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ADAPLAB-3: finite-frequency identification and adaptation toolbox for MATLAB

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Abstract: Description of ADAPLAB-3 (MATLAB ToolBox) for finite-frequency identification and adaptation is given. As distinct from known MATLAB ToolBoxes, ADAPLAB-3 algoritms proceed from assumption that an external disturbance applied to a plant and a measurement noise are unknown but bounded functions. A test signal as a sum of a minimal number of harmonics is used for identification. An adaptive control is formed on the base of H-infinity optimization and the results of identification of the plant and a closed-loop system. ADAPLAB-3 has some substantial differences from the early developed toolbox ADAPLAB-M: the discrete-time plants are considered; the amplitudes and the frequencies of the test signal are tuned automatically during the identification and adaptation process; the time of identification and adaptation is determined automatically in dependence on the current external disturbances and the noise.

Keywords: Identification, linear systems, frequency domain, software tools, algorithms

1. INTRODUCTION

The software of identification is an active developing direction of the software for automatic control systems designing. It is called both practical significance of identification and fast development of its theory. The theory of identification is developing in several directions. One of these is dedicated to an attenuation of limitations on a view of an external disturbances and measurement noise which are realized in an identification process. In this direction a finite frequency method of identification and adaptive control (Alexandrov and Orlov,2002) and method of recurrent target inequalities for an adaptive control (Yakubovich,1998) are developed. In these methods the external disturbance and measurement noise are assumed almost arbitrary. In the software of identification MATLAB Toolboxes are well known. MATLAB Toolboxes contain the software of methods of least squares and frequency domain methods and also method of instrument variables. The external disturbance and the measurement noise are guessed the white noise processes or it is supposed that the disturbances and the controlled inputs are not correlated.

In practice these suppositions are violated often and package ADAPLAB-M serves for such cases (Alexandrov, Orlov and etc, 2003). It is based on a method of finite frequency identification (Alexandrov, 1994). As distinct from known MATLAB ToolBoxes, ADAPLAB-M algoritms proceeds from assumption that an external disturbance applied to a plant and a measurement noise are unknown but bounded functions. A test signal as a sum of a minimal number of harmonics is used for identification. An adaptive control is formed on the base of H-infinity optimization and the results of identification of the plant and a closed-loop system.

New package ADAPLAB-3 which is considered in this paper has some substantial differences from the early developed toolbox ADAPLAB-M:

1) The discrete-time plants are considered.
2) The amplitudes and the frequencies of the test signal are tuned automatically (Alexandrov, 2005) during the identification and adaptation process. It allows to decrease the identification and adaptation time essentially to the contrast with the methods which the well known MATLAB ToolBoxes are based on.
3) The time of identification and adaptation are determined automatically in dependence on the current external disturbances and the noise.

2. FINITE FREQUENCY IDENTIFICATION OF SISO-PLANT

2.1 Problem statement

Consider a linear time invariant plant described by the following equation

$$y[kh]+d_1 y[k(h-1)]+\ldots+d_n y[k(h-n)]=$$
$$b_1 u[k(h-1)]+\ldots+b_n u[k(h-n)]+f[k(h-1)], \qquad (1)$$
$$(k=0,1,2,\ldots),$$

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

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

where f^* is the specified number, the plant coefficients d_i and b_i $(i=\overline{1,n})$ are unknown numbers, the plant order n is known number.

The signals $u(kh)$ and $y(kh)$ are bounded:

$$|u(kh)| \le u\_,\ |y(kh)| \le y\_ \ (k=0,1,2,\ldots) \qquad (3)$$

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:

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

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

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

2.2 The levels of uncertainty of plant coefficients

Let us write the transfer function of the plant (1) in the following form

$$W(s)=K\frac{\prod_{k=p1+p2+p3}^{p1+p2+p3}(T_k s+1)\prod_{k=p1+p2+p3+1}^{p=p1+p2+p3+p4}(T_k^2 s^2+2T_k\xi_{k-p1-p3}s+1)}{\prod_{k=1}^{p1}(T_k s+1)\prod_{k=p1+1}^{p1+p2}(T_k^2 s^2+2T_k\xi_{k-p1}s+1)} \qquad (5)$$

where K is the gain, Tk *(k=1,p)* are the time constants, ξk *(k=1,p2+p4)* are the dumping decrements.

Let us $K=K^0+\Delta K$, $T_k=T_k^0+\Delta T_k$ *(k=1,p)* and $\xi_k=\xi_k^0+\Delta\xi_k$ *(k=1,p2+p4),* where ΔK, ΔT_k and $\Delta\xi_k$ are the deviations of the plant's parameters from the known parameters of assumed plant's model $K^0, T_k^0(k=1,p)$ and $\xi_k^0(k=1,p1+p4)$. These deviations satisfy to the following inequalities

$$\left|\frac{\Delta K}{K^0}\right| \le \delta^k, \left|\frac{\Delta T_k}{T_k^0}\right| \le \delta_k^T \ k=1,p \ \left|\frac{\Delta\xi_k}{\xi_k^0}\right| \le \delta_k^\xi \ k=1,p2+p4, \qquad (6)$$

where $\delta^K, \delta_k^T(k=1,p)$ and $\delta_k^\xi(k=1,p2+p4)$ are positive numbers that are referred as the tolerances of the plant's parameters.

The three levels of the tolerances values define the three levels of uncertainty of the plant's (1) coefficients.

The first level of uncertainty *(the low level)* is characterised by the following tolerances to the plant coefficients

$$\delta^K \le 0.1, \delta_k^T \le 0.1(k=1,p), \delta_k^\xi \le 0.1(k=1,p2+p4) \qquad (7)$$

where the structural parameters n, p_i $(i = 1,4)$ are known numbers.

The second level of uncertainty *(the medium level)* is characterised by the following tolerances to the plant coefficients

$$\delta^K > 0.1, \delta_k^T > 0.1(k=1,p),$$
$$\delta_k^\xi > 0.1(k=1,p2+p4) \qquad (8)$$

The structural parameter n is known.

The third level of uncertainty *(the high level)* means that the structural parameter n is unknown.

The algorithm of identification is substantially depends on the level of uncertainty of the plant. The package ADAPLAB-3 has the procedures (further referred as the directives) for identification of the plants of first and second levels of uncertainty.

2.3. The directive D123 sdsu: finite-frequency identification with selftuning of identification time

This directive is intended for identification of plants of the first level of uncertainty. This kind of identification is used for diagnostic of regime of the plant operation. Let's consider the multiple-regime plant (1) (it has the regimes A, B, C and etc.). Its coefficients changes when the regime of the plant operation changes. The nominal coefficients of the each operation regime are known and the inequalities (7) are hold. In this case the identification purpose is to identify the regime of plant operation by means of comparison of identified plant coefficients with the nominal parameters of one of the plant operation regimes. The main part of the directive is the procedure of self-tuning of identification time that allows to decrease the time of identification process.

Procedure P1: The procedure of self-tuning of identification time

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

$$u(kh)=\sum_{i=1}^{n}\rho_i\sin\omega_i kh,\quad k=\overline{0,N-1}\qquad(9)$$

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:

$$\begin{aligned}\hat{\alpha}_{yi}(N)&=\frac{2}{\rho N}\sum_{k=0}^{N-1}y(kh)\sin\omega_i kh,\\ \hat{\beta}_{yi}(N)&=\frac{2}{\rho N}\sum_{k=0}^{N-1}y(kh)\cos\omega_i kh,\\ \hat{\alpha}_{ui}(N)&=\frac{2}{\rho N}\sum_{k=0}^{N-1}u(kh)\sin\omega_i kh,\\ \hat{\beta}_{ui}(N)&=\frac{2}{\rho N}\sum_{k=0}^{N-1}u(kh)\cos\omega_i kh.\quad i=\overline{1,n}\end{aligned}\qquad(10)$$

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 of the plant's output.

3) The estimates of the frequency domain parameters of the plant are calculated as following (Alexandrov, 2007)

$$\hat{\alpha}_i=\frac{\hat{\alpha}_{yi}\hat{\alpha}_{ui}+\hat{\beta}_{yi}\hat{\beta}_{ui}}{\hat{\alpha}_{ui}^2+\hat{\beta}_{ui}^2},\qquad \hat{\beta}_i=\frac{-\hat{\alpha}_{yi}\hat{\beta}_{ui}+\hat{\beta}_{yi}\hat{\alpha}_{ui}}{\hat{\alpha}_{ui}^2+\hat{\beta}_{ui}^2},\qquad i=\overline{1,n}.\qquad(11)$$

4) The estimates of the plant (1) coefficients are determined on the base of the frequency domain parameters (11) of the plant by means of solution of following equation (the equation of frequency identification)

$$\begin{cases}\sum_{\nu=1}^{n}\hat{b}_\nu\cos\nu\omega_i h-\sum_{\nu=1}^{n}\hat{d}_\nu\left(\hat{\alpha}_i\cos\nu\omega_i h+\hat{\beta}_i\sin\nu\omega_i h\right)=\hat{\alpha}_i\\ -\sum_{\nu=1}^{n}\hat{b}_\nu\sin\nu\omega_i h+\sum_{\nu=1}^{n}\hat{d}_\nu\left(\hat{\alpha}_i\sin\nu\omega_i h-\hat{\beta}_i\cos\nu\omega_i h\right)=\hat{\beta}_i\end{cases}\qquad(12)$$

$i=\overline{1,n}$

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

$$W(z^{-1})=\frac{b_1z^{-1}+\ldots+b_nz^{-n}}{1+d_1z^{-1}+\ldots+d_nz^{-n}}=\frac{b(z^{-1})}{1+d(z^{-1})}.\qquad(13)$$

5) Further the test is continued. After the determined quantity of filtration intervals N (corresponding to the period T of the least test frequency) the step(1)-(4) are repeated. Then the following conditions are examined:

$$\begin{aligned}&\left|\hat{\alpha}_i^{Ptau\cdot T+jT}-\hat{\alpha}_i^{Ptau\cdot T+(j+1)T}\right|<epsg,\\ &\left|\hat{\beta}_i^{Ptau\cdot T+jT}-\hat{\beta}_i^{Ptau\cdot T+(j+1)T}\right|<epsg,\\ &\left|\hat{b}_0^{Ptau\cdot T+jT}-\hat{b}_0^{Ptau\cdot T+(j+1)T}\right|<epsg,\\ &\left|\hat{b}_1^{Ptau\cdot T+jT}-\hat{b}_1^{Ptau\cdot T+(j+1)T}\right|<epsg,\\ &\left|\hat{d}_0^{Ptau\cdot T+jT}-\hat{d}_0^{Ptau\cdot T+(j+1)T}\right|<epsg,\ldots\\ &\left|\hat{d}_1^{Ptau\cdot T+jT}-\hat{d}_1^{Ptau\cdot T+(j+1)T}\right|<epsg,\\ &i=\overline{1,n},\ j=\overline{0,P1\max}.\end{aligned}\qquad(14)$$

where *epsg* is the maximal permissible difference (correlation factor) that is specified before the tests. If the conditions (14) are not satisfied the test is continued and the procedure P1 is repeated.

The test is continued until the conditions (14) will be satisfied. If the maximal duration of identification pMax is reached and the conditions (14) are not satisfied the test is terminated and the error message is displayed.

The procedure of finite-frequency identification with selftuning of identification time is executed by function *tunFoursur.*

```
[valf,vbet,vkd,vdd,Tend,x] = tunFoursur
 (Ad, Bd, Cd ,Dd ,np, par, h, om ,rho,
      Ptau, epsg, Pmax, Tbegin, x)
```

where `Ad, Bd, Cd ,Dd` are the matrix of the plant model in discrete 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 the denominator and numerator of the plant transfer function, `Tend` is the termination time of identification.

2.4. The directive D123 sfloadsu: finite-frequency identification with selftuning of test signal and time of identification

This directive is intended for identification of plants of the second level of uncertainty. In this case the substantial dispersion of the plant coefficients doesn't allow to find priory the amplitudes and the frequencies of the test signal (9). So the directive for identification includes the procedure of automatic tuning (self-tuning) of parameters of the test signal.

Procedure P2: The procedure of search of the lower bound of test frequencies:

1) The some small number $\omega = \omega_{in}$ is specified (it's named the initial value of estimates of lower bound of ω_l).
2) The plant (1) is excited by the harmonic (9) where $\omega = \omega_{in}$ and amplitude is determined by function *TunAmpsur* (it's consider in the end of this section).
3) The estimates of lower bound is calculated by formula $\hat{\omega}_l^{(1)} = \dfrac{\omega_0 \hat{\alpha}(N)}{\hat{\beta}(N)}$, where duration N is found by function *TunFoursur*.
4) Then the steps (1)-(3) are repeated for $\omega = \omega_{in}/2$ and new estimates $\hat{\omega}_l^{(2)}$ is calculated untill the following condition will be satisfied

$$\frac{|\hat{\omega}_l^{(i)} - \hat{\omega}_l^{(i-1)}|}{|\hat{\omega}_l^{(i-1)}|} \le \varepsilon_{om} \qquad (15)$$
$$i = 2,3,\ \ldots\ , maxom,$$

where ε_{om} is specified number, *maxom* is the quantity of iterations of the procedure P2.

The search of lower bound of test frequencies is executed by function *tunfLosu.*

```
[vomLo,Tend,x]=tunfLosu(Ad, Bd, Cd,
Dd, np, par, h, y_, u_, inom, PtauLo,
PamaxLo, PmaxLo, epsomLo,Pommax,Tbegin,x)
```

where `y_`, `u_` are the bounds of plant output and input, `inom` is the initial value for lower bound search , `PtauLo`, `PamaxLo`, `PmaxLo`, `epsomLo`,`Pommax` are the parameters of seltuning algorithm, `vomLo` is the found lower bound of test frequencies. Function *tunfLosu* calls the function of tuning of identification time *tunFoursur* (Procedure P1).

The estimate of upper bound of test frequencies is calculated by formula

$$\hat{\omega}_u = M\hat{\omega}_l,$$

where M is the estimate of range of test frequencies. It's assumed that M is known number.

The calculation of test frequencies is performed by function *TestOm2.*

```
[om] = TestOm2 (np, omLow, omup, h)
```

where `omLow`, `omup` are the estimates of lower and upper bounds of test frequencies, `om` is the vector of test frequencies.

The amplitude p of test signal (9) is searched by way of decreasing of its value from

$$\rho_i = \frac{u\_ \cdot \omega_i}{\sum_{j=1}^{n} \omega_j}, i = \overline{1,n} \qquad (16)$$

where n is the plant order. The process of seltuning is terminated when the plant output is satisfied to the condition $|y| \le y\_$, where $y\_$ is specified positive number.

The selftuning of amplitudes of test signal is executed by function *TunAmpsur*.

```
[rho,Tend,x] =tunampsur
(Ad,Bd,Cd,Dd,np,par,h,om,ampi,
rhoi,y_,u_,Ptau,Pamax, Tbegin,x)
```

where `rho is` the tuned amplitudes of test signal.

3. IDENTIFICATION OF MIMO-PLANT

Consider a linear time invariant MIMO-plant described by equation

$$\begin{aligned} &y[kh] + d_1 y[k(h-1)] + \ldots + d_n y[k(h-n)] = \\ &b_1 u[k(h-1)] + \ldots\ldots + b_n u[k(h-n)] + f[k(h-1)], \\ &(k = 0,1,2,\ldots), \end{aligned} \qquad (17)$$

where $y(kh) \in R^r$ is the measured output that is measured in time moments kh (where h *is* sampling time), $u(kh) \in R^m$ is controlled input, $f(kh) \in R^m$ is unknown but bounded external disturbance, d_i and b_i $(i = \overline{1,n})$ are unknown constant matrix of corresponding dimensions. The conditions (2)-(4) are satisfied for each components of vectors *y, u, f.*

The identification of MIMO-plant is based on the identification of $r \times m$ SISO-pants. Actually, the transfer matrix of plant (1) has the following view:

$$W(z)=\begin{pmatrix} W_{11}(z) & W_{12}(z) & \cdots & W_{1m}(z) \\ W_{21}(z) & W_{22}(z) & \cdots & W_{2m}(z) \\ \vdots & \vdots & \ddots & \vdots \\ W_{r1}(z) & W_{r2}(z) & \cdots & W_{rm}(z) \end{pmatrix} \quad (18)$$

where $W_{ij}(z), i=\overline{1,r}, j=\overline{1,m}$ are the transfer functions which identification is performed by ADAPLAB-3 functions that are analogous to the functions for identification of SISO-plant.

Procedure P3. The procedure of finite-frequency identification of MIMO-plant

1) The parameters of test signal (19) are determined by functions that are similar with the functions *TunAmpsur* and *tunfLosu*

$$\begin{aligned} u_j(kh) &= \sum_{i=1}^{r}\sum_{p=1}^{n} \rho_{ij}{}^{[p]} \sin \omega_{ij}{}^{[p]}(kh), \\ k &= \overline{0,N-1}, j=\overline{1,m}. \end{aligned} \quad (19)$$

where $\rho_{ij}{}^{[p]}, \omega_{ij}{}^{[p]}$ are the amplitudes and frequencies of test signal.

They are represented as the matrixes

$$P=\begin{pmatrix} P_1 \\ P_2 \\ \vdots \\ P_n \end{pmatrix}, \quad \Omega=\begin{pmatrix} \Omega_1 \\ \Omega_2 \\ \vdots \\ \Omega_n \end{pmatrix}, \quad (20)$$

which blocks have the following view

$$P_l=\begin{pmatrix} \rho_{11}^{[l]} & \rho_{12}^{[l]} & \cdots & \rho_{1m}^{[l]} \\ \rho_{21}^{[l]} & \rho_{22}^{[l]} & \cdots & \rho_{2m}^{[l]} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{r1}^{[l]} & \rho_{r2}^{[l]} & \cdots & \rho_{rm}^{[l]} \end{pmatrix}$$

$$\Omega_l=\begin{pmatrix} \omega_{11}^{[l]} & \omega_{12}^{[l]} & \cdots & \omega_{1m}^{[l]} \\ \omega_{21}^{[l]} & \omega_{22}^{[l]} & \cdots & \omega_{2m}^{[l]} \\ \vdots & \vdots & \ddots & \vdots \\ \omega_{r1}^{[l]} & \omega_{r2}^{[l]} & \cdots & \omega_{rm}^{[l]} \end{pmatrix}$$

$$l=\overline{1,n}$$

The matrixes (20) is formed by function *TestM:*

```
function Gen = TestM (Rho, lambda, Omega,
                t, flag)
```

where `Rho, lambda, Omega, t` are the parameters of test signal (19), `Gen` is the matrix $[P \quad \Omega]$.

2) The plant (17) is excited by test signal (19). The output of the plant is fed to the input of Fourier's Filter

$$\begin{aligned} \hat{\phi}_{ij}^{[l]}(N) &= \frac{2}{\rho N}\sum_{k=0}^{N-1} y(kh)\sin \omega_{ij}^{[l]}kh, \\ \hat{\psi}_{ij}^{[l]}(N) &= \frac{2}{\rho N}\sum_{k=0}^{N-1} y(kh)\cos \omega_{ij}^{[l]}kh. \end{aligned} \quad (21)$$

where $\hat{\phi}_{ij}^{[l]}, \hat{\psi}_{ij}^{[l]} (l=\overline{1,n}, i=\overline{1,r}, j=\overline{1,m})$ are the estimates of frequency domain parameters of the plant.

In accurate case the estimates (21) is used for forming of the following matrix

$$W=\begin{pmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{pmatrix} \quad (22)$$

which blocks have the view:

$$W_l=\begin{pmatrix} W_{11}(\omega_{11}^{[l]}) & W_{12}(\omega_{12}^{[l]}) & \cdots & W_{1m}(\omega_{1m}^{[l]}) \\ W_{21}(\omega_{21}^{[l]}) & W_{22}(\omega_{22}^{[l]}) & \cdots & W_{2m}(\omega_{2m}^{[l]}) \\ \vdots & \vdots & \ddots & \vdots \\ W_{r1}(\omega_{r1}^{[l]}) & W_{r2}(\omega_{r2}^{[l]}) & \cdots & W_{rm}(\omega_{rm}^{[l]}) \end{pmatrix}, \quad l=\overline{1,n}, \quad (23)$$

where

$$W_{ij}(\omega_{ij}^{[l]}) = \phi_{ij}^{[l]} + j\psi_{ij}^{[l]}, i=\overline{1,r}, j=\overline{1,m}, l=\overline{1,n}.$$

The estimates of frequency domain parameters of the plant are calculated by function *FilterDM:*

```
function [Wfil, Tend, x] = FilterDM (A,
   B, G, C, D, H, Rho, lambda, Omega,
  Ndelay, Nfilter, nfilter, Ndiv,par,
 Tbegin, x, tol, lim, key, flag, temp)
```

where `Wfil` is the matrix (22).

3) The coefficients of transfer functions (23)

$$W_{ij}(s)=\frac{\hat{k}_{ij}^{[\gamma_{ij}]}s^{\gamma_{ij}}+\ldots+\hat{k}_{ij}^{[1]}s+\hat{k}_{ij}^{[0]}}{s^{n_{ij}}+\hat{d}_{ij}^{[n_{ij}-1]}s^{n_{ij}-1}+\ldots+\hat{d}_{ij}^{[1]}s+\hat{d}_{ij}^{[0]}} \quad (24)$$

$$(i=\overline{1,r}, j=\overline{1,m}).$$

are calculated on the base of the following sets:

$$\hat{\phi}_{ij} = \phi_{ij}(\tau) = \begin{bmatrix} \phi_{ij}^{[1]}(\tau) \\ \phi_{ij}^{[2]}(\tau) \\ \vdots \\ \phi_{ij}^{[n]}(\tau) \end{bmatrix} \quad \hat{\psi}_{ij} = \psi_{ij}(\tau) = \begin{bmatrix} \psi_{ij}^{[1]}(\tau) \\ \psi_{ij}^{[2]}(\tau) \\ \vdots \\ \psi_{ij}^{[n]}(\tau) \end{bmatrix}$$

$$\omega_{ij} = \begin{bmatrix} \omega_{ij}^{[1]}(\tau) \\ \omega_{ij}^{[2]}(\tau) \\ \vdots \\ \omega_{ij}^{[n]}(\tau) \end{bmatrix}, \quad (i = \overline{1,r}, j = \overline{1,m}) . \tag{25}$$

The identified transfer functions (24) are united to the transfer matrix of the plant:

$$\hat{W}(z) = \begin{pmatrix} \hat{W}_{11}(z) & \hat{W}_{12}(z) & \cdots & \hat{W}_{1m}(z) \\ \hat{W}_{21}(z) & \hat{W}_{22}(z) & \cdots & \hat{W}_{2m}(z) \\ \vdots & \vdots & \ddots & \vdots \\ \hat{W}_{r1}(z) & \hat{W}_{r2}(z) & \cdots & \hat{W}_{rm}(z) \end{pmatrix} \tag{26}$$

This operation is performed by function *FridTm.*

```
function [degDen, degNum, Den, Num] =
  FrIdTM (DegDen, DegNum, vro, S, W)
```

where `Den, Num` are the coefficients of denominators and numerators of transfer functions (24).

4) Then the model of the plant is converted to the Luenberger's state-space canonic form with use of functions *FDPPardd, FrIdPardd* and *Cauchy (*these functions are analogous to the function *FDPPard, FrIdPard* and *Cauchy* of ADAPLAB-M toolbox). The model in state space-form is used for the controller synthesis.

4. ADAPTIVE CONTROL

The controller synthesis is performed with use of H_∞ technique (Alexandrov and Orlov, 2002). Rough speaking the functions for controller synthesis in ADAPLAB-3 are the same as in ADAPLAB-M.

For SISO-plant the function *akord3* is used for controller synthesis.

```
[rd,gd] = akord3 (dd,kd,q,h)
```

where rd, dr are the polynomials of numerator and denominator of controller's transfer function.

The controller synthesis for MIMO-plant is performed by function *ContRic*

```
function [Ac, Bc, Cc, Dc, gamma] =
ContRic (A, B1, B2, C1, C2,  alpha, beta,
           Q0, Q1, R1, R2)
```

where `Ac, Bc, Cc, Dc` are the matrixes of controller.

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