NICONET: NETWORK FOR PERFORMANT NUMERICAL SOFTWARE DEVELOPMENT IN CONTROL ENGINEERING

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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 systems design. To avoid duplicating the implementation efforts and ensure a wider dissemination, the originators of the SLICOT and RASP libraries have agreed to combine their libraries and make the joint library freely available. To extend the scope of cooperation, a thematic network for numerics in control NICONET is set up. This paper motivates the need for such a network and describes the objectives, benefits and main network activities.

Keywords. Computer-aided control systems design, numerical algorithms, software tools, software performance, control algorithms, system theory

1. INTRODUCTION

One of the great challenges of modern society is to find a good balance between industrial activities, i.e. the production of goods, and environmental needs. Control engineering can contribute to finding such a balance. Control techniques offer the possibility to analyse processes for detecting the underlying causes of unwanted behaviour, e.g. losses in the start-up and change-over phases of operation, pollution, emission of harmful elements and unwanted by-products. Furthermore, these techniques are very well suited for finding controllers which enable processes to operate in such a way that:

- resulting products have *higher quality and tighter tolerances*;
- *less energy and material* is consumed during manufacturing;
- change-over times are drastically reduced so that *smaller product series* can be made;
- processes are operated to the *limits* of their physical, chemical or biological possibilities.

In order to achieve these objectives, **advanced control techniques**, which are carefully tuned to the process to be controlled, are needed. Such techniques deal very often with the construction of a model for the process, leading to **system identification**, and with optimal and adaptive control. A nice application of control techniques is the modeling and model-based controller design of glass tube production processes as described in (Backx *et al.*, 1992).

Progress in **information technology** has considerably facilitated the implementation of advanced control strategies and has been ever increasing in industrial applications the last 10 years. These applications range from *home appliances* (such as the CD player) to *complex production processes* (such as glass furnaces, assembly lines or chemical plants). An essential part of a control strategy consists of numerical calculations. However, this aspect of the software, as implemented in industrial sites, frequently fails to satisfy the *reliability criteria* that are already commonly used in **numerical mathematics**. This is because an industrial designer often is not well informed about the state of the art in numerical analysis, and may choose a straightforward method in control and systems theory. These methods do not always work well when applied to real-life problems, which are often ill-posed or are of too high dimensionality, in other words: difficult from the computational point of view (Laub *et al.*, 1993). Control engineers and system theorists gradually begin to realise the necessity of paying more attention to the **numerical quality** of their methods. In the last decade, a growing and fruitful interaction has emerged between the fields of numerical linear algebra and that of control and systems theory.

At the same time, much effort has been invested in the construction of user-friendly **Computer Aided Control Systems Design (CACSD)** packages. Nowadays, some of these packages, like Matlab and Xmath, have become generally accepted. This has highly influenced the practice of analysis and design of control systems, as many useful techniques have become available, in a *user-friendly interactive* fashion, to the designers of control systems.

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. 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, interactive CACSD packages. In the past, several attempts have been made to realise a basic routine library: see (van den Boom *et al.*, 1996) for an overview. Major reasons why these attempts have been terminated before they reached maturity were an *insufficiently broad basis* of collaboration or termination of funds, and consequently a lack of manpower. Apparently, to date, only two libraries, RASP (Grübel *et al.*, 1991; Grübel *et al.*, 1993) and SLICOT (Numerical Algorithms Group, 1993), are still being developed actively. The effort to develop a library is very intensive. Therefore a coordinated future development of the RASP and the SLICOT libraries into a joint library has been established to reduce the implementation efforts.

The aim of the presented thematic network **NICONET** is *to extend these RASP/SLICOT coordination efforts* to other European initiatives on software development in the area of **numerical control** and to act as an **information center**.

2. STATE OF THE ART AND OBJECTIVES

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 layers of basic computational algorithms.* In fact this layer in particular determines the quality of the outcome. Examples are described in (van den Boom *et al.*, 1992), which 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 interpreted Matlab code, e.g. for deadbeat control, solving Lyapunov, Ricatti and Sylvester equations, pole placement, and so on.

At this moment there is a lot of expertise at the research institutes with respect to useful methods. However these methods have to be converted to algorithms and software of a professional level and special emphasis on **numerical quality** should be given. More precisely these software products can best be incorporated in a well defined and standardised control library that can be used and integrated in all levels of application in industry and in all kinds of designing, testing and production environments. The RASP/SLICOT cooperation is a first step towards this goal.

SLICOT (Numerical Algorithms Group, 1993), a general purpose basic control library realised by the Working Group on Software (WGS) [1] in cooperation with NAG, can primarily be viewed as a *mathematical library for control theoretical computations.* The library provides tools to perform basic system analysis and synthesis tasks. The main emphasis in SLICOT is on *numerical reliability* of implemented algorithms and the *numerical robustness and efficiency* of routines. Special emphasis is put on providing maximal algorithmic flexibility to users, and on the use of rigorous implementation and documentation standards (see (Working Group on Software, 1990)). The present release of the SLICOT library contains about 90 user-callable routines (see (van den Boom *et al.*, 1991; Numerical Algorithms Group, 1993)).

RASP (Grübel *et al.*, 1991; Grübel *et al.*, 1993) 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

[1] For more information, see the WGS web site http://www.win.tue.nl/wgs/wgs.html

and is used in education and research at many universities and research sites in Germany. RASP, together with the engineering-database and -operating system RSYST, form the software infrastructure of the computer aided control engineering environment ANDECS. RASP and ANDECS are products of the Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V. (DLR) Oberpfaffenhofen, Germany.

In order to reduce the implementation efforts, DLR and WGS have agreed to combine their activities and set up a joint library. For the sake of this cooperation, the **RASP/SLICOT mutual compatibility concept** has been introduced (Grübel *et al.*, 1994). Part of this agreement is the incorporation of the numerical linear algebra packages, BLAS (Dongarra *et al*, 1990) and LAPACK (Anderson *et al.*, 1995), in both libraries and in the future joint library.

To extend this current collaboration, the Commission of the European Communities has given an exploratory award to WGS in order to set up a thematic Numerics in Control network in the field of Industrial and Applied Technologies, entitled NICONET [2] . The objectives of **NICONET** can be summarized as follows:

- to *intensify* the research in and collaboration on **Numerics in Control** in which European teams play a prominent role on a world scale. This is achieved by stimulating the collaboration of control specialists and numerical scientists, by exchanging specialists between academic and industrial research units and by the organisation of information exchange between academic and industrial research units within Europe.
- to *integrate* the SLICOT and RASP control libraries into a joint library, to *extend, improve* and *benchmark* it and to *adapt* it for easy implementation in general purpose CACSD packages.
- 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 in using it.

3. NETWORK ACTIVITIES

A lot of coordination activities necessary in a network have been already set up by WGS, in particular:

- a restricted control library (SLICOT), which covers part of the control area, is already available;
- implementation and documentation standards for the routines in the SLICOT library have been set up and are described in (Working Group on Software, 1990);
- information exchange is realised by the issue of the WGS Newsletter containing information on the evaluation of the SLICOT library and the newest developments on software related to control and system theory, and the publication of an Extended List of Control Software (ELCS), a collection of one-page summaries on CACSD packages and related software libraries.

The present network NICONET can benefit from these past efforts in setting up a well-operating European network built on active collaboration. In order to evaluate the feasibility and importance of the network activities proposed below, WGS has set up a questionnaire for obtaining an inventory of existing research activities in the area of control software, a list of potential partners ready to contribute, and an assessment of the relevance of the NICONET objectives and the network activities. The questionnaire has been sent out to 285 people and the results, based on 55 answers from people working at universities or research institutes and 17 answers from people working in industry, are reported below. For more details, see (Working Group on Software, 1997). Ten network activities to be coordinated through NICONET have been proposed and evaluated by means of a number from zero (no interest) to five (high priority). For each activity, the sample mean score is given together with the sample standard deviation (after the $\pm$ sign), as well as a short summary of the given comments (in italics).

(1) "In the past, WGS essentially relied on the expertise and software developed by its own members. Each contributor had its own focus, so that the present library only covers part of the whole field. Therefore the participants list should be expanded and a **European network is ideal** for this purpose" (score: 3.76 ± 1.24).
The establishment of a European network for control systems analysis and design software is of primary importance for both the software developers and users. It provides the opportunity to enlarge the areas covered, and to fulfill better the users' requirements. However, quality control on the software made available must be imposed. Therefore, feedback from others than the developers is absolutely necessary. Contributions from outside Europe could be interesting too, but the creation of a European network is certainly a major step. In addition, it is important that the network has a group of members active in software related topics, in order

[2] For more information, see the NICONET web site http://www.win.tue.nl/wgs/niconet.html

to have some efficiency.

(2) "The main aim of WGS is to see the library be used by as many scientists and engineers in industry as possible, so that the careful efforts of the contributors bear fruit. This requires a wider distribution, and in order to guarantee this, **a better integration of the SLICOT library in a user friendly environment** is needed" (score: 4.06 ± 1.19).
Most software users want to have flexible and powerful, but easy-to-use tools. Therefore, an integration of the SLICOT library in a user-friendly environment such as Matlab is a prerequisite for a wide distribution of software. If it is not easy to use it will not be used, certainly not in industry!

(3) "A first step in this direction could be the **use of a compiler that automatically passes the function parameters** from the CACSD environment, such as Matlab, to any Fortran routine of the SLICOT library and back (e.g. the NAGWare Gateway Generator, developed by NAG), which clearly makes the routines of a Fortran library available to a broader group of users" (score: 3.99 ± 1.27).
This is strongly encouraged since most people in control only use Matlab and refuse to use SLICOT because of a lack of user-friendliness. However, the routines in Matlab beyond Eispack/Linpack are often quite bad. Therefore, many people would appreciate it if the routines of SLICOT are available in a package like Matlab. A single homogeneous user-interface is of high importance: often people are willing to sacrifice speed for ease of use. However, people do want reliable answers, and therefore reliable software is needed. In addition, the availability of SLICOT in other common packages and on different platforms would be very much appreciated.

(4) "**Software engineering aspects** have to be further elaborated and **tested in the context of a practical industrial application**. This should allow us to evaluate and benchmark the SLICOT library on end-user problems and will be a more realistic validation of the user-friendliness of the product" (score: 3.85 ± 1.23).
The real-world applications are the ultimate means for validating any theory, design, or software product. Moreover, these applications provide useful suggestions for extending the scope of the SLICOT library, for improving the efficiency, robustness, and usefulness. In industry the SLICOT library is most likely to be used in a research department, not in actual manufacturing.

(5) "The further evolution of the library should be assessed by real industrial applications with respect to its performance, reliability, versatility and so on. In particular, SLICOT should be turned into an **efficient package for large scale applications**" (score: 3.53 ± 1.23).
SLICOT should be at first kept as a subroutine library for standard problems without having large-scale applications in mind. First of all, there will always be the need for the numerical solution of standard problems. Second, not all control problems have also large-scale counterparts. Moreover, large-scale problems are often very different in nature and therefore require different programming models/computer environments. The design of a library for large-scale applications should complement SLICOT, but first there is a need to define the problems where large-scale problems arise. The approach could be similar to the extensions of LAPACK: there is a basic subroutine library, and then there are subroutine libraries for several large-scale applications, e.g., ScaLAPACK, PLAPACK,... In this context high performance computer tools are appropriate (software packages like BLAS, LAPACK and new parallel packages should be used).

(6) "We will not only implement our software in applications of industrial partners of the network, but also **try out more advanced control strategies** that were developed by academic experts and proven to perform better than the conventional methods" (score: 4.08 ± 1.07).
It is of major importance to develop demonstration programs that prove that the academic approach has significant advantages over the approach the engineer uses which may be well-known, robust, used for years, and much easier to understand. The proof should be such that applied engineers having only a basic mathematical/numerical knowledge can easily see that the new approach saves time and money. In addition, cooperation with toolboxes or solution providers (Aspentech, Mathworks) is important.

(7) "In order to guarantee a proper distribution of the SLICOT library, we are convinced that the product ought to be made **freely available**" (score: 4.29 ± 1.36). 16 persons are interested in commercial support, 38 are not interested and 18 persons didn't answer this question (some of which found the question too unclear).
Free availability is great but a commercial version with support is the best choice for another group of people. Optimally, both should be available. Indeed, there is a difference between academic and industrial users. In academia, one is happy to have freely available software. For industrial users, it can be of major importance that there is an address where they can ask for support/troubleshooting. Often, people trust software only because it is commercial rather than public domain. In addition, this

policy allows to use most of the NETLIB programs, e.g. LAPACK, GNU.

(8) "We want to start an **electronic journal for control and systems software**. The rationale for this is twofold. First, we expect that software submissions to this journal will be valuable additions to the SLICOT library. Secondly, we wish to try to collect evaluations and comparisons of software for systems and control theory" (score: 3.88 ± 1.28).
If the review procedure is fast this is a very interesting way to speed up the spread of results (in many journals it takes about 2 or 3 years). However, the number of journals already existing is rather high. In particular, there is a new electronic journal of control that was just started by INRIA. Could this activity be combined with this journal or another journal in control or software? In addition, control benchmarks should be included.

(9) "The **use of electronic means** is most appropriate in setting up our network: the newsletter (electronic version) and the WWW home page, the software repository of the SLICOT freeware and a new electronic journal will be major assets for the participants of the network to be established" (score: 3.99 ± 1.35).
The use of electronic means as described above is clearly most appropriate in setting up the network. These means will also provide the needed communication between the teams working in control system areas, either in academia or industry. However, the care and cost to maintain an electronic system must not be underestimated. In addition, it should be noted that outside of universities the use of electronic means is not standard, or sometimes an expensive standard.

(10) "**Regional workshops** around the topic of control algorithms and software with emphasis on **industrial applications** will be organised" (score: 3.67 ± 1.24).
These workshops could best be organized in connection with existing conferences and should not necessarily be regional. International (European) conferences could also be organized occasionally in order to stimulate exchanges and collaborations. Costs are to be kept low. It is expected that these workshops will promote the recent advances in the field of control algorithms and software and will strengthen the relationship between researchers from academia and industry. Of course, industrial participation should be assured. In addition, the organisation of short courses for researchers in industry is encouraged.

Nineteen people expressed their strong interest in contributing actively to the network and also specified their possible contribution.

In addition, the following **additional network activities** have been proposed. *NICONET should grow to a network of excellence. However, the above activities are already extensive. Therefore, it is better to concentrate on those before trying to expand further. The transfer of automatic control technology and tools from one region (or country) to another could also be an important topic for the network. In particular, a related objective of the network could be to facilitate the effective cooperation between teams and individuals involved in control systems analysis, design and implementation. Providing some financial support, for instance for participating in regional workshops, could be necessary for some individuals, especially from eastern and central European countries.*

Finally, it should be noted that all but one replier use Matlab which is mainly due to the user-friendliness of the product. Also, the Matlab toolboxes are very popular (used by 65 people). More than 30 software contributions have been reported in diverse control areas, in particular in system identification, optimal control, model reduction, time and frequency response. Despite these contributions, almost all repliers expressed their needs for new software (preferably in Matlab or Fortran 77) in all areas of systems and control and pointed out the lack of tools to increase the efficiency of software development in process control applications.

4. CONCLUSION

A thematic Numerics in Control network NICONET has been presented. The aim is to formalise and extend current collaboration into a European network to coordinate the development of robust numerical software for control systems analysis and design. The objectives and proposed network activities have been evaluated recently by means of a questionnaire. The results show that the control community has a high interest in all proposed NICONET activities. The expansion of the present WGS network (NICONET partners in the exploratory phase) to a European level is strongly encouraged in order to obtain a wider base of software developers and potential users. The network should focus on the development of numerically reliable and efficient control related software which should be freely available and embedded in a user-friendly environment such as Matlab in order to guarantee its widespread use in both academia and industry. In addition, the library should be benchmarked and validated by means of real industrial examples. Commercial support should be provided too, especially for industry. Finally, the use of electronic means is the most flexible and user-friendly way to enhance information exchange and collaboration within the network.

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