Frequency identification, software, control theory

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SOFTWARE FOR FINITE-FREQUENCY IDENTIFICATION WITH SELF-TUNING OF IDENTIFICATION ALGORITHM IN SYSTEM GAMMA-3

The finite-frequency identification method was designed for the needs of active identification. The test signal is represented by the sum of harmonics where the number of harmonics does not exceed the state space dimension of the plant. The discrete-time plants are considered; the amplitudes and the frequencies of the test signal are tuned automatically during the identification process; the time of identification is determined automatically in dependence on the current external disturbances. In this paper the software implementation of finite-frequency identification method in the system GAMMA-3 is considered. System GAMMA3 is a new generation of the facilities automatic decision of the problems of control system design. GAMMA-3 has some substantial differences from the early developed versions of the system: problem-oriented MATLAB-like language GAMMA, three layers of presentations of the knowledge about methods of the decisions of the problems.

1. INTRODUCTION

The software of identification is an active developing direction of the software for automatic control systems design. It is called both practical significance of identification and fast development of its theory. The finite-frequency identification method was designed for the needs of active identification. It means that in addition to control, the measured input contains an extra component, a test signal aimed at identifying the plant. 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.

New procedures of GAMMA-3 which are considered in this paper have some substantial differences from the early developed procedures [1]:

1) The discrete-time plants are considered.
2) The amplitudes of the test signal are tuned automatically [2] during the identification process. It allows to decrease the identification time.

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3) The time of identification is determined automatically in dependence on the current external disturbances.

In this paper the software implementation of this method in the system GAMMA-3 is considered.

MATLAB and GAMMA are oriented on different groups of users. MATALB is intended for the researchers who well know the control theory. The researcher easily creates the program for the solution of real problems of its data domain using a rich spectrum of m-functions. GAMMA is intended for the engineers-developers of a control system. The purposes of this group and a small time for control system design eliminate a capability of their participation in creation of the software for the solution of their problem.

2. GAMMA-3 FEATURES

New system GAMMA-3 is based on the principles that were implemented in the previous versions of GAMMA [3] and INSTRUMENT [4]. We consider two groups of specialists who use the computer-aided design tools (CAD tools). First group is represented by highly skilled scientists (further called as the researchers) who develop and explore new methods of control systems design. Second group is the practicing engineers that use the CAD tools for design of real world control systems. This classification is based on the difference in the subject and the purpose of research. For scientists, the purpose is the algorithm of solution of new problem. For engineers, the purpose is the control law that meets the specified requirements. So these specialists need different CAD tools. The matrix systems like MATLAB [5], SCILAB [6] are the perfect CAD for scientists because they have a rich spectrum of basic functions and the high-level language that allows to write and try new method in shortest time. The engineers don't have enough time for developing the programs for solution of their problems. In addition, in some case they don't have deep knowledge of control theory. So the engineers need the tool which allows to solve the problem in automatic mode making use the procedures written by the researchers. In this case, we say that they formulate the problem in procedural term by means of choosing the needful procedure. Described conception was implemented in the range of CAD tools (GAMMA-1, GAMMA-2PC, INSTRUMENT-3M-I) The main feature of these tools is the partitioned access to the facilities of the system for different groups of users: Engineer's IDE and Researcher's IDE.

From the other hand, the parameters of plant, disturbances and even the control aim can change during the control system action. So the statement of control problem changes dynamically. In this case, only CAD system that is based on the artificial intelligence can solve the problem. We can mention here the system INSTRUMENT-3M-I that can automatically create the procedure for solution of control problems [7] This system is based on the mechanism of artificial planning neural networks and formalized model of problems of control theory. The engineer describe the problem in non-procedural form, in terms of formalized model of problems of control theory.

But this approach doesn't quiet meet the real state of the art. Particularly, it doesn't take into account the fact that in engineer's practice, the number of typical problems exceed the number of new problems in non-procedural statement. From the other hand, the typical problems are not interesting for researchers that should develop procedures for automatic solution of engineers problems by means of Researcher's IDE. The difference in structure of MATLAB-like tools and CAD systems developed on the base of artificial intelligent produce number of difficulties when we try to join their facilities in one CAD tool. The main difficulty is the difference in the data structures. In MATLAB-like systems, the data don't structured by their meaning. In the artificial intelligent tool, the formalized and structured presentation of data is used. Previous attempt of simple "mechanical" join of modules of systems GAMMA-2PC and INSTRUMENT-3M-I showed the limitation of this approach. So we decided to develop integrated system GAMMA-3.

We offer to control engineer the facilities for automatic solution of his tasks (the toolboxes for finite-frequency identification, adaptive control and synthesis of controllers by know model of controlled plant); the tools for new toolboxes development (problem-oriented language GAMMA); the facilities for automatic toolboxes development with the intelligent subsystem which is implemented as the part of the system INSTRUMENT. To the contrast with previous version, GAMMA-3 has advanced problem-oriented MATLAB-like language GAMMA. The program in GAMMA language can be used in two ways: as the tool for solution of particular engineer's problem by analogy with MATLAB; as the procedural definition of operation in formalized model of problems of control theory.

3. PROCEDURES OF FINITE-FREQUENCY IDENTIFICATION

3.1 PROBLEM STATEMENT

Consider a linear time invariant plant described by the following equation

$$y[kh]+d_1 y[h(k-1)]+\ldots+d_n y[h(k-n)]=k_1 u[h(k-1)]+\ldots+k_n u[h(k-n)]+f[h(k-1)] \\ (k=0,1,2,\ldots), \tag{1}$$

where $y(kh)$ is the measured output that is measured in time moments kh (where h *is* the sampling time), $u(kh)$ is controlled input, $f(kh)$ is unknown but bounded external disturbance:

$$|f(kh)|\le f^* \quad (k=0,1,2,\ldots), \tag{2}$$

where f^* is the specified number, d_i and k_i $(i=\overline{1,n})$ are unknown numbers, the plant order n is known number. The signals $u(kh)$ and $y(kh)$ are bounded:

$$|u(kh)|\le u\_,\ |y(kh)|\le y\_ \quad (k=0,1,2,\ldots), \tag{3}$$

where $u\_$ and $y\_$ are specified positive numbers that are the bounds of plant input and output. Number y_ such that the following condition is satisfied:

$$|\bar{y}(kh)|\le y\_ \ ,(k=0,1,2,\ldots) \tag{4}$$

where $\bar{y}(kh)$ is the "natural" plant output when the test signal absents.

The problem is to find the estimates of the plant (1) coefficients.

3.2 THE PROCEDURES OF FINITE-FREQUENCY IDENTIFICATION

The toolbox for finite-frequency identification in GAMMA-3 is implemented as the number of procedures:

- D123su – finite-frequency identification with specified parameters of identification;
- D123sdsu – finite-frequency identification with self-tuning of time of identification;
- D123sad – finite-frequency identification with self-tuning of time of identification and amplitudes of test signal.

Let us describe the procedure of finite-frequency identification with selftuning of identification time

1) The plant (1) is excited by the test signal

$$u(kh) = \sum_{i=1}^{n} \rho_i \sin \omega_i kh, \quad k = \overline{0, N-1}, \tag{5}$$

where n is the plant order , N is the quantity of filtration intervals.

2) The plant's input and output are applied to the Fourier's filter:

$$\begin{aligned} \alpha_y(N) &= \frac{2}{\rho N}\sum_{k=0}^{N-1} y(kh)\sin \omega kh, & \alpha_u(N) &= \frac{2}{\rho N}\sum_{k=0}^{N-1} u(kh)\sin \omega kh, \\ \beta_y(N) &= \frac{2}{\rho N}\sum_{k=0}^{N-1} y(kh)\cos \omega kh, & \beta_u(N) &= \frac{2}{\rho N}\sum_{k=0}^{N-1} u(kh)\cos \omega kh. \end{aligned} \tag{6}$$

where $(\hat{\alpha}_y, \hat{\beta}_y)$ are the estimates of the frequency domain parameters of the plant's input and $(\hat{\alpha}_u, \hat{\beta}_u)$ are the estimates of the frequency domain parameters (FDP) of the plant's output.

2) The estimates of the frequency domain parameters of the plant are calculated as following

$$\alpha_i = \frac{\alpha_{yi}\alpha_{ui} + \beta_{yi}\beta_{ui}}{\alpha_{ui}^2 + \beta_{ui}^2}, \qquad \beta_i = \frac{-\alpha_{yi}\beta_{ui} + \beta_{yi}\alpha_{ui}}{\alpha_{ui}^2 + \beta_{ui}^2}, \qquad i = \overline{1, n}. \tag{7}$$

3) The estimates of the plant (1) coefficients are determined on the base of the frequency domain parameters (7) of the plant by means of solution of following equation (the equation of frequency identification)

$$\begin{cases} \sum_{\nu=1}^{n} \hat{k}_\nu \cos \nu\omega_i h - \sum_{\nu=1}^{n} \hat{d}_\nu \left(\hat{\alpha}_i \cos \nu\omega_i h + \hat{\beta}_i \sin \nu\omega_i h\right) = \hat{\alpha}_i \\ -\sum_{\nu=1}^{n} \hat{k}_\nu \sin \nu\omega_i h + \sum_{\nu=1}^{n} \hat{d}_\nu \left(\hat{\alpha}_i \sin \nu\omega_i h - \hat{\beta}_i \cos \nu\omega_i h\right) = \hat{\beta}_i \end{cases}, \quad i = \overline{1, n} \tag{8}$$

where $\hat{k}_\nu$ and $\hat{d}_\nu$ $\nu = \overline{1,n}$ are estimates of coefficients of the following transfer function:

$$W(z^{-1}) = \frac{k_1 z^{-1} + \ldots + k_n z^{-n}}{1 + d_1 z^{-1} + \ldots + d_n z^{-n}} = \frac{k(z^{-1})}{1 + d(z^{-1})}. \tag{9}$$

4) Nextly, we compare the estimations of plant FDPs and plant coefficients obtained on the current interval of selftuning with the estimation obtained on the previous interval.

$$\begin{gathered}
\left| \hat{\alpha}_i^{Ptau\cdot T + jT} - \hat{\alpha}_i^{Ptau\cdot T + (j+1)T} \right| < epsg, \quad \left| \hat{\beta}_i^{Ptau\cdot T + jT} - \hat{\beta}_i^{Ptau\cdot T + (j+1)T} \right| < epsg, \quad i = \overline{1,n} \\
\left| \hat{k}_0^{Ptau\cdot T + jT} - \hat{k}_0^{Ptau\cdot T + (j+1)T} \right| < epsg, \left| \hat{k}_1^{Ptau\cdot T + jT} - \hat{k}_1^{Ptau\cdot T + (j+1)T} \right| < epsg, \\
\left| \hat{d}_0^{Ptau\cdot T + jT} - \hat{d}_0^{Ptau\cdot T + (j+1)T} \right| < epsg, \left| \hat{d}_1^{Ptau\cdot T + jT} - \hat{d}_1^{Ptau\cdot T + (j+1)T} \right| < epsg,
\end{gathered} \tag{10}$$

$$j = \overline{0, P\max}.$$

where $epsg$ is specified before the tests. If the conditions (10) are not satisfied the test is continued and the procedure is repeated. The test is continued until the conditions (10) will be satisfied. If the maximal duration of identification pMax is reached and the conditions (10) are not satisfied the test is terminated and the error message is displayed.

The procedure of finite-frequency identification with selftuning of identification time includes the following GAMMA-3 functions:

- Transformation of plant model to state-space form

function [A,B,C,D]=Cauchy1(d,k,m),
where d,k,m are the polynomials of input–output equation of the plant (1); A,B,C,D are the matrices of state-space form.

- Recalculation of test frequencies so that they must be divisible to the sampling time *h*.

function[om]=omm2(om,h)
where om are vector of test frequencies, h is the sampling time; om is the new vector of test frequencies.

- Calculation of plant time response

function [y,x] = analysis1 (A,B,C,D, u,t,x0),
where u is the vector of plant input, t is the vector of time, x is the vector of plant states; y is calculated vector of plant output.

- Solution of equation of frequency identification (8)

function [vkd,vdd]=freqd2(sd,valf,vbet),
where valf,vbet are the estimates (7) of of the frequency domain parameters of the plant; vkd,vdd are the estimates of coefficients of discrete time transfer function (9) of the plant.

- Self-tuning of time of identificatiom process

function [valf,vbet,vkd,vdd,Tend,x] = tunFoursur (A, B, C ,D ,np, par, h, om ,rho, Ptau, epsg, Pmax, Tbegin, x)

where A, B, C ,D are the matrices of the plant model in discrete time state-space form, np is the plant order, par is the parameters of disturbance, h is the sampling time, om, rho are the frequencies and amplitudes of test signal, Ptau, epsg, Pmax are the parameters of the seltuning algorithm, Tbegin is the start time of identification, x is the vector of the plant states; valf, vbet are the estimates of the frequency domain parameters of the plant, vdd, vkd are the estimates of coefficients of discrete time transfer function (9) of the plant, Tend is the termination time of identification.

4. CONCLUSIONS

The software for finite-frequency identification in system GAMMA-3 is considered. The difference of concerned procedures with well-known MATLAB toolboxes is the possibility of self-tuning of identification algorithm.

Further work is related with implementation of methods of finite-frequency identification for MIMO plants.

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