$\mathcal{H}_2$ for HIFOO

D. Arzelier[†], **G. Deaconu**[†], **S. Gumussoy**[‡] and **D. Henrion**[†§],

[†]CNRS, LAAS
7 avenue du colonel Roche, F-31077 Toulouse, France
{e-mail: denis.arzelier, georgia.deaconu, didier.henrion}@laas.fr

[§]Faculty of Electrical Engineering, Czech Technical University in Prague,
Technická, CZ-16626 Prague, Czech Republic

[‡]Department of Computer Science, K. U. Leuven
Celestijnenlaan 200A, 3001, Heverlee, Belgium
{e-mail: suat.gumussoy@cs.kuleuven.be}

Keywords: fixed-order controller design, $\mathcal{H}_2$ control, mixed $\mathcal{H}_2/\mathcal{H}_\infty$ control, optimization.

Extended Abstract

HIFOO is a public-domain Matlab package initially designed for $\mathcal{H}_\infty$ fixed-order controller synthesis, using nonsmooth nonconvex optimization techniques. It was later on extended to multi-objective synthesis, including strong and simultaneous stabilization under $\mathcal{H}_\infty$ constraints. In this paper we describe a further extension of HIFOO to $\mathcal{H}_2$ performance criteria, making it possible to address mixed $\mathcal{H}_2/\mathcal{H}_\infty$ synthesis. We give a demonstration on the usage of HIFOO and report some of our extensive benchmark results.

HIFOO is a public-domain Matlab package originally conceived during a stay of Michael Overton at the Czech Technical University in Prague, Czech Republic, in the summer of 2005. HIFOO relies upon HANSO, a general purpose implementation of an hybrid algorithm for nonsmooth optimization, mixing standard quasi-Newton (BFGS) and gradient sampling techniques. The acronym HIFOO (pronounce [haɪfu:]) stands for H-infinity Fixed-Order Optimization, and the package is aimed at designing a stabilizing linear controller of fixed-order for a linear plant in standard state-space configuration while minimizing the $\mathcal{H}_\infty$ norm of the closed-loop transfer function.

The first version of HIFOO was released and presented during the IFAC Symposium on Robust Control Design in Toulouse, France in the summer of 2006, see [3], based on the theoretical achievements reported in [4]. HIFOO was later on extended to cope with multiple plant stabilization and multiple conflicting objectives and the second major release of HIFOO was announced during the IFAC Symposium on Robust Control Design in Haifa, Israel, in the summer of 2009, see [5].

Since then HIFOO has been used by various scholars and engineers. Benefiting from feedback from users, we feel that it is now timely to extend HIFOO to $\mathcal{H}_2$ norm specifications. Indeed, $\mathcal{H}_2$ optimal design, a generalization of the well-known linear quadratic regulator design, is traditionally used in modern control theory jointly with $\mathcal{H}_\infty$ optimal design, see [8]. In particular, the versatile framework of mixed $\mathcal{H}_2/\mathcal{H}_\infty$ design described e.g. in [6] is frequently used when designing high-performance control laws for example in aerospace systems, see [2]. See also [7] for an application of the $\mathcal{H}_2$ norm for smoothening $\mathcal{H}_\infty$ optimization.

The objective in this paper is to describe the extension of HIFOO to $\mathcal{H}_2$ norm specifications in such a way that users understand the basic mechanisms underlying the package, and may be able to implement their own extensions to fit their needs for their target applications. For example, the algorithms of HIFOO can also be extended to cope with discrete-time systems, pole placement specifications or time-delay systems. On the HIFOO webpage

www.cs.nyu.edu/overton/software/hifoo

we are maintaining a list of publications reporting such extensions and applications in engineering. The HIFOO and HANSO packages can also be downloaded there.

In our presentation, we give a demonstration of HIFOO and design fixed-order controllers for some of the control problems. Further information on the extension of HIFOO to $\mathcal{H}_2$ performance criteria and mixed $\mathcal{H}_2/\mathcal{H}_\infty$ synthesis can be found in [1].

References

[1] Arzelier, D., Deaconu, G., Gumussoy, S., Henrion, D., "$\mathcal{H}_2$ for HIFOO", *LAAS-CNRS Research Report 10613*, (2010), web: `http://homepages.laas.fr/henrion/Papers/h2hifoo.pdf`

[2] Arzelier, D., Clément, B., Peaucelle, D., "Multi-objective $\mathcal{H}_2/\mathcal{H}_\infty$/impulse-to-peak control of a space launch vehicle", *European Journal of Control*, Vol. 12, No. 1 (2006).

[3] Burke, J. V., Henrion, D., Lewis, A. S., Overton, M. L., "HIFOO - A Matlab Package for Fixed-order Controller Design and H-infinity Optimization", *IFAC Symposium on Robust Control Design*, (2006), Toulouse, France.

[4] Burke, J. V., Henrion, D., Lewis, A. S., Overton, M. L., "Stabilization via nonsmooth, nonconvex optimization", *IEEE Transactions on Automatic Control*, Vol. 51, No. 11, (2006), pp. 1760-1769.

[5] Gumussoy, S., Henrion, D., Millstone, M., Overton, M. L., "Multiobjective Robust Control with HIFOO 2.0", *IFAC Symposium on Robust Control Design (ROCOND)*, (2009), Haifa, Israel.

[6] Scherer, C. W., "Multi-objective $\mathcal{H}_2/\mathcal{H}_\infty$ control", *IEEE Transactions on Automatic Control*, Vol. 40, (1995), pp. 1054-1062.

[7] Vanbiervliet, J., Vandereycken, B., Michiels, W., Vandewalle, S., Diehl, M., "Smoothed spectral abscissa for robust stability optimization", *SIAM Journal on Optimization*, Vol. 20, No. 1, (2009), pp. 156-171.

[8] Zhou, K., Doyle, J.C., Glover, K., *Robust and optimal control*, Prentice Hall (1995).