his group.

Besides exposing my work into a presentation to the people from the group (facilitated by Prof. Diehl) I also had the chance to listen and meet researchers from different departments. The first part of my visit coincided with the visit of Prof. Annick Sartenaer and together with her I was scheduled for meetings with various researchers from the departments having links with Prof. Diehl. Latter, I participated at the “Simon Stevin Lecture on Optimization in Engineering” held by Prof. Sartenaer.

Lastly, I had meetings with phd and postdoc students from the group with whom I have discussed about my work.