System GAMMA: the directives of finite-frequency identification

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Abstract

Purpose

To present the results in the area of modern computer-aided control system design tools relating to system identification.

Design/methodology/approach

The finite-frequency identification method was designed for the needs of active identification. The test signal represents the sum of harmonics with automatically tuned (self-tuned) amplitudes and frequencies where the number of harmonics does not exceed the state space dimension of the plant. The self-tuning of amplitudes is carried out to satisfy those requirements on the bounds of the input and output which hold true in the absence of a test signal.

Findings

In this paper the software implementation of finite-frequency identification method in the system GAMMA is considered. GAMMA is the two-level computer-aided design (CAD) tool for identification and controllers algorithms synthesis for linear plants.

Practical implications

The system GAMMA is the complete and really working system.

Originality/value

The new structure of the CAD tool for engineers-developers of control system is proposed and its program implementation is described. The new variant of finite-frequency identification method with self-tuning of identification parameters (test signal and identification time) is considered.

Article type: Research paper

Keywords: Computer-aided design, finite-frequency identification.

1. Introduction

At present, the control theory has at its disposal a number of identification methods for plants specified by linear differential equations. Conventionally, these methods fall into two categories depending on the assumptions on the measurement errors and exogenous disturbances affecting the plant.

The methods of the first class deal with the plants subjected to disturbances of the stochastic nature; i.e., random processes having known statistical characteristics. These are various versions of the method of least squares and the stochastic approximation method; e.g., see well-known monographs (Ljung, 1987).

The second class comprises the identification methods under unknown-but-bounded disturbances (whose statistical properties are not known) such as randomized algorithms (Granichin and Polak, 2003) and finite-frequency identification, see (Alexandrov, 2005).

A somewhat specific position is occupied by the method of instrumental variables (Wong and Polak, 1967). It is developed in the framework of the first class; however, in contrast to the other methods in the class, it is applicable to the problems of the second class so that it is reasonable to consider it as a method of the second category.

The identification process can have passive or active forms. In the *passive* identification, the measured input of the plant has the meaning of a control action which depends on the control objectives and is not related to identification of the plant. With such an input, identification might not be possible; hence, *active* identification is often practiced where, in addition to control, the measured input contains an extra component, a so-called test signal aimed at identifying the plant. The finite-frequency identification method was designed for the needs of active identification. The test signal is represented by the sum of harmonics with automatically tuned (self-tuned) amplitudes and frequencies where the number of harmonics does not exceed the state space dimension of the plant. The self-tuning of amplitudes is carried out to satisfy those requirements on the bounds on the input and output which hold true in the absence of a test signal.

The MATLAB-toolbox for finite-frequency identification is described in (Alexandrov, Orlov etc, 2003). In this paper the software implementation of this method in the system GAMMA is considered.

MATLAB (MATLAB, 2001) and GAMMA (Alexandrov, Isakov etc, 2005; Stepanov, 2000) are oriented on different groups of users. MATALB is intended for the scientists primarily. These specialists easily create the programs for solution of real problems of their data domain using a rich spectrum of m-functions. GAMMA is intended for the engineers-developers of control system. The purposes of this group and a small time for Control System development eliminate a capability of their participation in creation of the software for the solution of their problem. Besides the necessity of a profound knowledge of the theory of control also handicaps their work with the MATLAB.

2. Finite-frequency identification

A completely controllable, asymptotically stable plant is described by the following equation:

$$d_n y^{(n)} + ... + d_1 \dot{y} + y = k_\gamma u^{(\gamma)} + ... + k_1 \dot{u} + k_0 u + f, t \ge t_0, \qquad (1)$$

where $y(t)$ is the measured output, $u(t)$ is the input to be controlled, $y^{(i)}$, $u^{(j)}$ $(i = \overline{1,n}, j = \overline{1,\gamma})$ are the derivatives of these functions, $f(t)$ is unknown-but-bounded disturbance. The coefficients d_i and k_j $(i = \overline{1,n}, j = \overline{0,\gamma})$ are some unknown numbers; n and γ are known, and $\gamma < n.$.

The identification problem is to find the estimates $\hat{d}_i$ and $\hat{k}_j$ $(i = \overline{1,n}, j = \overline{0,\gamma})$ of the plant coefficients such that the identification errors satisfy the following relations:

$$\hat{d}_i \div d_i \le \varepsilon_i^d, \hat{k}_j \div k_j \le \varepsilon_j^k \quad i = \overline{1,n} \quad j = \overline{0,\gamma} \qquad (2)$$

where ε_i^d and ε_j^k $(i=\overline{1,n},\ j=\overline{0,\gamma})$ are given numbers, and the symbol $\div$ means: $a \div b = |a-b|/|b|$ if $b \neq 0$ and $a \div b = |a|$ otherwise.

Let us consider the finite-frequency identification technique which gives a solution of this problem. A set of 2*n* numbers

$$\alpha_k = \operatorname{Re} w(j\omega_k), \beta_k = \operatorname{Im} w(j\omega_k) \quad k=\overline{1,n} \tag{3}$$

where

$$w(s) = \frac{k_\gamma s^\gamma + \ldots + k_0}{d_n s^n + d_{n-1} s^{n-1} + \ldots + 1} \tag{4}$$

is named the *frequency domain parameters* (FDP).

The FDP estimates are determined experimentally as follows: after the plant (1) is excited by the test signal

$$u = \sum_{k=1}^{n} \rho_k \sin \omega_k (t - t_0), t \geq t_0 \tag{5}$$

where the amplitudes $\rho_k (k=\overline{1,n})$ and the test frequencies $\omega_k (k=\overline{1,n})$ are given positive numbers, its output is fed to the Fourier filter, whose outputs give the following FDP estimates:

$$\hat{\alpha}_k = \alpha_k(\tau) = \frac{2}{\rho_k \tau} \int_{t_F}^{t_F+\tau} y(t) \sin \omega_k (t - t_0) dt, \tag{6}$$
$$\hat{\beta}_k = \beta_k(\tau) = \frac{2}{\rho_k \tau} \int_{t_F}^{t_F+\tau} y(t) \cos \omega_k (t - t_0) dt, \quad (k=\overline{1,n})$$

where τ is the filtering time and $t_F \geq t_0$ is the initial instant for filtering.

In order to formulate the conditions on the convergence of the FDP estimates (6) to the true FDP, the following functions are introduced:

$$l_k^\alpha(\tau) = \frac{2}{\rho_k \tau} \int_{t_F}^{t_F+\tau} \bar{y}(t) \sin \omega_k (t - t_0) dt, \tag{7}$$
$$l_k^\beta(\tau) = \frac{2}{\rho_k \tau} \int_{t_F}^{t_F+\tau} \bar{y}(t) \cos \omega_k (t - t_0) dt, \quad (k=\overline{1,n})$$

where $\bar{y}(t)$ is the “natural” output of the plant when the test signal (5) is absent (*u*(*t*) = 0).

A disturbance *f*(*t*) is said to be strongly FF-filterable if, for the given numbers δ^α and δ^β, there exists filtering time τ^* such that

$$\frac{|l_k^\alpha(\tau^*)|}{|\alpha_k(\tau^*)|} \leq \delta^\alpha, \tag{8}$$

$$\frac{|\, l_k^{\beta}(\tau^*)\,|}{|\,\beta_k(\tau^*)\,|} \le \delta^{\beta} \ , \ (k=\overline{1,n}) \ , \ \tau \ge \tau^* \, .$$

Conditions (8) can be examined by experiment.

If the disturbance $f(t)$ is strongly FF-filterable, then the filtering errors $\Delta\alpha_k(\tau) = \alpha_k - \alpha_k(\tau)$, $\Delta\beta_k(\tau) = \beta_k - \beta_k(\tau)$ $(k=\overline{1,n})$ have the following properties: $\lim_{\tau\to\infty} \Delta\alpha_k(\tau) = \lim_{\tau\to\infty} \Delta\beta_k(\tau) = 0$ $(k=\overline{1,n})$.

The estimates of the plant coefficients are found using the FDP estimates. In fact, the identity $w(s) = \dfrac{k(s)}{d(s)}$ and the expressions (3) give the following system of the linear algebraic equations:

$$\hat{k}(s_k) - (\alpha_k + j\beta_k)\hat{\bar{d}}(s_k) = \alpha_k + j\beta_k \, , \ (k=\overline{1,n}) \ , \tag{9}$$

where $\hat{\bar{d}}(s) = \hat{d}\ (s) - 1 = \hat{d}_n s^n + \ldots + \hat{d}_1 s$, $\hat{k}(s) = \hat{k}_\gamma s^\gamma + \ldots + \hat{k}_0$, $s_k = j\omega_k$ $(k=\overline{1,n})$.

If the plant (1) is completely controllable then the system (9) has a unique solution d_i, k_j $(k=\overline{1,n},\, j=\overline{1,\gamma})$ which does not depend on the choice of the frequencies $\omega_i\, (\omega_i \ne \omega_j\, (i \ne j), \omega_i \ne 0 (i=\overline{1,n}))$.

Substituting the FDP by their estimates, the following *frequency equations* of identification

$$\hat{k}(s_k) - (\hat{\alpha}_k + j\hat{\beta}_k)\hat{\bar{d}}(s_k) = \hat{\alpha}_k + j\hat{\beta}_k \, , \ (k=\overline{1,n}) \ , \tag{10}$$

are obtained.

In order to examine requirements (2), the frequency technique of model validation (Alexandrov, 1999) may be used. The described method of identification is implemented in the system GAMMA as the directive d123su.

In considered case the parameters of test signal and identification time are given numbers. In (Alexandrov, 2005) the method of self-tuning of these parameters are described. The amplitudes and the frequencies of the test signal are tuned automatically during the identification process. The time of identification is determined depending on the current external disturbances and the noise. The self-tuning of identification time is implemented in the directive d123sdsu. The self-tuning of amplitudes is carried out to satisfy the requirements on the bounds of the input and output of the plant which hold true in the absence of a test signal. This operation is executed by the directive d123sursad.

3. System GAMMA features

Family of systems GAMMA was developed since 1970 (Alexandrov, Nebaluev and etc.,1975; Alexandrov and Panin, 1997). To describe the features of GAMMA architecture let us introduce the notion of group of the user of CAD tools:

1. The first group is the engineers-developers of control system. Such specialist uses the CAD tools for solution of different problems of control system design in concrete domain (aircraft, power engineering and etc). He has the deep knowledge of concrete plants and principles of control system design. But it is possible he has not deep knowledge of mathematical methods of

his problems solution. Besides the program implementation of these methods is not his employment duty. It is clear that the matrix systems like MATLAB in some cases are not convenient for such users because the users of these system should write the programs using the set of elementary m-functions.
2. The second group is the scientists who use the CAD tools for exploring and program implementation of different methods of control system design (further such specialists are referred as the researchers). The researchers are the experts in the control theory besides they have some skills of programming.

The GAMMA system has been created as the CAD tool for engineers-developers of control system primarily. So it is based on the following principals:
1. The engineer need not develop the program for solution of its problem.
2. The system must support the problem description in the “natural” language. For the control engineer it means that the interface of system provides the input of initial data in the form of matrixes, vectors, differential equations and etc. On the other hand it means that the system allows to solve the design problems when the design purpose is described by the technical indices (steady-state errors, the bounds of input and output of the plant, the settling time and etc).
3. The problem must be solved automatically without user participation.
4. The system must have the tools for its modernization by a researcher.

Some of these principals were discussed in (Alexandrov, Isakov etc, 2005; Shumann, R., S. Kornera and etc, 1996; Syska, 2002).

The main features of GAMMA is the sharing the functions of different user-groups on the level of the system interface. GAMMA is the two-level system: the first level (the engineers environment) is the set of design procedures (we refer them as the directives) that provide the automatic solution of design problems by an engineer-developers of control system. The second level (the researchers environment) intends for development and modernization the software of first level by a researcher. The principal scheme of GAMMA architecture is shown in Figure 1.

3.1 The engineers environment

The Engineers environment’s basis is a directive. The directive is the special program that has the following features:

- The directive solves the definite class of problems of a design of control algorithm.
- The directive is complete self-documenting program such that the non-expert user can use it for solution of rather complicated design problem.
- The interfaces of all directives are unified.
- The directive consists of three parts: the interface part , the calculation part, the operations of input and output.
- The directive is the program written in language INSTRUMENT (it is described in next subsection). The calculation part consists in calling of calculation modules written in C and functions written in INSTRUMENT.

All directives are subdivided into three classes:

- Synthesis (LQ-optimization, H_∞ - suboptimal control, controller synthesis under the given tolerance on steady-state errors and etc);
- Identification (finite-frequency identification, identification with selftuning of test signal, identification with selftuning of identification time and etc);
- Adaptive control.

In Engineers environment a user chooses the directive from the directives list; after a request of computer, he enters in natural form the initial data: the differential equations of plant, disturbance boundaries, technical indices tolerances, etc in dependence on class of problem. The dialog form for initial data input is shown in Figure 2. Then a directive is performed automatically (without user participation). Analyzing the results he makes a decision on an acceptability of outcome. The example of the report of directive executing is shown in Figure 3.

3.2 The researchers environment

The researchers environment intends for directives development. The main components of researchers environment are the modules library and interpreter of language INSTRUMENT.

The directives of GAMMA are developed with use of program modules. Each module solves the elementary problem of control theory (for example, controlability analysis, Fourier filter and etc.). The researcher may use any high-level programming language for modules writing, but there are the some rules that he must observe.

The modules library stores the detailed description of the modules. It includes the modules ID, modules name, inputs and outputs description and so on. This information is used by interpreter during directive executing. The modules library contains about two hundred modules. It is divided into some groups in according to the modules intends: transformation, analysis, synthesis, identification, adaptive control, simulation and etc. The window of the modules library with description of the module is shown in Figure 4.

The problem-oriented language INSTRUMENT is used for directives implementation in the GAMMA system. The interpreter of this languages is the part of GAMMA. Before INSTUMENT-1 had the limited set of operators: operators for input and output of data, operator for running of calculation modules, conditional and unconditionally control transfer. So the calculation modules were writing in C and PASCAL.

Now the possibilities of INSTUMENT are substantially increased. All standard operation were added into the INSTRUMENT: loops, conditional, subroutines, operations with arrays and etc. As the result the most of calculation modules are wrote in the INSTRUMENT now. Besides the possibility for using modules written in the another languages (C or PASCAL or the other) is maintained as in the previous version of INSTRUMENT.

4. GAMMA software for finite-frequency identification

The software for finite-frequency identification is implemented as the number of directives:

- D123su -- the finite-frequency identification where the amplitudes and the frequencies of the test signal and the identification time are given numbers;
- D123sdsu -- the finite-frequency identification with self-tuning of identification time;
- D123sursad -- the finite-frequency identification with self-tuning of amplitudes of test signal.

Let us describe the directive D123su.

4.1 The structure of the directive D123su

The directive has the following structure:

<D123su>=<interface><calculation part><results>

<calc. part>=<Cauchy><PMV1><ABtoFR><Analysis><FourSu> <Freqd>.

The initial data of the directive:

- `d,k,m` – polynomials of the plant;
- `np` – plant order;
- `par` – external disturbance parameters;
- `h` – sampling time,
- `om` – test frequencies;
- `rho` – amplitudes of the test frequencies;
- `Ptau` – identification time (number of periods of the minimal test frequency);
- `Tfi` – start time of filtration (number of periods of the minimal test frequency);
- `x` - initial conditions;
- `Tbegin` – start time of simulation.

The results:

- `vdd` – estimates of the denominator coefficients of the plant transfer function;
- `vkd` - estimates of the numerator coefficients of the plant transfer function;

4.2 The modules of the directive D123su

The following modules were used in the directive:

Cauchy1 – conversion of the plant model to the state space form.

Syntax: Cauchy1`[d,k,m][A,B,C,D]`,

where `A,B,C,D` – the matrixes of the state space form;

PMV1 – computation of plant inputs and recalculation of test frequencies

Syntax: `PMV1[om,rho,par,h,Ptau,np,TBegin][t,u1,u,om1]`,

where `t` – time vector, `u,u1` – plant inputs, `om` – new test frequencies.

ABtoFR – computation of matrix of discrete-time model.

Syntax: `ABtoFR[A, B, h][F, R]`,

where `F,R` are the matrix of discrete-time model.

Analysis – plant simulation.

Syntax: `Analysis[F,R,C,D,u1,t,x0][x,y]`,

where `y` is the plant output.

FourSu – computation of the FDP estimates.

Syntax:

`FourSu[y,u,om1,rho,np,h,Ptau,Tfi][valf,vbet]`,

where `valf,vbet` – the estimates of the plant FDP.

Freqd – solution of the frequency equations of identification

Syntax:

`Freqd[om,h,valf,vbet][vkd,vdd]`,

where `vdd` and `vkd` are the estimates of coefficients of discrete-time model of the plant.

5. Example

The following plant has been used to test the directive D123su:

$$0.2\dddot{y}+1.24\ddot{y}+5.24\dot{y}+y=-0.4\dot{u}+u+f$$

Discrete-time transfer function of this plant under sampling time $h=0.2$ is

$$W(z)=\frac{-0.0206z^2+0.0224z+0.0192}{z^3-1.7260z^2+1.0360z-0.2894} \tag{11}$$

The initial data of the directive:

- Polynomials of the plant $d(s) = 0.2s^3 + 1.24s^2 + 5.24s + 1, k(s) = -0.4s + 1, m(s) = 1$.
- Plant order *np=3;*
- External disturbance $f(t) = sign(\sin(2.1t))$;
- Sampling time *h=0.2;*
- Test signal *u(t)* $= 0.3\sin 0.2t + 3\sin 4t + 3\sin 6t$;
- Identification time *Ptau=3;*
- Start time of filtration *Tfi=1.*

The following results were obtained:

- FDP estimates:

  $\hat{\alpha} = [0.460051 \quad -0.0591760 \quad 0.022480\,]$; $\hat{\beta} = [-0.63288 \quad 0.0723600 \quad 0.0533290\,]$.

- Identified discrete-time model of the plant:

$$W(z) = \frac{-0.0192z^2 + 0.0203z + 0.0218}{z^3 - 1.7092z^2 + 1.0009z - 0.2713} \qquad (12)$$

The coefficients of model (11) and (12) are sufficiently closed.

6. Conclusion and further work

In this paper the software implementation of finite-frequency identification method in the system GAMMA is considered. GAMMA is the two-level CAD tool for identification and controllers algorithms synthesis for the linear plants.

Further work is related both with the improvement of the frequency-identification technique and GAMMA development. The further improvement of finite-frequency identification method allows to decrease the identification time in case when the external disturbances and noise are sufficiently small and processes in the plant depends on initial conditions primarily.

The evolution of the GAMMA is performed in following directions:

– The modernization of INSTRUMENT language. In particular we intend to change the mechanism of calculation modules executing in order to decrease the time of directives executing.
– The increasing of set of calculation modules in order to make the GAMMA more universal system.
– The implementation of methods for identification of multivariable plant. The corresponding method is developed in (Alexandrov, Orlov etc, 2003).

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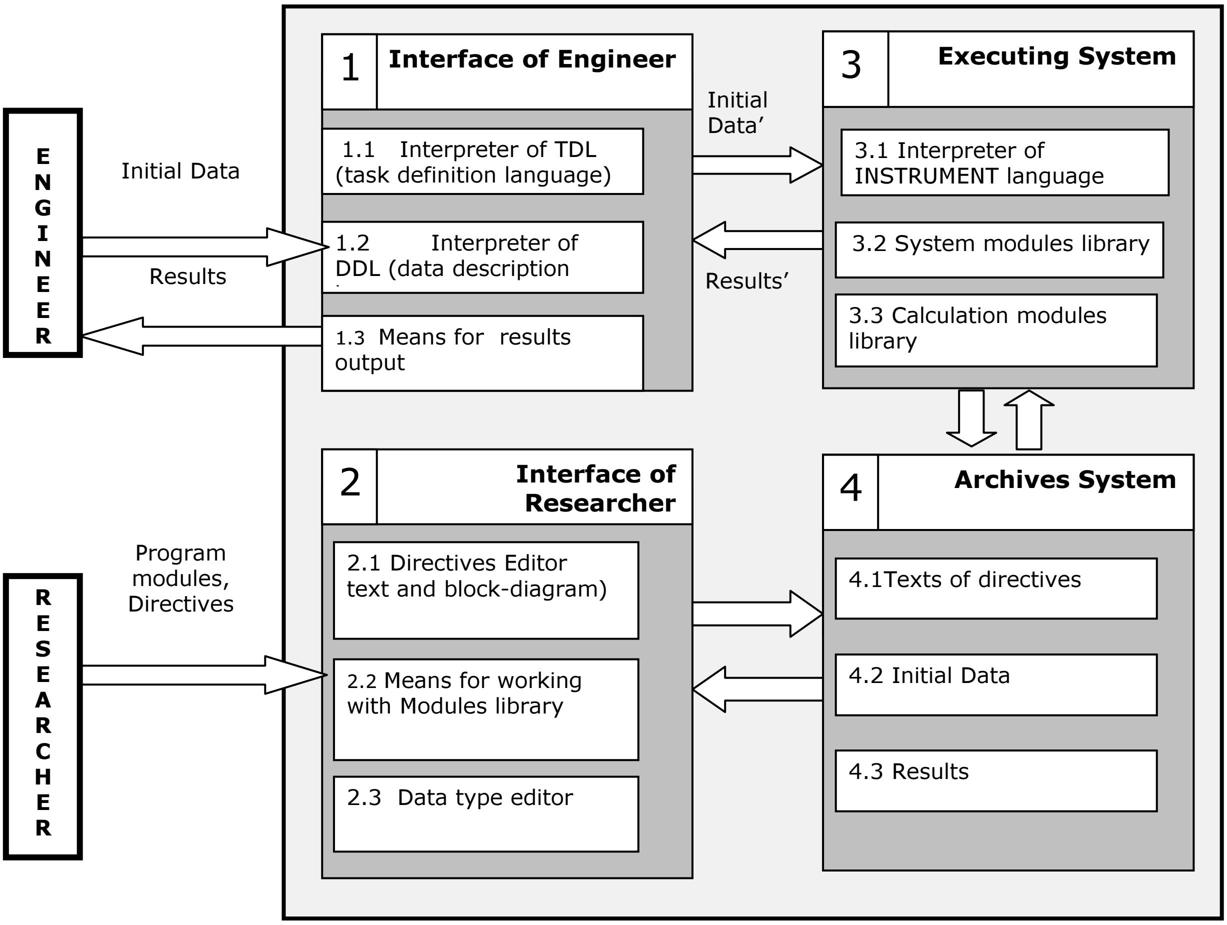


Figure 1 The architecture of GAMMA

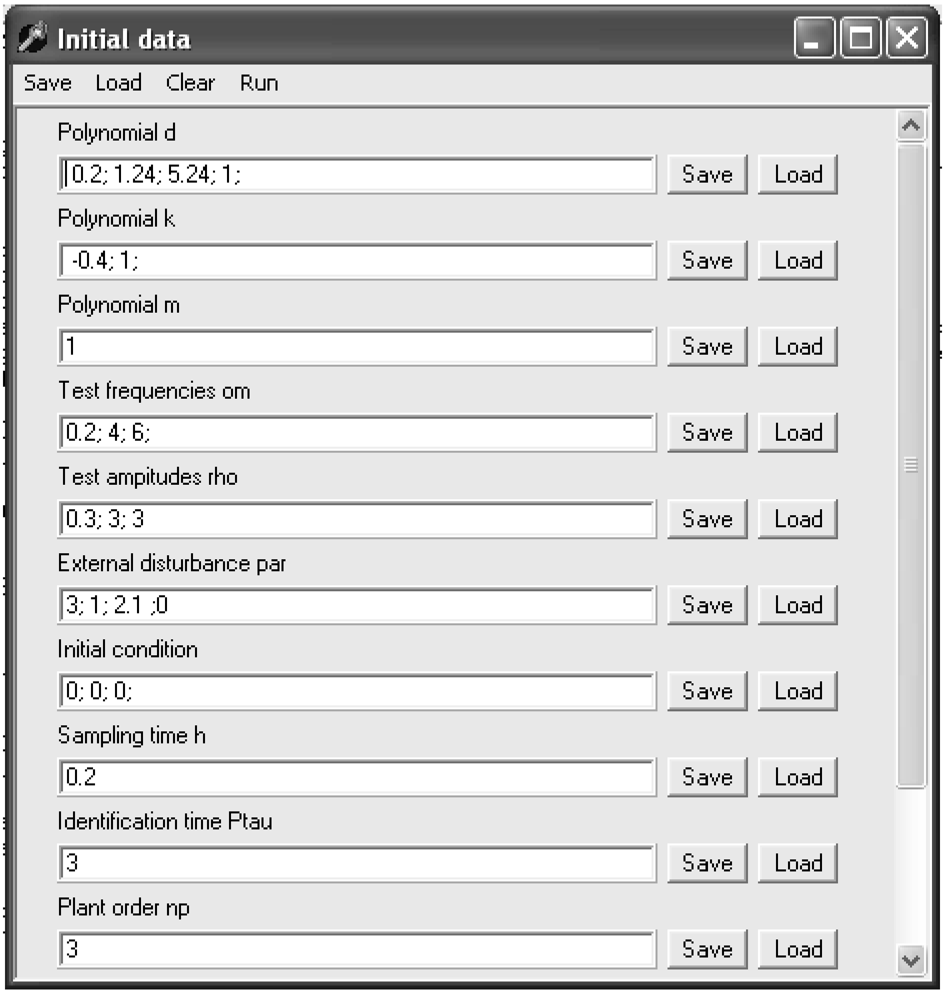
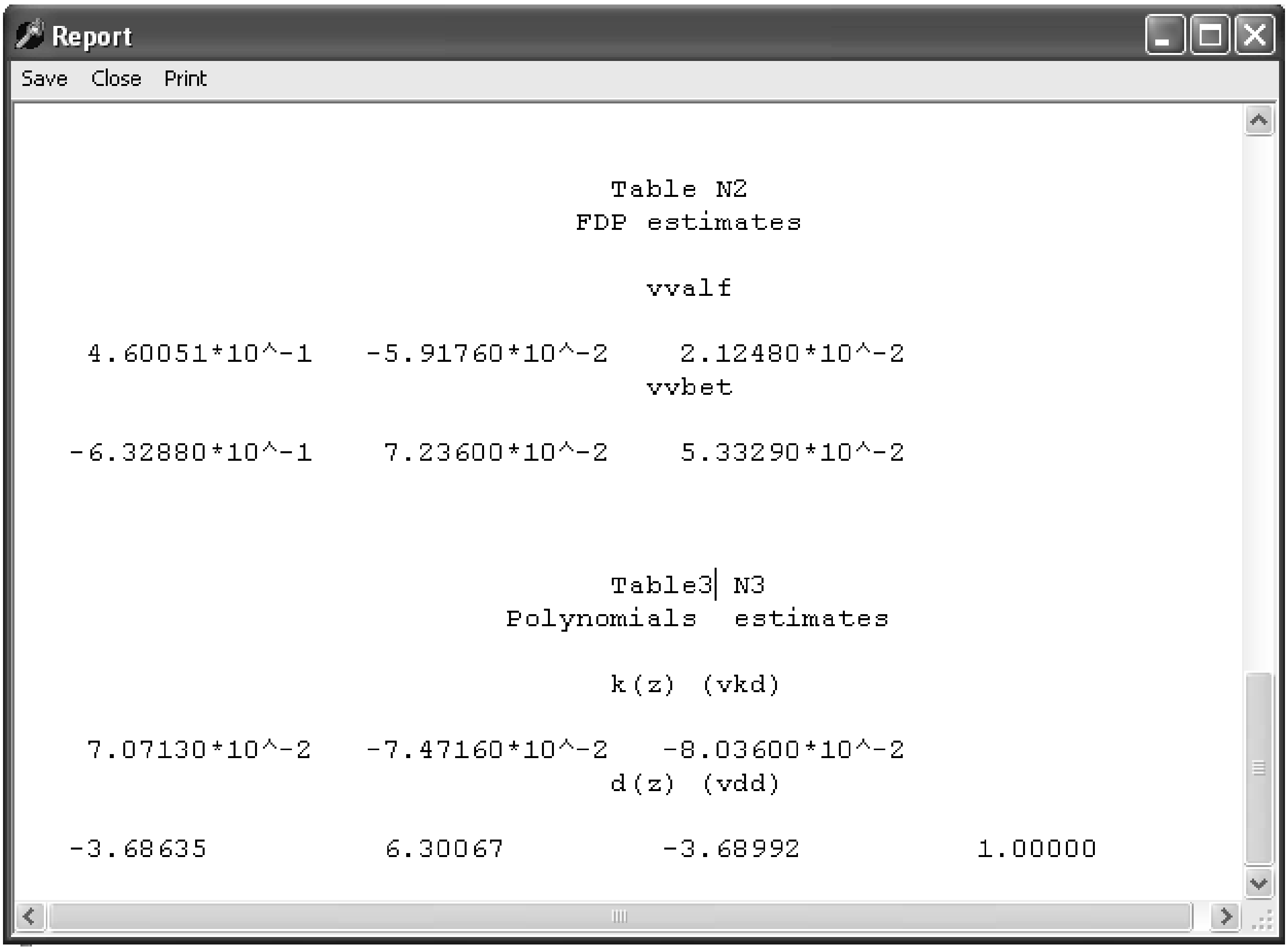


Figure 2 The dialog form with initial data of directive D123su



Report

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Table N2
FDP estimates

vvalf

4.60051*10^-1	-5.91760*10^-2	2.12480*10^-2

vvbet

-6.32880*10^-1	7.23600*10^-2	5.33290*10^-2

Table3 N3
Polynomials estimates

k(z) (vkd)

7.07130*10^-2	-7.47160*10^-2	-8.03600*10^-2

d(z) (vdd)

-3.68635	6.30067	-3.68992	1.00000

Figure 3 The fragment of report of directive D123su executing

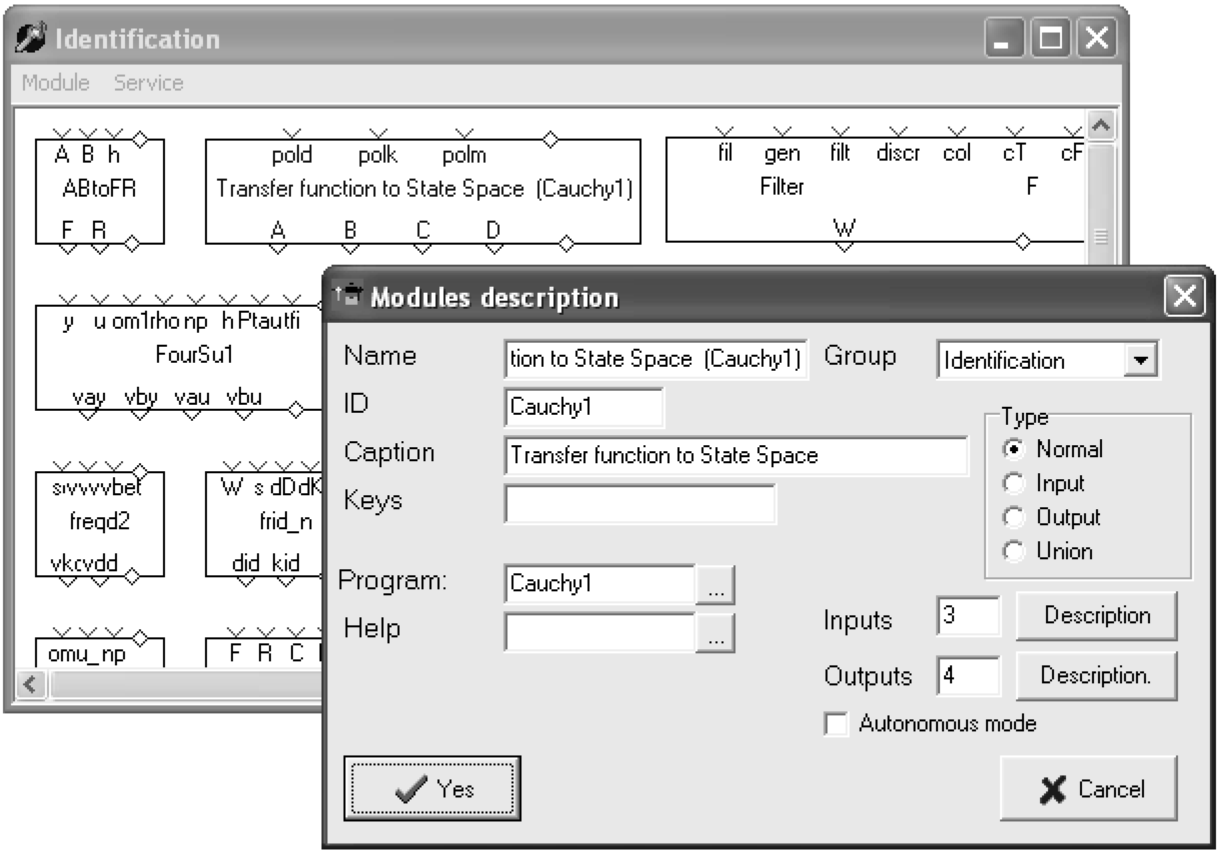

Figure 4 The window of the modules library with description of the module Caushy1