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NICONET Newsletter

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1 Editorial

Welcome to the seventh issue of the NICONET newsletter which informs you about the evolution of the SLICOT library and its integration in user-friendly environments such as `Scilab` and MATLAB, as well as about other NICONET activities related to CACSD software developments.

In the last 6 months several important events happened which are worthwhile to be mentioned. First of all, we submitted a new EC proposal in the Growth programme (accompanying measures) in March 2001 in order to guarantee further support for NICONET activities upon termination of the NICONET project (December 31, 2001). Unfortunately, the proposal hasn't been approved. At present we are exploring other ways to support our activities. In particular, we are setting up an international society NICONET which promotes and supervises the dissemination of the SLICOT software.

Sections 2 to 6 present as usual the new updates of the SLICOT library in subfields of systems and control. In Section 7, the importance of SLICOT in industrial control is discussed. In particular, the company OMRON and the *Universidad Politécnica de Valencia* (UP-Valencia), both NICONET partners, have developed a demonstrator for the simulation and optimisation of water supply networks, which is presented here. Section 8 gives more details about the newest additions to the SLICOT library, new reports and forthcoming events. Finally, Section 9 includes the announcement of our SLICOT training course in Bremen, Germany, in September 2001. We invite all of you to register for this training course, a unique opportunity we offer our users to learn about SLICOT and its toolboxes, its power and advantages with respect to other CACSD packages such as Matlab!!

I hope you enjoy reading this newsletter.

Sabine Van Huffel
NICONET coordinator

2 Basic numerical SLICOT tools for control

2.1 Task I.A : Standard and generalized state space systems and transfer matrix factorizations

The final report of Task I.A can be found in Newsletter 4, but as explained there we decided to continue to add new routines if such a need would be justified by the other tasks. The following basic routines were added for diverse tasks.

Name	Function
AB08MD	to compute the normal rank of the transfer-function matrix of a state-space model (A,B,C,D).
AB09JD	to compute a reduced order model (Ar,Br,Cr,Dr) for an original state-space representation (A,B,C,D) by using the frequency weighted optimal Hankel-norm approximation method.
AB09JV	to construct a state-space representation (A,Bs,Cs,Ds) of the projection of V*G or conj(V)*G containing the poles of G, from the state-space representations (A,B,C,D) and (AV-λ*EV,BV,CV,DV), of the transfer-function matrices G and V, respectively.
AB09JW	to construct a state-space representation (A,Bs,Cs,Ds) of the projection of G*W or G*conj(W) containing the poles of G, from the state-space representations (A,B,C,D) and (AW-λ*EW,BW,CW,DW), of the transfer-function matrices G and W, respectively.
AB09JX	to check stability/antistability of finite eigenvalues with respect to a given stability domain.
AB13DD	to compute the L-infinity norm of a continuous time or discrete-time system, either standard or in the descriptor form.
AB13DX	to compute the maximum singular value of a given continuous-time or discrete-time transfer-function matrix, either standard or in the descriptor form.
AG07BD	to compute the inverse (Ai-λ*Ei,Bi,Ci,Di) of a given descriptor system (A-λ*E,B,C,D).
TG01BD	to reduce the matrices A and E of a system pencil corresponding to the descriptor triple (A-λ E,B,C) to generalized upper Hessenberg form using orthogonal transformations.
TG01WD	to reduce the pair (A,E) of a descriptor system to a real generalized Schur form using an orthogonal equivalence transformation, (A,E) $\leftarrow$ (Q'*A*Z,Q'*E*Z) and to apply the transformation to the matrices B and C: B $\leftarrow$ Q'*B and C $\leftarrow$ C*Z.

Most of these routines are for Task II.B, where they are also briefly reported.

Vasile Sima, Andras Varga and Paul Van Dooren

2.2 Task I.B : Structured matrix computations

The routines for Hankel and Toeplitz matrices described in the previous newsletter have been updated in order to increase their functionality. The following routines were implemented as basic routines :

Name	Function
MB02FD	to compute the incomplete Cholesky (ICC) factor of a symmetric positive definite block Toeplitz matrix T, defined by either its first block row, or its first block column.
MB02GD	to compute the Cholesky factor of a banded symmetric positive definite block Toeplitz matrix.
MB02HD	to compute the Cholesky factor of the matrix T'*T, with T a banded block Toeplitz matrix of full rank.
MB02ID	to solve overdetermined or underdetermined real linear systems involving a full rank block Toeplitz matrix.
MB02JD	to compute a full QR factorization of a block Toeplitz matrix of full rank.
MB02JX	to compute a low rank QR factorization with column pivoting of a block Toeplitz matrix.
MB02KD	to compute the product C = alpha*op(T)*B + beta*C, where alpha and beta are scalars and T is a block Toeplitz matrix.

These Fortran programs are accessed in the interactive environment Matlab or Scilab via the same mex and m.files as for the earlier Fortran codes :

Name	Function
fstoep.f	a mexfile to access all structured matrix routines
fstchol.m	computes the Cholesky factor of a symmetric positive (block) Toeplitz matrix and its inverse
fstgen.m	factors a symmetric positive definite (block) Toeplitz matrix and computes the generator of its inverse.
fstsol.m	solves a linear system $X * BT = B$ or $BT * X = B$, with BT a symmetric positive definite (block) Toeplitz system.
fstupd.m	updates a factorization of a symmetric positive definite (block) Toeplitz matrix or solves the associated linear system

The associated test functions and a Matlab 5.3 demonstration package are available via the NICONET homepage. The revised report SLWN2000-2(b) describes the functionality of these routines.

[1] D. Kressner and P. Van Dooren, Factorizations and linear system solvers for matrices with Toeplitz structure, SLICOT Working Note 2000-2 (revised), June 2001.

Daniel Kressner, Vasile Sima and Paul Van Dooren

3 SLICOT tools for model reduction

3.1 SLICOT tools for controller reduction

Recently, within Subtask II.B.1, a new user callable routine **AB09JD** for the *frequency-weighted Hankel-norm approximation* (FWHNA) method has been implemented. This routine solves the FWHNA problem for invertible proper weights using the recently developed descriptor system formulation for computing stable projections [6]. The new projection formulas do not need to assume that the weights are biproper or have zeros restricted to special regions of the complex plane. The lower level routines **AB09JV** and **AB09JW** implement the computation of stable projections for left and right frequency weights using the new descriptor system formulation proposed in [6].

Four new user callable basic routines have been implemented for the special needs of model/controller reduction software. These are: **AG07BD** to perform descriptor system inversion, **AB13DD** to compute the L_∞-norm of a system, **AB08MD** to determine the normal rank of the transfer-function matrix of a state-space system, and **TG01BD** to reduce a descriptor system to orthogonal generalized Hessenberg form. These new basic routines enter in SLICOT as contributions to Task I.A (extended over the whole period of the project). Overall, 37 new routines have been implemented within subtask II.B.1.

The main activity within Subtask II.B.2 was the development of flexible and powerful user friendly interfaces to the newly implemented model and controller reduction routines for both MATLAB and Scilab.

The implemented mex-functions complement the mex-function `sysred` implemented for additive error methods in the first part of the NICONET Project. The new mex-functions are able to reduce both stable and unstable as well as continuous- and discrete-time systems or controllers. The frequency-weighted model reduction functions can also be used for unweighted reduction. The implemented new mex-functions for model/controller reduction are:

Name	Function
`bstred`	balanced stochastic truncation based model reduction [5, 4] (based on AB09HD)
`fwered`	frequency-weighted balancing related model reduction [2, 7] (based on AB09ID)
`fwehna`	frequency-weighted Hankel-norm approximation [6] (based on AB09JD)
`conred`	frequency-weighted balancing related controller reduction [1, 8] (based on SB16AD)
`sfored`	coprime factorization based reduction of state feedback controllers [3] (based on SB16BD and SB16CD)

Easy-to-use m-functions have been implemented for MATLAB and Scilab to provide a convenient interface to the implemented mex-functions. These tools allow to work directly with control objects as defined in the Control Toolbox of MATLAB or in Scilab. The implemented m-functions for model/controller reduction are:

`bst`	balanced stochastic truncation based model reduction
`fwbred`	frequency-weighted balancing related model reduction
`fwhna`	frequency-weighted Hankel-norm approximation
`fwbconred`	frequency-weighted balancing related controller reduction
`sfconred`	coprime factorization based state feedback controller reduction
`sysredset`	creation of a SYSRED options structure
`sysredget`	extracts the value of a named parameter from a SYSRED options structure

To manage the combinatorial complexity of the multitude of possible user options, a special SYSRED structure has been defined. Each entry in this structure represent a specific setting of a method parameter or of an algorithmic options. Two special functions `sysredset` and `sysredget` have been implemented to create/setup this structure and to extract values of option parameters. The available options can be seen in Figure 1.

```
          BalredMethod: [ {bta} | spa ]
     AccuracyEnhancing: [ {bfsr} | sr ]
                Tolred: [ positive scalar {0} ]
            TolMinreal: [ positive scalar {0} ]
                 Order: [ integer {-1} ]
             CStabDeg: [ nonpositive scalar | {-sqrt(eps)} ]
             DStabDeg: [ subunitary scalar | {1-sqrt(eps)} ]
               BstBeta: [ scalar {0}  ]
      FWEContrGramian: [ {standard} | enhanced ]
     FWEObservGramian: [ {standard} | enhanced ]
        FWEAlphaContr: [ positive subunitary scalar {0} ]
       FWEAlphaObserv: [ positive subunitary scalar {0} ]
  CoprimeFactorization: [ left | {right} ]
          OutputWeight: [ {stab} | perf | none]
           InputWeight: [ {stab} | none]
        CFConredMethod: [ {fwe}  | nofwe ]
       FWEConredMethod: [ none | outputstab | inputstab | {performance} ]
          FWEHNAMethod: [ {auto} | inverse | noinverse ]
            FWEHNAopV: [ {none} | inv | conj | cinv ]
            FWEHNAopW: [ {none} | inv | conj | cinv ]
           FWEOptimize: [ none | {d} | cd ]
```

Figure 1: SYSRED Options Structure

An intensive testing of all implemented routines for model and controller reduction has been performed via the newly developed m- and mex-files. For this purpose, special benchmark problems for controller reduction have been chosen and the capabilities of different approaches to perform controller reduction preserving closed-loop stability and performance have been investigated. Four test suites for testing the implemented m- and mex-functions have also been implemented. All these functions can be freely downloaded from the SLICOT library ftp site.

References

[1] B. D. O. Anderson and Y. Liu. Controller reduction: concepts and approaches. *IEEE Trans. Autom. Control*, 34:802–812, 1989.

[2] D. Enns. *Model Reduction for Control Systems Design.* PhD thesis, Dept. Aeronaut. Astronaut., Stanford Univ., Stanford, CA, 1984.

[3] Y. Liu, B. D. O. Anderson, and U. L. Ly. Coprime factorization controller reduction with Bezout identity induced frequency weighting. *Automatica*, 26:233–249, 1990.

[4] M. Green and B.D.O. Anderson. Generalized balanced stochastic-truncation. In *Proc. 29th CDC*, pages 476–481, 1990.

[5] M. G. Safonov and R. Y. Chiang. Model reduction for robust control: a Schur relative error method. *Int. J. Adapt. Contr.&Sign. Proc.*, 2:259–272, 1988.

[6] A. Varga. Numerical approach for the frequency-weighted Hankel-norm approximation. *(submitted ECC'2001)*, 2001.

[7] A. Varga and B. D. O. Anderson. Square-root balancing-free methods for the frequency-weighted balancing related model reduction. *(submitted CDC'2001)*, 2001.

[8] A. Varga and B. D. O. Anderson. Frequency-weighted balancing related controller reduction. *(paper in preparation to be submitted IFAC'2002).*

Andras Varga

3.2 SLICOT tools for model reduction of high order systems

3.2.1 Direct methods for model reduction

Direct methods for Model Reduction based on Balanced Realisations require the solution of standard Lyapunov equations. This also requires the computation of the Schur form of a matrix. The work done by UP-Valencia regarding this point is the implementation of two driver parallel routines for computing the Schur decomposition and solving Standard Lyapunov Equations. ScaLAPACK library constitutes a very good parallel kernel for many basic algebra problems. However, the computation of the Schur form from a general matrix was not provided as a driver routine. Instead, routines for reduction from general to Hessenberg form and from Hessenberg to Schur form were provided. UP-Valencia has integrated both routines in a single one. The second problem taken into account is the solution of the Standard Lyapunov Equation. It is first reduced to a simpler form, by means of the Schur factorisation and products of matrices, which have been improved for this particular purpose. To solve the reduced Lyapunov equation, a parallel kernel has been implemented by using Hammarling's approach. The kernel works on a distributed memory PC cluster with good accuracy and efficiency. The performance is only limited by the behaviour of the `PDGEES` ScaLAPACK routine, which does not provide very high efficiency at some cases. The test cases used comprise two 2001x2001 matrices (composed of 3x3 blocks) with different eigenvalues. Example test cases

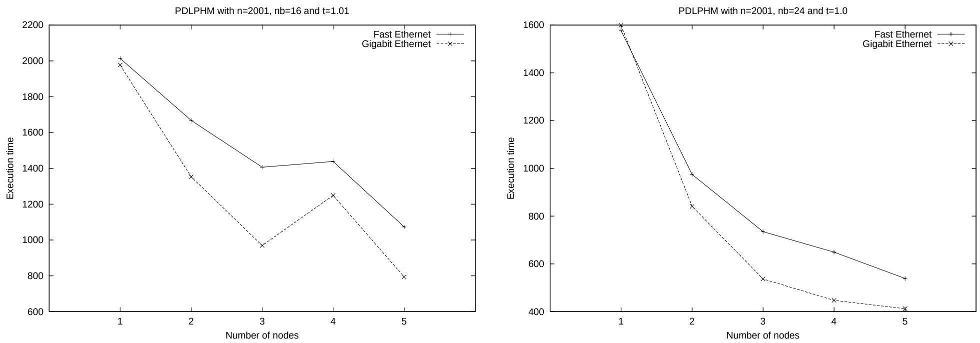

Figure 2: Time spent solving example 1 (left) and example 2 (righ t) Lyapunov equations in parallel using different configurations.

comprise a coefficient matrix obtained as $W_n^{-1} diag(A_1, A_2, ..., A_q) W_n$, where W is a matrix of ones, except for the diagonal, which contains zeros, and A_i matrix blocks with the form

$$A_i = \begin{pmatrix} t^i & 0 & 0 \\ 0 & t^i & t^i \\ 0 & -t^i & t^i \end{pmatrix}$$

where t is 1.0 for example 1 and 1.01 for example 2. Coefficient matrix B is of the form

$$B = \begin{pmatrix} n & n-1 & \cdots & 1 \\ n-1 & n & \cdots & 2 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 2 & \cdots & n \end{pmatrix}.$$

Figure 2 shows the time spent on solving the 2 examples using up to five processors.[1]

Vicente Hernandez

3.2.2 Model reduction based on iterative solvers for computing the system Gramians

The integration on parallel computers of the model reduction subroutines based on iterative solvers was finalized. Table 1 lists the user-callable subroutines that have been integrated into PSLICOT. These routines will be available from the SLICOT ftp site after the next update.

Besides, 12 lower-level subroutines were also tested and integrated into PSLICOT. All routines have been successfully installed on a cluster of Linux-PCs with 32 nodes. Numerical results reporting the accuracy, reliability and performance of the underlying methods can be found in [1–4]. The implementation and standardization of these methods for integration into PSLICOT is reported in [5].

References

[1] The experiments were executed on a 5 biprocessor 866 MHz Pentium III PC system linked with a Gigabit Ethernet LAN.

Routine	Purpose
PAB09AX	computes reduced (or minimal) order balanced models using either the **SR** or the **BFSR** B&T method
PAB09BX	computes reduced order models using the **BFSR** or **SR** SPA method
PAB09CX	computes reduced order models using the optimal HNA method based on **SR** balancing
PAB09DD	applies the singular perturbation approximation formulae to a general system
PSB03ODC	solution of coupled stable Lyapunov equations for full-rank factor using sign function method.
PSB03ODD	solution of coupled stable Stein equations for full-rank factor using squared Smith iteration or sign function method.
PSB04MD	solves a stable Sylvester equation using the sign function method.
PMB05RD	computes the sign function of a matrix using the Newton iteration.
PMB03TD	computes the singular value decomposition of a matrix product.
PMB03OX	estimates the rank of a triangular matrix using an incremental condition estimator.

Table 1: PSLICOT subroutines for absolute error model reduction based on iterative solvers

1. Peter Benner, Enrique S. Quintana-Ortí and Gregorio Quintana-Ortí, *Balanced Truncation Model Reduction of Large-Scale Dense Systems on Parallel Computers*, Mathematical and Computer Modelling of Dynamical Systems, vol. 6, no. 4, pp. 383–405, 2000.

2. Peter Benner, Enrique S. Quintana-Ortí and Gregorio Quintana-Ortí, *Efficient Numerical Model Reduction Methods for Discrete-Time Systems*, *Proceedings of the IMACS Symposium on Mathematical Modelling, 3rd MATHMOD Vienna, Vienna University of Technology, Austria, February 2-4, 2000*, vol. 1, pp. 277–280. ARGESIM-Reports No. 15.

3. Peter Benner, Enrique S. Quintana-Ortí and Gregorio Quintana-Ortí, *Singular Perturbation Approximation of Large, Dense Linear Systems*, *Proc. 2000 IEEE Intl. Symp. CACSD, Anchorage, Alaska, USA, September 25–27, 2000*, pp. 255–260. Omnipress, Madison, WI, 2000.

4. Peter Benner, Enrique S. Quintana-Ortí and Gregorio Quintana-Ortí, *Parallel Algorithms for Model Reduction of Discrete-Time Systems*, Report 00–18, Berichte aus der Technomathematik, Fachbereich 3 – Mathematik und Informatik, Universität Bremen, December 2000. Available from `http://www.math.uni-bremen.de/zetem/berichte.html`.

5. Peter Benner, Enrique S. Quintana-Ortí and Gregorio Quintana-Ortí, *PSLICOT Routines for Model Reduction of Stable Large-Scale Systems*, *Proc. 3rd NICONET Work-*

shop on Numerical Software in Control Engineering, Louvain-la-Neuve, Belgium, January 19, 2001, pp. 39–44.

Peter Benner

4 SLICOT tools for subspace identification

4.1 Standard software for nonlinear state space model identification

The previous phase of this task concentrated on the identification of multivariable nonlinear Wiener systems. Such systems are a concatenation of a linear dynamic block followed by a static nonlinearity. An inventory of existing algorithms focused on schemes that enable the linear part to be represented in state space form. This inventory lead to the selection of a combination of a variant of the subspace identification method and a single layer neural network to model the static nonlinearity.

The standardization of the associated, planned routines for identification of nonlinear, state space systems has been completed, but further polishing appeared as necessary for improving the reliability and speed. Improvements will be performed in the next months, in parallel with the work on the other subtasks of the Task III.B (integration of the routines in Matlab and Scilab, selection of benchmark problems, preparation of the toolbox).

A list of the routines and a brief description of their functionality is given below. The list includes the related mathematical and transformation routines which have been developed for the Task III.B.

Name	Functionality
IB03AD	to compute a set of parameters for approximating a Wiener system in a least-squares sense, using a neural network approach and a Levenberg-Marquardt algorithm.
MB02WD	to solve a system of linear equations $Ax = b$, with A symmetric, positive definite, or, in the implicit form, $f(A, x) = b$, where $y = f(A, x)$ is a symmetric positive definite linear mapping from x to y, using the conjugate gradient algorithm without preconditioning.
MB02XD	to solve a set of systems of linear equations, $A^T AX = B$, or, in the implicit form, $f(A)X = B$, with $A^T A$ positive definite, using symmetric Gaussian elimination.
MD03AD	to find the parameters θ for a function $F(x, \theta)$ that give the best approximation for $y = F(x, \theta)$ in a least-squares sense.
NF01AD	to compute the output of a Wiener system.
NF01AY	to compute the output of a set of neural networks.
NF01BD	to compute the Jacobian of a Wiener system.
NF01BU	to compute the matrix $J^T J + cI$, for the Jacobian J given in a compressed form.
NF01BV	to compute the matrix $J^T J + cI$, for the Jacobian J fully given, for one output variable.
NF01BW	to compute the matrix-vector product $x \leftarrow (J^T J + cI)x$, where J is given in a compressed form.
NF01BX	to compute $x \leftarrow (A^T A + cI)x$, where A is an $m \times n$ real matrix, and c is a scalar.
NF01BY	to compute the Jacobian of the error function for a neural network (for one output variable).

`TB01VD` to convert the linear discrete-time system given as (A, B, C, D), with initial state x_0, into the output normal form, with parameter vector θ. The matrix A is assumed to be stable. The matrices A, B, C, D and the vector x_0 are transformed, so that on exit they correspond to the system defined by θ.

`TB01VY` to convert the linear discrete-time system given as its output normal form, with parameter vector θ, into the state-space representation (A, B, C, D), with the initial state x_0.

`TF01MY` to compute the output sequence of a linear time-invariant open-loop system given by its discrete-time state-space model (A, B, C, D), where A is an $n \times n$ general matrix (the input and output trajectories are stored differently from SLICOT Library routine `TF01MD`).

Several mexfiles have been developed. They could be used both for testing purposes, but also for problem solving. The documentation of the use of the developed routines, and their integration into Matlab and Scilab via mexfiles will be documented in a SLICOT Working Note (a preliminary version has already been produced).

Vasile Sima and Michel Verhaegen

5 SLICOT tools for robust control

The Topic IV group in the last six months has been working on development of subroutines, testing and case studies, and development of interface with Scilab.

Two subroutines were completed: **sb10zd**, for the discrete-time $\mathcal{H}_\infty$ loop shaping design procedure for the general case of non-zero D term; and, **sb10gd**,for the standard $\mathcal{H}_\infty$ design based on direct formulae, which possibly improves computational efficiency and increases numerical accuracy. Another subroutine which aims at improving the coding of μ-calculation is currently in development.

For testing of developed subroutines and applying them in control systems design, several case studies were completed in the period. They include: a mass-damper spring system ($\mathcal{H}_\infty$ design), a two-cart benchmark system ($\mathcal{H}_\infty$ LSDP design), a triple inverted pendulum system (μ-synthesis and analysis), and a flight control system design exercise on the RCAM model from the GARTEUR group ($\mathcal{H}_\infty$ S over KS design and LSDP design). Good results were obtained with the SLICOT software in all the case studies.

The interface between SLICOT and Scilab is currently being developed. The interface for matrix solving routines has been completed. Those at higher levels, for instance, at design level, would be finished during the summer.

Da-Wei Gu

6 SLICOT tools for nonlinear systems in robotics

6.1 Nonlinear Systems Control

The work carried out by UP-Valencia in this area has focused on the implementation of SLICOT and MATLAB interfaces for existing software packages related to nonlinear control systems. In particular, such interfaces have been developed for the package FSQP, aimed at the solution of nonlinear optimization problems, and KINSOL, a package for the solution of algebraic nonlinear equation systems.

The FSQP (*Feasible Sequential Quadratic Programming*) package was originally developed by André Tits' group, at the Institute for Systems Research (ISR), University of Maryland. In the year 2000, it was transferred to the company *AEM Design* (http://gachinese.com/aemdesign). The package is free for academic institutions, although other research organisations and companies have to pay for its use.

FSQP solves problems of the form

$$minimize \max_{i=1,\dots,nf} f_i(x),$$

subject to

$$\begin{array}{ll} bl \leq x \leq bu & \\ g_j(x) \leq 0, & j = 1,\dots,n_i \\ g_j(x) \equiv x^T c_{j-n_i} - d_{j-n_i} \leq 0, & j = n_i+1,\dots,t_i \\ h_j(x) = 0, & j = 1,\dots,n_e \\ h_j(x) \equiv x^T a_{j-n_e} - b_{j-n_e} = 0, & j = n_e+1,\dots,t_e, \end{array}$$

that is, nonlinear optimization problems, with bounds on the decision variables, and inequality and equality constraints, both linear and nonlinear.

A SLICOT-compliant interface for FSQP has been implemented. This provides a user-callable routine (named FSQP) with a calling sequence conform to the SLICOT standards. The calling sequences of the different user-defined routines used by the package have not been altered by the SLICOT interface. A MATLAB interface for FSQP has also been implemented.

On the other hand, the package KINSOL has been developed at the Center for Applied Scientific Computing, Lawrence Livermore National Laboratory. The package is part of a larger software framework for the solution of differential (ODE and DAE) and algebraic systems, which includes the packages PVODE and IDA. It is freely downloadable from the web (http://www.llnl.gov/CASC/PVODE/).

KINSOL (*Krylov Inexact Newton SOLver*) is a general purpose nonlinear system solver, callable from either C or Fortran programs. Its most notable feature is that it uses Krylov Inexact Newton techniques in the system's approximate solution. It also requires almost no matrix storage for solving the Newton equations as compared to direct methods. The package has been designed so that selecting one of two forms of a single module in the compilation process allows the entire package to be created in either sequential (serial) or parallel form.

The nonlinear system of equations

$$F(u) = 0,$$

where $F(u)$ is a nonlinear function from $\mathbf{R}^n$ to $\mathbf{R}^n$, is solved by this package.

The SLICOT-compliant interface for KINSOL provides a user-callable routine (named KINSOL), which performs a complete non-linear system solution by calling a sequence of user-callable KINSOL routines. The MATLAB interface for the package makes use of MATLAB structure data types in order to keep the user interface as simple as possible, with a reduced number of arguments in the function calls.

Vicente Hernandez and Fernando Alvarruiz

Figure 3: The demonstrator for simulation and optimization of water supply networks.

7 SLICOT: a useful tool in industry?

7.1 Simulation and Optimisation of Water Supply Networks

7.1.1 Introduction

Computer simulation of urban water supply networks by means of mathematical models is nowadays a necessity for the exploitation and design of such networks. This simulation allows to assess whether the user demands for water will be adequately met, or if sufficient water storage will be available to be used in case of necessity, or if there might be problems with the quality of the water being supplied. For this reason, computer simulation is used both in the design of new supply networks or modifications to existing ones, and in every-day normal operation of any network.

Different software packages are available for the simulation of water supply networks. Among them, one of the most extended is EPANET, a public domain software developed by the US Environment Protection Agency (EPA).

Based on EPANET, the company OMRON and the *Universidad Politécnica de Valencia* (UP-Valencia), have developed a demonstrator for the simulation and optimisation of water supply networks (see Figure 3). The nonlinear nature of the problems solved by this demonstrator is strongly connected to Task V of the NICONET project.

In the following we describe the problems faced by the demonstrator, linking each one with a corresponding SLICOT-related nonlinear problem.

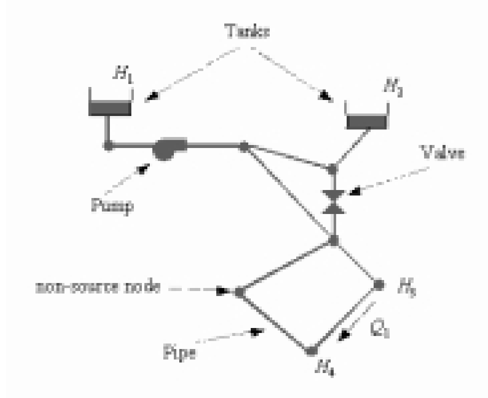

Figure 4: Scheme of a water supply network.

7.1.2 Hydraulic Simulation

A water supply network consists of a number of hydraulic elements (or links), such as pipes, pumps and valves, which are connected together by nodes (see Figure 4). Each node can have an associated inflow/outflow (typically demands consumed by network users). Each hydraulic element is characterized by a nonlinear equation linking the flow through the element and the head loss (difference of piezometric head between the ends of the element).

The process of hydraulic simulation allows to obtain the node pressures and the flows at the links of the network, during a given network operation period (e.g. one day). This involves the solution of algebraic nonlinear systems.

7.1.3 Water Quality Simulation

Water quality changes while water travels through the network. For instance, while the water is on the network the concentration of disinfectants decreases as a consequence (e.g. chlorine) of chemical reactions, with the corresponding health risk if a minimum concentration is not maintained. This kind of information is essential, due to the growing concern for guaranteeing acceptable quality levels in drinking water.

Water quality simulation obtains information about the concentration of a given chemical product (e.g. a disinfectant, or a pollutant), the water age (the time that the water is on the network), or the percentage of water coming from a given source. Water quality simulation involves the solution of differential-algebraic equations.

7.1.4 Leakage Minimization

A problem of growing importance is the reduction of water leakage in the supply networks. For this reason, the demonstrator developed by OMRON and UP-Valencia incorporates a module to compute the optimal settings of a set of Pressure Reducing Valves, so as to minimize leakage, while keeping pressure at a set of reference nodes above given values.

Unlike the two previous simulation problems, this is an optimization problem. Optimization problems involve the solution of many simulation problems, and are therefore of a higher level of complexity.

In particular, the leakage minimization problem involves a non-linear programming problem, which is solved by means of the FSQP (Feasible Sequential Quadratic Programming) package. Interfaces to the FSQP package for SLICOT users and for the MATLAB environment have been developed in the context of the Niconet project.

7.1.5 Conclusions

SLICOT incorporates interfaces to packages for the solution of algebraic nonlinear systems of equations, differential-algebraic equations, and non-linear programming. These tools provided by SLICOT can be used effectively for the implementation of software for the simulation and optimization of water supply networks.

Vicente Hernandez, Alejandro Moner and Fernando Alvarruiz

8 NICONET information corner

This section informs the reader on how to access the SLICOT library, the main product of the NICONET project, and how to retrieve its routines and documentation. Recent updates of the library are also described. In addition, information is provided on the newest NICONET reports, available via the NICONET website or ftp site, as well as information about upcoming workshops/conferences organized by NICONET or with a strong NICONET representation.

Additional information about the NICONET Thematic Network can be found from the NICONET homepage World Wide Web URL

`http://www.win.tue.nl/wgs/niconet.html`

8.1 Electronic Access to the Library

The SLICOT routines can be downloaded from the WGS ftp site,

`ftp://wgs.esat.kuleuven.ac.be`

(directory `pub/WGS/SLICOT/` and its subdirectories) in compressed (gzipped) tar files. On line `.html` documentation files are also provided there. It is possible to browse through the documentation on the WGS homepage at the World Wide Web URL

`http://www.win.tue.nl/wgs/`

after linking from there to the SLICOT web page and clicking on the `FTP site` link in the freeware SLICOT section. The SLICOT index is operational there. Each functional "module" can be copied to the user's current directory, by clicking on an appropriate location in the `.html` image. A "module" is a compressed (gzipped) tar file, which includes the following files: source code for the main routine and its example program, example data, execution results, the associated `.html` file, as well as the source code for the called SLICOT routines.

The entire library is contained in a file, called `slicot.tar.gz`, in the SLICOT root directory `/pub/WGS/SLICOT/`. The following Unix commands should be used for decompressing this file:

```
gzip -d slicot.tar
```

and

```
tar xvf slicot.tar
```

The created subdirectories and their contents is summarized below:

`slicot`	contains the files `libindex.html`, `make.inc`, `makefile`, and the following subdirectories:
`benchmark_data`	contains benchmark data files for Fortran benchmark routines (`.dat`);
`doc`	contains SLICOT documentation files for routines (`.html`);
`examples`	contains SLICOT example programs, data, and results (`.f`, `.dat`, `.res`), and `makefile`, for compiling, linking and executing these programs;
`src`	contains SLICOT source files for routines (`.f`), and `makefile`, for compiling all routines and creating an object library;
`SLTools`	contains Matlab `.m` files and data `.mat` files;
`SLmex`	contains Fortran source codes for mexfiles (`.f`).

Another, similarly organized file, called `slicotPC.zip`, is available in the SLICOT root directory; it contains the MS-DOS version of the source codes of the SLICOT Library, and can be used on Windows 9x/2000 or NT platforms. Included are several source makefiles.

After downloading and decompressing the appropriate SLICOT archive, the user can then browse through the documentation on his local machine, starting from the index file `libindex.html` from `slicot` subdirectory.

8.2 SLICOT Library updates in the period January 2001—July 2001

There have been two major SLICOT Library updates during the period January 2001—July 2001: on March 3, and June 29. Intermediate updates took place on February 2001. Known bugs have been removed on each update. Details are given in the files `Release.Notes` and `Release.History`, located in the directory `pub/WGS/SLICOT/` of the ftp site.

The update on March 3, 2001 has been described in the previous issue of this Newsletter. The update on June 29, 2001 is described below. Few changes have been made in the routines `AB08NX`, `AB09CX`, `MB04ZD`, and `SB16AY` for removing some bugs. Details are given in the file `Release.Notes`.

About 25 new user-callable and computational routines for basic control problems, for structured matrices, and for model and controller reduction, have been posted on the SLICOT ftp site in June 29. They include *Analysis Routines*, *Data Analysis Routines*, *Mathematical Routines*, and *Transformation Routines*, performing the following main computational tasks:

- computing the normal rank of the transfer-function matrix of a state-space model (A, B, C, D).
- computing a reduced order model for an original state-space representation, using the frequency weighted optimal Hankel-norm approximation method; the weights are defined by $\text{op}(W)$, where $\text{op}(W)$ stands for W, $\texttt{conj}(W)$, $\texttt{inv}(W)$, or $\texttt{conj}(\texttt{inv}(W))$, with W a given transfer-function matrix, and they may be applied to the left, and/or to the right.
- constructing a state-space representation of the projection of VG or $\texttt{conj}(V)G$ containing the poles of G, from the state-space representations of the transfer-function matrices G and V, for G assumed to be stable and with its state matrix A in a real Schur form.
- constructing a state-space representation of the projection of GW or $G\texttt{conj}(W)$ containing the poles of G, from the state-space representations of the transfer-function matrices G and W, for G assumed to be stable and with its state matrix A in a real Schur form.
- checking stability/antistability of finite eigenvalues with respect to a given stability domain.
- computing the L_∞ norm of a continuous-time or discrete-time system (possibly unstable), either standard or in the descriptor form.
- computing the maximum singular value of a given continuous-time or discrete-time transfer-function matrix, either standard or in the descriptor form.
- computing the inverse of a given descriptor system.

- computing the convolution or deconvolution of two real signals using the Hartley transform.
- computing the (scrambled) discrete Hartley transform of a real signal.
- reducing the first blocks of a generator to proper form; (extended version of `MB02CX`, with a higher BLAS 3 fraction and a pivoting scheme for rank-deficient generators).
- computing the incomplete Cholesky factor of a symmetric positive definite block Toeplitz matrix, defined by either its first block row, or its first block column.
- computing the Cholesky factor of a banded symmetric positive definite block Toeplitz matrix.
- computing the Cholesky factor of the matrix $T^T T$, with T a banded block Toeplitz matrix of full rank.
- solving overdetermined or underdetermined real linear systems involving a full rank block Toeplitz matrix.
- computing a full QR factorization of a block Toeplitz matrix of full rank.
- computing a low rank QR factorization with column pivoting of a block Toeplitz matrix.
- computing the product $C \leftarrow \alpha \mathrm{op}(T)B + \beta C$, where α and β are scalars, T is a block Toeplitz matrix, and $\mathrm{op}(T)$ is either T, or its transpose, T^T.
- reducing the matrices A and E of a system pencil corresponding to the descriptor triple $(A - \lambda E, B, C)$ to generalized upper Hessenberg form using orthogonal transformations.
- reducing the pair (A, E) of a descriptor system to a real generalized Schur form using an orthogonal equivalence transformation, and applying the transformation to the matrices B and C.

In addition, six new mexfiles and over ten Matlab m files have been added in the subdirectories `./SLmex` and `./SLTools`, respectively. They are useful for model and controller reduction, or computing the L_∞ norm.

8.3 New NICONET Reports

Recent NICONET reports (available after January 2001), that can be downloaded as compressed postscript files from the World Wide Web URL

`http://www.win.tue.nl/wgs/reports.html`

or from the WGS ftp site,

`ftp://wgs.esat.kuleuven.ac.be`

(directory `pub/WGS/REPORTS/`), are the following:

- Daniel Kressner and Paul Van Dooren. *Factorizations and linear system solvers for matrices with Toeplitz structure* (file `SLWN2000-2.ps.Z`, revised June 2001).

  This report describes new routines for several factorizations of matrices with Toeplitz or block Toeplitz structure and shows how this can be used to solve the corresponding systems of equations or least squares systems of equations. Certain implementation details are given. Matrices of low rank or of low bandwidth are also considered.

- David Guerrero and Vicente Hernández and José E. Román. *Integration and development of routines for the parallel solution of Lyapunov equations by Hammarling's method* (file `SLWN2001-3.ps.Z`, June 2001).

  This report describes the integration of some routines for solving standard Lyapunov equations by Hammarling's method on parallel machines.

Previous NICONET/WGS reports are also posted at the same address.

8.4 Forthcoming Conferences

Forthcoming Conferences related to the NICONET areas of interest, where NICONET partners submitted proposals for NICONET/SLICOT-related talks and papers, and disseminated or will disseminate information and promote SLICOT, include the following:

- Fifth SIAM Conference on Control and its Applications, San Diego, USA, July 11–14, 2001.
- SIAM Conference on Linear Algebra in Signals, Systems and Control, Boston, USA, August 13–16, 2001.
- IFAC Workshop on Periodic Control Systems, Cernobbio-Como, Italy, August 27–28, 2001.
- Third International Workshop on TLS and Errors-in-Variables Modeling, Arenberg Castle, Leuven, Belgium, August 27–29, 2001.
- First SIAM-EMS Conference on Applied Mathematics in Our Changing World, Berlin, Germany, September 3–6, 2001.
- European Control Conference (ECC 2001), Seminario de Vilar, Porto, Portugal, September 4–7, 2001.
- GAMM Workshop on Numerical Linear Algebra with special emphasis on Numerical Methods for Structured and Random Matrices, Berlin, Germany, September 7–8, 2001.

Vasile Sima

9 Announcement of upcoming SLICOT training course in Bremen, Germany

A workshop and training course

ADVANCED COMPUTATIONAL TOOLS FOR COMPUTER-AIDED CONTROL SYSTEMS DESIGN

will be held at the University of Bremen, Germany, September 27–29, 2001.
The workshop is organized by

Peter Benner and *Angelika Bunse-Gerstner*
Zentrum für Technomathematik
University of Bremen
D-28334 Bremen
Germany

in cooperation with the

Numerics in Control Network (NICONET)
funded by the European Community BRITE-EURAM III Thematic Networks Programme
and chaired by
Sabine Van Huffel
Katholieke Universiteit Leuven
Dept. of Electrical Engineering (ESAT-SISTA/COSIC)
Kasteelpark Arenberg 10
3001 Leuven-Heverlee
Belgium

AIMS AND TOPIC:

With the ever-increasing complexity of control systems, efficient computational methods for their analysis and design are becoming more and more important. These computational methods need to be based on reliable and robust numerical software provided by well-tested and user-friendly software libraries.

This workshop and training course is intended as a tutorial on the use of the freeware Subroutine Library in Systems and Control Theory (SLICOT) for solving practical control engineering problems within computer-aided control systems design (CACSD) environments. SLICOT-based software usually has improved reliability and efficiency as well as extended functionality compared to the computational methods implemented in other CACSD software packages.

Some of the world's leading experts in the field of computational methods in CACSD will introduce SLICOT-based software to be used either within MATLAB and the MATLAB Control Toolbox or the CACSD package Scilab.

The course includes hands-on training during which participants will solve practical problems in control systems design using this software. Major topics of the course are

- *basic control software*
- *system identification*

- *model reduction*
- *robust control design using H-infinity techniques*

SPEAKERS:

- Peter Benner (University of Bremen, Germany)
- Joris de Cuyper (Leuven Measurement Systems Intl. (LMS), Belgium)
- Da-Wei Gu (Leicester University, UK)
- Sven Hammarling (NAG - The Numerical Algorithms Group, Oxford, UK)
- Petko Petkov (Technical University of Sofia, Bulgaria)
- Vasile Sima (Research Institute for Informatics, Bucharest, Romania)
- Helmuth Stahl (The MathWorks Deutschland GmbH, Munich, Germany)
- Paul Van Dooren (Université Catholique de Louvain-La-Neuve, Belgium)
- Sabine Van Huffel (Katholieke Universiteit Leuven, Belgium)
- Andras Varga (German Aerospace Center (DLR), Oberpfaffenhofen, Germany)
- Vincent Verdult (University of Twente, Netherlands)

PROGRAM:

Thursday, September 27, 2001

09.00–09.15	Welcome addresses	Sabine Van Huffel, Angelika Bunse-Gerstner
09.15–09.45	Introduction to NICONET and SLICOT	Sabine Van Huffel
09.45–10.30	The backbone of reliable numerical software: BLAS and LAPACK	Sven Hammarling
10.30–11.00	Coffee break	
11.00–12.00	The MATLAB Control Toolbox	Helmuth Stahl
12.00–13.30	Lunch	
13.30–15:00	Basic control software	Paul Van Dooren, Peter Benner
15.00–16.00	Coffee & Posters	
16.00–19.00	Training I	Vasile Sima

Friday, September 28, 2001

09.00–10.30	System identification with SLICOT	Vincent Verdult
10.30–11.00	Coffee break	
11.00–12.30	SLICOT model reduction tools	Andras Varga
12.30–14.00	Lunch	
14.00–15.00	Applications of SLICOT in industry	Joris de Cuyper
15.00–15.30	Coffee break	
15.30–18.30	Training II	Vasile Sima
19:30–??	Banquet	

Saturday, September 29, 2001

09.00–10.30	Robust control design using SLICOT	Petko Petkov, Dawei Gu
10.30–11.00	Coffee break	
11.00–13.00	Training III	Vasile Sima
13.00–14.00	Lunch	

During the poster session participants will have the opportunity to present their own projects and to discuss current problems or open questions.

For program updates see

`http://www.math.uni-bremen.de/zetem/workshops/cacsd/cacsd_prg.html`

FURTHER INFORMATION AND REGISTRATION:

For more information on the workshop please visit

`http://www.math.uni-bremen.de/zetem/workshops/cacsd`

or contact

```
Dr. Ronald Stoever
Phone:  +49 (0) 421 218-9502
Fax:    +49 (0) 421 218-4863
E-Mail: stoever@math.uni-bremen.de
```

You may register electronically at

`http://www.math.uni-bremen.de/zetem/workshops/cacsd/anmeldung.html`

Deadline for registration is September 1, 2001.

Peter Benner