DEVELOPMENTS AROUND THE FREEWARE STANDARD CONTROL LIBRARY SLICOT

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Abstract

Robust and performant numerical software for control systems analysis and design, such as the SLICOT and RASP libraries, is an essential ingredient in modern computer aided control system design. SLICOT, realised by WGS in cooperation with NAG, can primarily be viewed as a mathematical library for control theoretical computations. To avoid duplicating the implementation efforts of good quality software existing elsewhere, WGS and DLR, originator of the RASP control engineering library, have agreed to integrate their libraries into a joint standard control library. Making the product now freely available will ensure a wider and faster distribution of these computational tools and will make the much needed software more easily accessible to European industry in the short term. Detailed plans have been developed for the instigation of a thematic network on numerics in control with the intention of extending the scope of cooperation to a European level.

Introduction

Industrial processes are often designed, analyzed and controlled by a computer system, mostly in the form of a package. Two kinds of packages can be recognised:
- general CACSD packages for analysis and design of control systems and feasibility studies of solutions. Examples are: MATLAB (Simulink) and XMath;
- dedicated, industrial oriented, controller design packages, such as SMCA (Setpoint Multivariable Control Architecture), that enable flexible modelling, controller simulation, operator training and interfacing to the industrial plant.

The design of a high performance controller requires packages of high quality with respect to functionality, efficiency, usability, numerical reliability and flexibility. The present state of these control packages is such that the performance can be substantially improved by improving the (numerical) quality of the underlying layer of basic computational algorithms. In fact, this layer in particular determines completely the quality of the outcome. Examples, described in [4], illustrate the gain in efficiency (up to an order of magnitude) one can obtain when using compiled and carefully written Fortran routines from the SLICOT library instead of an interpreted MATLAB code, e.g. for deadbeat control, solving Lyapunov, Riccati and Sylvester equations, pole placement, and so on.

The present state of the art with respect to control methods, algorithms and software is that:
- systems theory has generated many powerful methods for analysis, modelling and optimal control, that have been successfully tested on industrial pilot plants. However, for flexible use on a larger scale, these methods have to be further developed with respect to numerical aspects and maximal attainable performance;
- cooperation between system theorists and numerical analysts of the recent decades has resulted in the development of good algorithms for many of these above-mentioned methods and has generated high performant (prototype) numerical software implementations of several of these methods;
- upgrading of these prototype implementations to professional standards, (i.e. well-tested, reliable and robust) in a context of a well defined and standardised control library is a necessary but nevertheless a rather neglected professional activity which still needs more support;
- for basic computations in numerical linear algebra, reliable packages have been developed with special emphasis on high performance computers. Much of this software is not directly related to control problems, but can be used as a basic layer for a control library, thus bringing the benefits of high performance computations to specific control problems with a more complex structure.

This sketch of the present situation of the trio of control methods, algorithms and software reveals the need for professional, comprehensive software implementations for all existing good methods in control and systems theory.

The purpose of this paper is to review recent activities with respect to generating a professional and comprehensive collection of control and systems theory software and to introduce and discuss the forthcoming steps to be taken.

Short history of control libraries

A fundamental basis for the research and development of reliable analysis and design tools using sophisticated CACSD programs is the availability of high quality basic software for numerical computations. The generally accepted form for such software is a **software library**, i.e. a portable, integrated collection of basic subroutines which can be used as building blocks for the construction of all sorts of complex CACSD packages. Several efforts have been initiated in the past to develop such control libraries, e.g. the Scandinavian control library, AUTLIB (a Swiss initiative), SLICE (a British cooperation initiative), BIMAS and BIMASC (a Rumanian initiative); see [2]. Apparently, to date, only RASP (an initiative from the German Aerospace Research Establishment DLR) and SLICOT (a Benelux initiative from the Working Group on Software WGS) are in active further development. The other initiatives failed to evolve due to a number of reasons, such as a lack of sufficient supporting and contributing research sites, the vast amount of work associated with the development of a more or less complete library on a professional level, the absence of facilities of maintenance and the apparently small market of potential customers.

In the early eighties, WGS was founded as a Benelux working group, involving several academic institutes and some industries, that felt the need to combine software implementation efforts with respect to realising reliable control software. The objectives of the WGS were initially to bring together the existing numerical software for control and systems theory in a widely available library and subsequently to extend this library to cover as far as possible the area of industrial applications. WGS has a strong academic representation, which means that the members of the group are very active in the development and implementation of numerical methods for control systems design. Although the WGS is a Benelux initiative, it has recently started to operate on a European level.

Important aspects of a software product are consistency in development and continuity in maintenance. These were not sufficiently covered in the early constitution of the WGS. Also, in order to produce a library of a quality that meets professional standards (documentation, implementation, portability,...), the WGS associated itself with Numerical Algorithms Group NAG in Oxford (UK). NAG is the software company that produces the world renowned NAG Library for numerical and statistical computations. NAG and WGS decided to combine their expertise. This cooperation was quite effective and led to the first release of the SLICOT library in 1990. In a later phase a collaboration with the originators of the RASP library (DLR, Germany) was pursued and the resulting extension of routines in the SLICOT collection led to a second release of the SLICOT library.

Standard libraries RASP and SLICOT, present status and future developments

RASP [5] covers a broad area of control engineering computations supporting frequency- and time-domain analysis and synthesis techniques, multi-criteria parameter optimisation, simulation and graphics. Special attention is given to the *numerical reliability* of the implemented algorithms. Currently, RASP consists of about 320 user-callable routines and is used in education and research at many universities and research sites, especially in Germany. RASP, together with the engineering-database and operating system RSYST [6], form the software infrastructure of the modern computer-aided control engineering environment ANDECS [7]. RASP and ANDECS are products of DLR, Germany.

SLICOT [3], a general purpose basic control library realised by WGS in cooperation with NAG, can primarily be viewed as a *mathematical library for control theoretical computations*. The main emphasis in SLICOT is on *numerical reliability* of implemented algorithms and the *numerical robustness and efficiency* of the routines. Special emphasis is put on providing maximal algorithmic flexibility to users, and on the use of rigorous implementation and documentation standards, see [10]. The present release of the SLICOT library contains about 90 user-callable routines, related to analysis, modelling, transformation and synthesis of systems and to signal analysis and filtering. Future extensions will cover routines for descriptor systems, model reduction and subspace identification.

NAG and WGS have agreed to turn SLICOT into *copyrighted freeware*. This should give a much wider distribution of the library but at the same time endangers its proper future maintenance, which has been taken care of in the past by NAG. However, to promote the use of the library on a large scale, NAG and WGS are now convinced that the product ought to be made *freely available*. Therefore ftp sites are established; one main site in Leuven (active at wgs.esat.kuleuven.ac.be) and soon a few mirror sites.

Because both libraries will continue to evolve, there are serious concerns about *rationalising future developing activities*, that is, to avoid duplication of implementation of existing software of good quality. DLR and WGS have agreed to combine their activities in order to come to a joint library. This joint library is the first step towards a *standard platform for computational tools*. For the sake of cooperation, the **RASP/SLICOT mutual compatibility concept** has been introduced. A first result of this cooperation is the next release of SLICOT, which will contain about 160 user-callable routines.

RASP/SLICOT mutual compatibility concept

An essential part of the mutual compatibility concept [8] is the incorporation of generally accepted supporting basic libraries such as LAPACK for linear algebra computations and BLAS for elementary vector and matrix computations. As a consequence, new RASP routines will be based exclusively on LAPACK and BLAS and therefore will be usable for other similar libraries. In particular, they can be included in new releases of SLICOT without modification. The same holds for the forthcoming releases of SLICOT, in particular Release 3 of SLICOT in which all routines will be made independent of the NAG library and will be based solely on LAPACK and BLAS instead. There are, of course, other requirements that have to be fulfilled in order to make the libraries mutually compatible, such as the use of the same naming conventions, the exclusive transfer of data or results or error information through formal parameters, the avoidance of common blocks for data transfer and the way of error processing at the computational layer.

Numerics in Control Network NICONET, aims and tasks

The cooperation as sketched above between the partners within the consortium WGS, NAG and DLR has proved to be fruitful. Detailed plans have been developed to extend the scope of this cooperation to a European level. Therefore a European network for development and evaluation of numerically reliable software in control engineering will be set up. This network will be called Numerics in Control Network NICONET. The exploratory phase of NICONET will be part of the Brite/EuRam III RTD Thematic Network program. The objectives of NICONET can be summarised as follows:

- to intensify the research in and collaboration on numerics in control, to be achieved by stimulating collaboration, exchanging specialists between academic and industrial research units in Europe;
-to organise and stimulate information exchange between institutes. The availability of freeware of scientific quality and improvement of information exchange should appeal to many potential partners. The availability of expert advice should be a valuable addition to this for industrial partners. The use of electronic means to contact these partners is most appropriate: the WGS newsletter (electronic version), the www home page of WGS, which can now be found at the site http://www.win.tue.nl/wgs and the software repository of the SLICOT freeware will be major assets to be established;
- to realise a standard control library SLICOT which is mature with respect to size, completeness and quality. This is achieved firstly by integration of RASP and SLICOT and next by improving and benchmarking it and by adapting it for easy implementation in general purpose CACSD packages. WGS started recently the benchmarking program that aims for developing tools for evaluation and comparison of control methods. A freely available SLICOT benchmark collection will be composed which will accompany the SLICOT library for each of the major problem areas. These examples will show the domain of applicability and the shortcomings of the methods, especially in application-oriented examples;
- to further evaluate the library for industrial use. This should be assessed by real industrial applications with respect to performance, reliability, versatility etc. In particular SLICOT should be turned into an efficient package for large scale applications. There is a growing need for such software, since large scale models are being used more and more in industrial applications. Such models result from higher precision discretisations of continuous phenomena that are being dealt with in industry and from further integration of processes;
- to ensure the transfer of information technology related to control of industrial processes to industry; to facilitate access to high technology software and convince industrial developers of the feasibility of this software, and the benefits of using it.

Relevance to industry

As already mentioned, in recent decades the impact of control engineering on industrial processes has spectacularly increased. The main aspects are:

- simple, conventional control strategies are replaced by strategies that aim for objectives related to production efficiency, costs, pollution, waste, etc;
- accurate and flexible operation of production processes requires extensive use of available knowledge on process behaviour. Processes can be directly driven to desired condition on the basis of known characteristics of process dynamics. Modelling and model-based control of process dynamics therefore has become an important field for most process industries;
- various forms of model based controller design have been proposed recently by researchers in academia. Several successful implementations have been realised, especially in the Hydrocarbon Processing Industries;
- multi-variable predictive control now has become an important technology in advanced process control systems. It is important to bridge the gap between industrial applied technology (such as Model Predictive Control) and scientific research in the field of process control. Reliable and robust numerical tools and techniques are the driving forces that bring these areas to each other;
- emphasis has been placed on multi-variable control, non-linear control and plant-wide control. Substantial progress in these areas can be expected in the near future;
- in the design of modern (industrial) processes an integration of the process and its controller is realised from the very first phase of the design. For instance, in mechatronics light mechanical structures are demanded. However, light structures are in principle not stiff. By using an appropriate controller a mechanical structure can be realised that is light as well as stiff.

Because of these developments a massive research on control methods, as mentioned in the preceding paragraphs,

is continuing. In recent decades the results of this research were applied in many pilot processes and in real industrial plants. Initially there was a period of scepticism in industry regarding the effectiveness and applicability of the proposed methods. This was because of a complexity of reasons: the hardware was not reliable and fast enough and the software implementation was not flexible and robust enough. Now there is a broad interest in these newer methods of modelling and control, as several convincing and successful industrial applications have been reported, see [1] and [9].

It will be clear that the applicability of, in principle, a good or promising control method is determined by the quality of its software implementation. All parts of the chain: method conception, method testing, algorithm construction, software implementation, practical implementation and instrumentation, should be of high and equal quality. Professional software will enhance the applicability of methods for practical situations, as instability of software will not play a dominant role.

As mentioned, there is still much prototype control software in research institutes that is not yet easily accessible for industrial applications. Transforming this software also to reliable and robust numerical tools and integrating it in existing CACSD software will narrow the gap between industrially applied technology and scientific research in the control area.

Conclusions

The development of efficient, reliable and portable numerical control software is a challenging and time-consuming task which involves cooperative efforts over a lasting period of time. Therefore, WGS, NAG and DLR decided to join their efforts and to come up with a joint standard control library. This library, called SLICOT, is the first step towards a standard platform for computational tools for control and systems theory. Making these tools freely available and improving information exchange, ensures an easier transfer to industry and research units, thereby attracting new contributors and enhancing the extension and use of the library. In particular, it is expected that these tools can be more easily and rapidly implemented in present CACSD packages, thereby substantially improving the performance and robustness of the existing controllers and the traditional production processes in industry. A European thematic network for numerics in control NICONET will be set up which aims to extend the basis of cooperation.

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