

LINEAR SYSTEMS' STABILIZATION BY USING DYNAMIC COMPENSATION

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Sistemele automate sunt proiectate astfel încât să asigure satisfacerea unor indici de performanță ai regimului dinamic și staționar. În acest articol este prezentată o procedură de stabilizare a unui sistem liniar multivariabil prin compensare dinamică. Proiectarea compensatorului dinamic stabilizator (CDS) este realizată în două variante: CDS cu estimator de stare de tip Kalman (unitar) și CDS cu estimator de stare de tip Luenberger (minimal). Validarea soluțiilor obținute este realizată prin simulare în Matlab-Simulink, prezentând atât programul Matlab cât și rezultatul simulării.

The automatic systems are projected so that they should ensure the fulfillment of some performance indexes of the stationary and dynamical regime. In this article is presented a stabilization procedure of a multivariable linear system by using dynamical compensation. The projection of the stabilizer dynamic compensatory (SDC) is realized in two ways: SDC with Kalman (unitary) state estimator and SDC with state estimator of Luenberger (minimal) type. The validation of the solutions obtained is realized by Matlab-Simulink simulation, by presenting both the Matlab program and the simulation's result.

Keywords: controllability, observability, control law, allocability, state estimators, stabilizability, detectability, stabilizer dynamic compensatory.

1. Introduction

In this work are presented ways of designing some dynamic compensatory in the purpose of the multivariable linear systems' stabilization. The stabilization problem by dynamic compensation (the elementary synthesis) embraces two distinct problems namely: the determination of a control law by feedback after state and implementation of this one by using a state estimator [1].

Problem formulation. We consider the multivariable linear system (continuous or discrete)

$$\begin{cases} \dot{x} = Ax + Bu & , \quad x \in \mathbb{R}^n, x(0) = x_0 \\ y = Cx \end{cases} \quad (1)$$

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Determine a **compensatory system**

$$\begin{cases} \dot{x}_c = A_c x_c + B_c y & , \quad x_c \in \mathbb{R}^{n_c}, x_c(0) = x_{co} \\ u = F_c x_c + G_c y \end{cases} \quad (2)$$

which, by processing of the measured dimension y of the system (A,B,C) , a command u provides so that, the resulted system (in closed-loop) from the connection of the two systems (Fig.1) should be intern asymptotic stable.

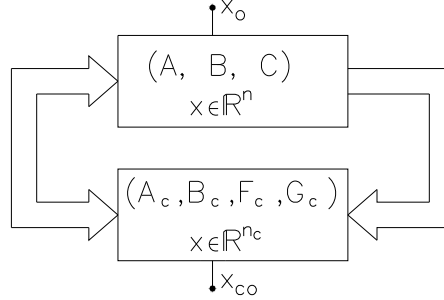


Fig. 1. Block diagram of connection of the two systems

The resulted system (in closed circuit) is characterized by the relation

$$\dot{x}_R = A_R x_R, \quad x_R \in \mathbb{R}^{n+n_c}, x_R(0) = x_{R0} \quad (3)$$

where

$$A_R = \begin{bmatrix} A + B G_c C & B F_c \\ B_c C & A_c \end{bmatrix} \quad (4)$$

By reformulating the stabilization problem by dynamic compensation, we have: “being given the system (1) (continuous or discrete-time), design a compensatory system (2) that, by processing the measured dimension y , provides a command u so that the system (in free regime) (3), resulted from the connection of the two systems, should be intern asymptotic stable [2], viz.

$$\sigma(A_R) \subset \begin{cases} C^- & , \text{ if } t \in \mathbb{R} \\ U_1(0) & , \text{ if } t \in \mathbb{Z} \end{cases} \quad (5)$$

The compensatory is called **stabilizer dynamic compensatory (SDC)**.

Solution of the problem. The necessary conditions so that the problem of stabilization by dynamic compensation should have solution are:

- 1) the pair (A,B) can be stabilized
- 2) the pair (C,A) is detectable

In the first stage we design a control law $u = Fx$ so that

$$\sigma(A + BF) \subset \begin{cases} C^- & , \text{ if } t \in \mathbb{R} \\ U_1(0) & , \text{ if } t \in \mathbb{Z} \end{cases} \quad (6)$$

In the second stage we build a stable state estimator. The assembly formed by the control law and the state estimator necessary for the implementation of this one constitute a **linear compensatory**.

Separation principle. If the pair (C,A) is detectable then the synthesis general problem of a governing algorithm for the system (A,B,C) may be separated in two independent problems namely:

- 1) the determination of a control law by feedback after state, $u = Fx$ and
- 2) the construction of a stable state estimator for the implementation of the control law $u = Fx$.

If one wish that:

$$\sigma(A_R) \equiv \Lambda_o \quad (7)$$

then the necessary conditions for solving the allocation problem by dynamic compensation become:

- 1) the pair (A,B) is controllable and
- 2) the pair (C,A) is observable

We present now the fundamental result given by the Theorem 1.

Theorem 1. The problem of the eigenvalues (poles) allocation by dynamic compensation has a solution if and only if the system (A,B,C) is controllable and observable. In this case an efficient solution has the dimension $\mathbf{v}=\mathbf{n}$ in case of the Kalman estimator or $\mathbf{v}=\mathbf{n}-\mathbf{p}$ in case of the **Luenberger** estimator [1].

We consider the continuous linear system:

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \end{bmatrix}, B = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}, C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Design a stabilizer dynamic compensatory knowing that:

$$\Lambda = \left\{ -1, -1, \frac{-1 \pm j\sqrt{3}}{2} \right\}, \Lambda_{\text{est}1} = \{-1, -1, -1 \pm j\} \quad \text{and} \quad \Lambda_{\text{est}2} = \{-1 \pm j\}.$$

2. Verifying the necessary conditions

2.1. The controllability matrix of the pair (A,B) is

$$R = [B \mid AB \mid A^2B \mid A^3B] = \text{ctrb}(A, B) = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

and we notice that $\text{rank } R = 4 = n$ and so (A,B) is controllable (and, obviously, the system (A,B,C) is controllable).

2.2. The observability matrix of the pair (C,A) :

$$Q = \text{obsv}(A, C) = \begin{bmatrix} C \\ CA \\ CA^2 \\ CA^3 \\ \vdots \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \vdots & & & \end{bmatrix}$$

As $\text{rank } Q = 4 = n$, the pair (C, A) is observable ((A, B, C) is observable).

3. Projection of the control law

$u = Fx$ (computing the stabilizing reaction F).

3.1. We notice that : $n = 4$, $m = 2$ and $p = 2$. We choose the pair $F_0 = 0_{2,4}$ and

$g = [0 \ 1]^T$ and we calculate the new pair :

$$A_{F_0} = A + BF_0 \equiv A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \end{bmatrix}, b = Bg = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

3.2. We calculate the controllability matrix :

$$R_{A_{F_0}} = [b : Ab : A^2b : A^3b] = \text{ctrb}(A_{F_0}, b)$$

or

$$R_{A_{F_0}} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

3.3. We calculate $R_{A_{F_0}}^{-1} \rightarrow R_{A_{F_0}}^{-1} \equiv R_{A_{F_0}}$.

3.4. $q^T = e_n^T R_{A_{F_0}}^{-1} = [1 \ 0 \ 0 \ 0]$ (the last line from $R_{A_{F_0}}^{-1}$)

3.5. $f^T = -q^T \chi_n(A_{F_0})$

in which : $\chi_n(s) = (s+1)^2(s^2+s+1) = s^4 + 3s^3 + 4s^2 + 3s + 1$. It results :

$$f^T = -[1 \ 0 \ 0 \ 0][A^4 + 3A^3 + 4A^2 + 3A + I_4]$$

viz. :

$$f^T = [-2 \ -3 \ -4 \ -3]$$

Observation. We notice that the pair (A_{F_0}, b) is a **controllable realization** and

we may apply the fast procedure in order to design the reaction f^T :

$$f^T = [\alpha_{00} - \alpha_{0n}, \alpha_{10} - \alpha_{1n}, \alpha_{20} - \alpha_{2n}, \alpha_{30} - \alpha_{3n}]$$

where: $\chi_o(s) = s^4 - 1$ and $\chi_n(s) = s^4 + 3s^3 + 4s^2 + 3s + 1$

We obtain: $f^T = [-2 \ -3 \ -4 \ -3]$

3.6. We calculate the reaction F : $F = F_0 + g f^T = \begin{bmatrix} 0 & 0 & 0 & 0 \\ -2 & -3 & -4 & -3 \end{bmatrix}$

The validation of the design: The characteristic polynomial of the resulting system is : $\chi_r(s) = \det[sI - (A + BF)]$

But: $A + BF = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & -3 & -4 & -3 \end{bmatrix}$ = controllable companion ,resulting :

$$\chi_r(\lambda) = \lambda^4 + 3\lambda^3 + 4\lambda^2 + 3\lambda + 1 \equiv \chi_{\text{new}}.$$

So, the designing of the F reaction is correct.

4. The state estimator projection

4.1. The first solution: Kalman (unitary) estimator. Due to the fact that the pair (C,A) is controllable, we have:

4.1.1. By dualling the pair (C,A) we obtain :

$$A^* \triangleq A^T = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, B^* \triangleq C^T = \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}$$

4.1.2. We choose the pair $F_0 = 0_{2,4}$ and $g = [0 \ 1]^T$ and we compute the new pair

$$A_{F_0} = A^* + BF_0 = A^* \text{ and } b = B^* g = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}.$$

4.1.3. We calculate the controllability matrix corresponding to the pair (A_{F_0}, b) :

$$R_{A_{F_0}} = [b \ : \ Ab \ : \ A^2b \ : \ A^3b] = \text{ctrb}(A_{F_0}, b) = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

4.1.4. We calculate the inverse $R_{A_{F_0}}^{-1}$ by using the MATLAB instruction:

$$R_{A_{F_0}}^{-1} = \text{inv}(R_{A_{F_0}}) = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

4.1.5. We calculate : $q^T = e_n^T R_{A_{F_0}}^{-1} = [0 \ 0 \ 0 \ 1] R_{A_{F_0}}^{-1} = [0 \ 0 \ 1 \ 0]$

4.1.6. We calculate the reaction f^T : $f^T = -q^T \chi_n(A_{F_0})$

in which : $\chi_n(s) = (s+1)^2(s^2+2s+2) = s^4 + 4s^3 + 7s^2 + 6s + 2$

It results :

$$f^T = -[0 \ 0 \ 1 \ 0][A_{F_0}^4 + 4A_{F_0}^3 + 7A_{F_0}^2 + 6A_{F_0} + 2I_4]$$

viz.:

$$f^T = [-7 \ -6 \ -3 \ -4].$$

4.1.7. We calculate the reaction F^* :

$$F^* = F_0 + g f^T = \begin{bmatrix} 0 & 0 & 0 & 0 \\ -7 & -6 & -3 & -4 \end{bmatrix}$$

The validation of F^* projection : the characteristic polynomial of the resulted pair is :

$$\chi_r(s) = \det[sI - (A^* + B^*F)]$$

viz.:

$$\chi_r(s) = s^4 + 4s^3 + 7s^2 + 6s + 2 \equiv \chi_{est1}(s)$$

the designing being correctly.

4.1.8. It is noted :

$$L = (F^*)^T = \begin{bmatrix} 0 & -7 \\ 0 & -6 \\ 0 & -3 \\ 0 & -4 \end{bmatrix}$$

4.1.8. We calculate the parameters of the full estimator dimension :

$$J = A + LC = \begin{bmatrix} 0 & 1 & 0 & -7 \\ 0 & 0 & 1 & -6 \\ 0 & 0 & 0 & -2 \\ 1 & 0 & 0 & -4 \end{bmatrix}, H = -L = \begin{bmatrix} 0 & 7 \\ 0 & 6 \\ 0 & 3 \\ 0 & 4 \end{bmatrix}, M = B = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}$$

$$K = I_4, N \equiv O, P \equiv O.$$

4.2. The second solution: minimal estimator.

4.2.1. The matrix C being epic we produce the nonsingular transform:

$$T = \begin{bmatrix} \tilde{C} \\ C \end{bmatrix}^{-1} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}^{-1} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = T^{-1}.$$

4.2.2. By applying the transform of coordinates $\hat{x} = T x$ we obtain the equivalent system on state :

$$\hat{A} = TAT^{-1} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \hat{B} = TB = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}$$

$$\hat{C} = CT^{-1} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

and from here it results :

$$A_1 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}, A_2 = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}, A_3 = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}, A_4 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix},$$

$$B_1 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}, B_2 = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}$$

4.2.3. The pair (A_2, A_1) is observable and by dualling we obtain the pair (A^*, B^*) :

$$A^* = A_1^T = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}, B^* = A_2^T = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$$

4.2.4. We choose the pair (F_o, g) : $F_o = 0_{2,2}$ and $g = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$

and we compute the pair (A_{F_o}, b) : $A_{F_o} = A^* + B^* F_o = A^*$, $b = Bg = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

4.2.5. We calculate the controllability matrix :

$$R_{A_{F_o}} = [b \quad A_{F_o} b] = \text{ctrb}(A_{F_o}, b) = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

4.2.6. $R_{A_{F_o}}^{-1} = R_{A_{F_o}}$

4.2.7. We calculate: $q^T = e_n^T R_{A_{F_o}}^{-1} = [1 \quad 0]$

4.2.8.: We calculate $f^T = -q^T \chi_n(A_{F_o})$, with $\chi_n(s) = s^2 + 2s + 2$

obtaining $f^T = -[1 \quad 0][A_{F_o}^2 + 2A_{F_o} + 2I_2]$ or $f^T = [-2 \quad -2]$.

Observation. The pair (A_{F_o}, b) is a controllable realization and so:

$$f^T = [\alpha_{oo} - \alpha_{on} , \alpha_{lo} - \alpha_{ln}]$$

where $\chi_o(s) = s^2$ and $\chi_n(s) = s^2 + 2s + 2$

resulting: $f^T = [-2 \quad -2]$.

4.2.9. We calculate $F^* = F_o + g f^T = \begin{bmatrix} -2 & -2 \\ 0 & 0 \end{bmatrix}$

4.2.10. We put: $L \equiv (F^*)^T = \begin{bmatrix} -2 & 0 \\ -2 & 0 \end{bmatrix}$

and we calculate the parameters of the Luenberger estimator:

$$J = A_1 + L A_2 = \begin{bmatrix} 0 & -2 \\ 1 & -2 \end{bmatrix}$$

$$H = A_3 + L A_4 - J L = \begin{bmatrix} -4 & 1 \\ -2 & 0 \end{bmatrix}$$

$$M = B_1 + L B_2 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$$

$$K = T^{-1} \begin{bmatrix} I_2 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, N = T^{-1} \begin{bmatrix} -L \\ I_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 2 & 0 \\ 2 & 0 \\ 0 & 1 \end{bmatrix}, P = 0$$

5. Projection of the stabilizer dynamic compensatory

We distinguish two solutions (depending on the state estimator's type used for the implementation of the control law by reaction after state $u = Fx$) :

5.1. SDC with Kalman estimator

We calculate the parameters of the compensatory:

$$A_c = J + MFK = \begin{bmatrix} 0 & 1 & 0 & -7 \\ 0 & 0 & 1 & -6 \\ 0 & 0 & 0 & -2 \\ -1 & -3 & -4 & -7 \end{bmatrix}, B_c = H + MFN = \begin{bmatrix} 0 & 7 \\ 0 & 6 \\ 0 & 3 \\ 0 & 4 \end{bmatrix}$$

$$F_c = FK = \begin{bmatrix} 0 & 0 & 0 & 0 \\ -2 & -3 & -4 & -3 \end{bmatrix} \text{ and } G_c = FN = 0.$$

5.2. SDC with Luenberger estimator.

The parameters of the compensatory are obtained like this :

$$A_c = J + MFK = \begin{bmatrix} 0 & -2 \\ 1 & -2 \end{bmatrix}, B_c = H + MFN = \begin{bmatrix} -4 & 1 \\ -2 & 0 \end{bmatrix}$$

$$F_c = FK = \begin{bmatrix} 0 & 0 \\ -4 & -3 \end{bmatrix} \text{ and } G_c = FN = \begin{bmatrix} 0 & 0 \\ -16 & -3 \end{bmatrix}.$$

6. Projection validation by MATLAB simulation.

6.1. SDC with Kalman estimator. In order to be able to verify by MATLAB simulation the designed system it is necessary the computing of the matrix A_R (of the closed circuit system):

$$A_R = \begin{bmatrix} A + BG_c C & BF_c \\ B_c C & A_c \end{bmatrix}, \quad A_R = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & -2 & -3 & -4 & -3 \\ 0 & 0 & 0 & 7 & 0 & 1 & 0 & -7 \\ 0 & 0 & 0 & 6 & 0 & 0 & 1 & -6 \\ 0 & 0 & 0 & 3 & 0 & 0 & 0 & -2 \\ 0 & 0 & 0 & 4 & -1 & -3 & -4 & -7 \end{bmatrix}$$

By using the MATLAB instruction:

$$v = \sigma(A_R) = \text{eig}(A_R) = \{-1, -1, -0.5 \pm j0.866, -1, -1, -1 \pm j\}$$

which means that $\sigma(A_R) = \Lambda \cup \Lambda_{\text{est}_1}$ and so the designing of SDC is correct.

The simulation of the designed system, in free regime,

$$\dot{x}_R = A_R \cdot x_R, \quad x_R \in \mathbb{R}^{n+n_c}, \quad x_R(0) = x_{R_0}$$

with $x_{R_0} = [1 \ 1 \ 1 \ 1 \ 1 \ 1 \ 1 \ 1]^T$ is presented (and the program MATLAB) in fig. 1a,b. We notice that the designed system is stable.

6.2. CDS with Luenberger estimator. In this case the size of the designed system is reduced, $n_R = 6$, obtaining:

```

rasp9241eng.m - C:\MATLABR11\work\rasp9241eng.m
a=[0 1 0 0 0 0 0 0;0 0 1 0 0 0 0 0;0 0 0 1 0 0 0 0;
  1 0 0 0 -2 -3 -4 -3;0 0 0 7 0 1 0 -7;0 0 0 6 0 0 1 -6;
  0 0 0 3 0 0 0 -2;0 0 0 4 -1 -3 -4 -7];
b=[1 0;0 0;0 0;0 0;0 0;0 0;0 0;0 1];
c=[1 0 0 0 0 0 0 0;0 0 0 0 0 0 0 1];
d=[0 0;0 0];
x0=[1 1 1 1 1 1 1 1]';
t=0:.1:10;
u=zeros(101,2);
y=lsim(a,b,c,d,u,t,x0);
plot(t,y,'k'),grid
title('FREE RESPONSE'),
gtext('t[sec]'),gtext('y(t)')

```

Fig. 1a

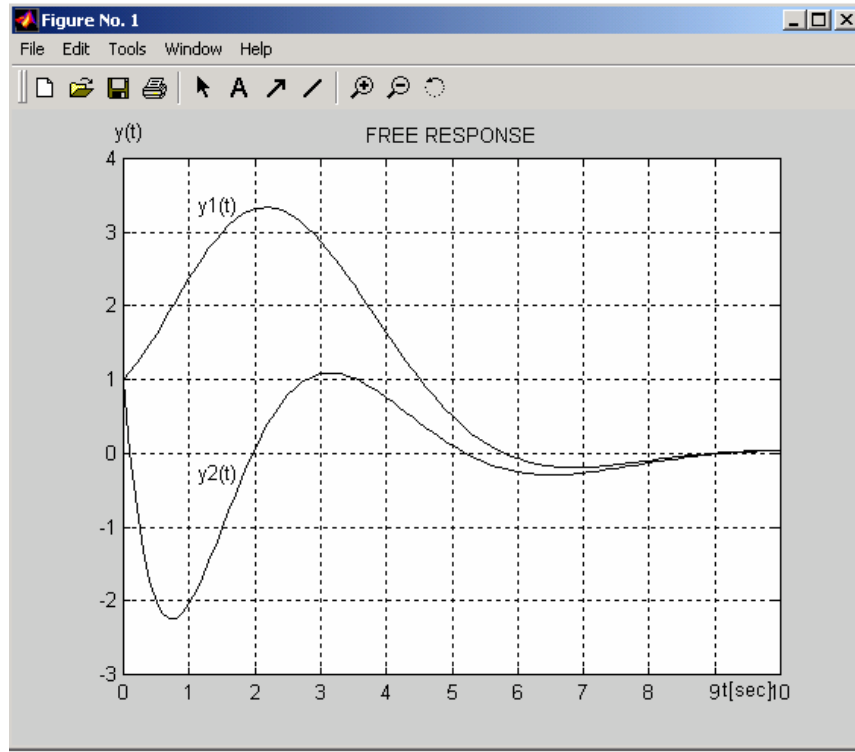


Fig. 1b

$$A_R = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ -15 & 0 & 0 & -3 & -4 & -3 \\ -4 & 0 & 0 & 1 & 0 & -2 \\ -2 & 0 & 0 & 0 & 1 & -2 \end{bmatrix} \text{ .By using the MATLAB instruction:}$$

$$v = \sigma(A_R) = \text{eig}(A_R) = \{-1, -1, -0.5 \pm j0.866, -1 \pm j\}$$

viz. $\sigma(A_R) = \Lambda \cup \Lambda_{\text{est}_2}$, fact that confirms the correctness of the SDC designing.

In fig.2a,b are presented the MATLAB program and the graphic representation of the response in free regime of the system obtained by designing, for the initial condition $x_{R_0} = [1 \ 1 \ 1 \ 1 \ 1 \ 1]^T$. So, the designed system is stable.

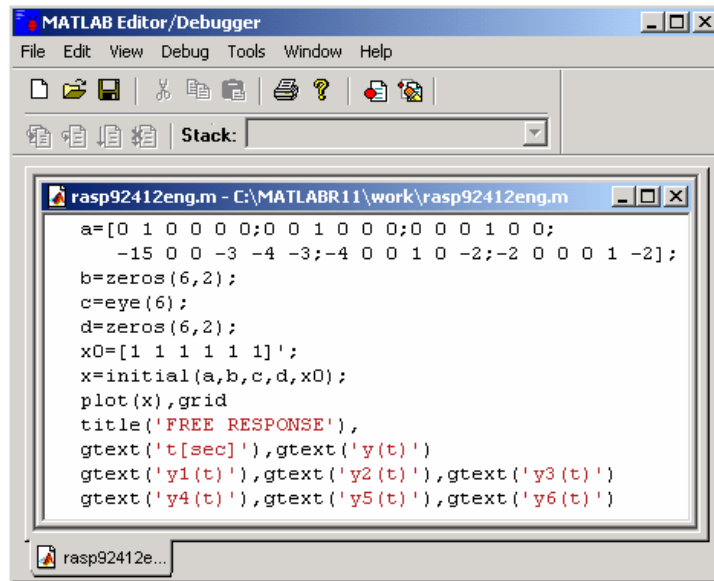


Fig. 2a

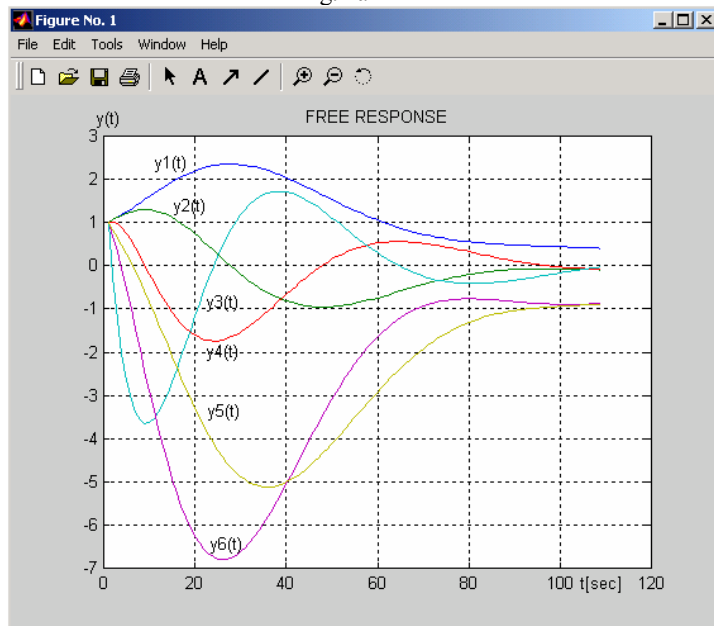


Fig. 2b

7. Conclusions

The stabilization problem by dynamic compensation (the elementary synthesis) embraces two distinct problems namely: the determination of a control

law by feedback after state and implementation of this one by using a state estimator (Kalman or Luenberger estimator).

As one may notice from the simulations for the validation of the stabilizing dynamic compensatory's projection the free response of the resulting system is stable and therefore the projection is efficient.

The original contributions of the autor are: the computer aided designing of the SDC and the computer aided analysis of the system behaviour by using Matlab program.

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