Optimization for Gain Scheduling—Final Report

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Summary of Results

This project has focused on the theoretical aspects of efficient optimization algorithms for analysis and design of gain scheduled controllers. The following research topics have been investigated:

- We have studied how to construct efficient Interior-Point (IP) algorithms for the Semidefinite Programs (SDPs) that originate from the Kalman-Yakubovich-Popov (KYP) lemma. They have several applications, e.g., linear system design and analysis, robust control analysis using integral quadratic constraints, Lyapunov function search. Several of these techniques can be used to analyze gain scheduled control systems. Typically standard SDP solvers cannot handle problems of more than small to medium size in reasonable time. The computational complexity stems from the cost of assembling and solving the equations for the search directions in the IP algorithms. Results have been presented in [WKH05, EHEGL$^+$05, VBW$^+$05, HJWH06, WHHJ09]. Another related approach based on dual decomposition with application to mixed H_2/H_∞-design is presented in [FH09].

- Very promising results have also been obtained for these SDPs using an analytical center cutting-plane method, see [WKH05, WKH08].

- For many approaches to gain scheduling it is desirable to solve optimization problems involving parameterized Linear Matrix Inequalities (LMI)s. Under certain assumptions the parameterized LMIs are equivalent to a finite number of LMIs involving the same symmetric matrix

variable. The essential difference as compared to the SDPs related to the KYP lemma is that there is more than one constraint for this variable. We have investigated how our results on iterative solvers for computing search directions for IP methods can be extended to this case. The challenge has been to develop efficient preconditioners. Results have been presented in[HH07, HJH08a, HJH08b, HJH08c, HJH10].

- We have also investigated how to make use of the general matrix variable structure often present in SDPs originating from control application. This work also involves an interface to YALMIP, [FLH10a, FLH10b].

Exams and Promotions

Janne Harju Johansson, [HJ08], and Rikard Falkeborn, [Fal10], have received their licentiate degrees within the project. Anders Hansson was promoted to full professor during the project.

Masters' Thesis

None

Personnel

The following personnel have been financed by the project: Anders Hansson, Ragnar Wallin, Janne Harju Johansson and Rikard Falkeborn

Industrial Contacts

In order to test our research results on industrial problems two application projects have been launched. One of the projects has been carried out in collaboration with Saab AB and Saab Bofors Dynamics AB in which clearance of flight control laws for fighter aircraft and missiles have been investigated. This has been funded by VINNOVA. The other project has been an EC-project, COFCLUO, co-ordinated by Anders Hansson and carried out in collaboration with AIRBUS, ONERA, DLR, FOI and University of Siena in which clearance of flight control laws for civil aircraft has been investigated.

CENIIT Collaboration

None

Research Group

Anders Hansson is heading a sub-group of researchers involved in optimization for control within the Division of Automatic Control. The group consists of 1 full professor, 1 adjunct professor, 3 research associates, and 3 PhD students.

List of Publications

[EHEGL+05] M. Enqvist, A. Hansson, G. Hendeby E. Geijer-Lundin, D. Lindgren, J. Sjöberg, H. Tidefelt, D. Törnqvist, and R. Wallin. Utilization of low-rank structure in control applications of semidefinite programming. In *SIAM Conference on Optimization*, Stockholm, Sweden, May 2005. Abstract presented at conference.

[Fal10] Rikard Falkeborn. *Structure exploitation in semidefinite programming for control.* Licentiate thesis no. 1430, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, February 2010.

[FH09] Rikard Falkeborn and Anders Hansson. A decomposition algorithm for kyp-sdps. In *Proceedings of the European Control Conference*, pages 3202–3207, August 2009.

[FLH10a] Rikard Falkeborn, Johan Löfberg, and Anders Hansson. Lowrank exploitation in semidefinite programming for control. In *Proceedings of the 2010 IEEE Multi-conference on Systems and Control*, SE-581 83 Linköping, September 2010.

[FLH10b] Rikard Falkeborn, Johan Löfberg, and Anders Hansson. Lowrank exploitation in semidefinite programming for control. In *Proceedings of reglermöte 2010*, Lund, Sweden, June 2010.

[HH07] J. Harju and A. Hansson. An inexact interior-point method for semi-definite programming, a description and convergence proof. Technical Report LiTH-ISY-R-2819, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, September 2007.

[HJ08] Janne Harju Johansson. *A Structure Utilizing Inexact Primal-Dual Interior-Point Method for Analysis of Linear Differential Inclusions*. Licentiate thesis no. 1367, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, May 2008.

[HJH08a] Janne Harju Johansson and Anders Hansson. Structure exploitation in semi-definite programs for systems analysis. In *Proceedings of IFAC World Congress*, Seoul, July 2008.

[HJH08b] Janne Harju Johansson and Anders Hansson. A tailored inexact interior-point method for systems analysis. In *Proceedings of IEEE Conference on Decision and Control*, Cancun, Mexico, December 2008.

[HJH08c] Janne Harju Johansson and Anders Hansson. A tailored inexact interior-point method for systems analysis. In *Proceedings of Reglermöte*, Luleå, June 2008.

[HJH10] Janne Harju Johansson and Anders Hansson. An inexact interior-point method for system analysis. *International Journal of Control*, 83(3):601–616, March 2010.

[HJWH06] Janne Harju Johansson, Ragnar Wallin, and Anders Hansson. Utilizing low rank properties when solving kyp-sdps. In *IEEE Conference on Decision and Control*, number LiTH-ISY-R-2758, SE-581 83 Linköping, Sweden, December 2006.

[VBW+05] L. Vandenberghe, R. Balakrishnan, R. Wallin, A. Hansson, and T. Roh. Interior-point algorithms for semidefinite programming problems derived from the KYP lemma. In A. Garulli and D. Henrion, editors, *Positive Polynomials in Control*, Lecture Notes in Control and Information Sciences, pages 193–237. Springer Verlag, New York, 2005.

[WHHJ09] R. Wallin, A. Hansson, and J. Harju Johansson. A structure exploiting preprocessor for semidefinite programs derived from the kalman-yakubovich-popov lemma. *IEEE Transactions on Automatic Control*, 54(4):697–704, April 2009.

[WKH05] R. Wallin, C.-Y. Kao, and A. Hansson. A decomposition approach for solving kyp-sdps. In *Proceedings of hte 16 th IFAC World Congress*, Prague, Czech Republic, July 2005. IFAC.

[WKH08] R. Wallin, C. Y. Kao, and A. Hansson. A cutting plane method for solving kyp-sdps. *Automatica*, 44(2):418–429, February 2008.