Using adaptive filters in controlling of electrical resistance furnace temperature based on a real time identification method

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1. Introduction

The slow processes are characterized by approximate models, having time constants greater than 10 seconds and very often containing time delay. To choose the controller there are some criteria which are verified in practice, taking into consideration the process characteristics and the imposed performance.
The heating process of an electrical resistance furnace is a slow process and is very difficult to control it because the parameters values of the system of the electrical resistance furnace cannot be compute with accuracy. These values are adequate for designing the controller of the heating process.
Because the parameters of the system can be modified in the heating process, it is required to compute them in real time. In order to solve this problem, for the identification of the system it can be used an adaptive filter (Alexander, 1986). The adaptive filter coefficients values are changing on every iteration, having as consequence that the parameters of the system can be also computed also on every iteration. The temperature control system is conditioned by the convergence of the adaptive algorithm. One of the convergence criterions for an adaptive filter is the initial value of the parameters of the filter so, for this reason, the initial values were computed using an on-line method. The process parameters values can be computed from the adaptive filter coefficients (Oppenheim & Schafer, 1986).
Knowing the process parameters values, it can be computed the controller parameters values, taking into consideration the criteria of tuning controllers.
An experimentally determination leads to the conclusion: if the values of the samples are distorted by the additive noises, it has to be used a smoother filter.

2. The parameters process identification methods

2.1. The on-line identification method of slow process parameters with time constant and delayed time

In some applications, such as heating process of electrical resistance furnace, the output signal is delayed comparative to the input signal by a time constant, as in relation

$$y(t) = x(t - \tau) \quad , \tau > 0 \quad , \tag{1}$$

where τ is a delayed time constant or time propagation constant.
The transfer function of such a process is

$$H_\tau(s) = e^{-\tau s} . \tag{2}$$

In (Dumitrache et al., 1993) it is shown that the model of the electrical resistance furnace is a model with a time constant and a delayed time defined by the relation:

$$H(s) = \frac{K \cdot e^{-\tau s}}{1 + Ts} , \tag{3}$$

where T, τ > 0.
In (3) K is the amplification coefficient, τ is the delayed time and T is the time constant.
The on-line identification method, that is presented in (Panoiu et al., 2008 c), consists in applying of an input signal to a system whom balanced state is described by the (X_0, Y_0) point. The relation (4) describes this input signal.

$$x(t) = \begin{cases} X_1 & 0 \le t \le T_0 \\ X_0 & t > T_0 \end{cases} . \tag{4}$$

The input signals form is presented in figure 1.

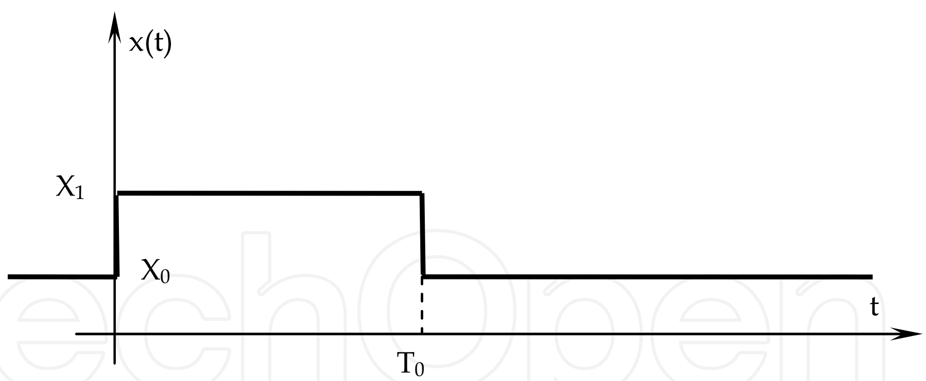


Fig. 1. The input signal form.

Applying this kind of input signal instead of the step signal presents two advantages. The first advantage consists in the fact that it can be observed if the Y output can be stabilized in the same stationary Y_0 point, or not. If the Y_0 value can't be reached, we conclude that or the process is no stationary, which can conduct to a better approach of the model, or a perturbation appeared during the experiment, so the experiment must be resumed. The second advantage consists in the fact that the differences $x(t) - X_0$ and $y(t) - Y_0$ are null after a time interval that is larger than process stabilization time interval, so the integrals

$$I_{XK} = \int_0^\infty (-t)^K \left[x(t) - X_0\right] \cdot dt \tag{5}$$

$$I_{YK} = \int_0^\infty (-t)^K \left[y(t) - Y_0\right] \cdot dt\ , \tag{6}$$

where $K = 0,\ 1,\ \dots\ ,$ will be finite.

Taking into consideration that the chosen model depends by N parameters, the identification process consists in evaluation of H(s) function and the first N-1 derivatives in origin. The result is an N equation system with N variables. The solution of this equation system is the N system parameters.

The N-1 derivatives can be determined in recursive way, by the relation:

$$Y(s) = H(s) \cdot X(s)\ , \tag{7}$$

from which result

$$Y(0) = H(0) \cdot X(0)\ , \tag{8}$$

and by successive derivations it can be obtained the general relation for the k^{th} order derivative in origin

$$H^{(K)}(0) = \frac{Y^{(K)}(0) - \sum_{i=1}^{K} C_K^i H^{(K-i)}(0) \cdot X^{(i)}(0)}{X(0)} \tag{9}$$

where

$$Y^{(K)}(0) = \int_0^\infty (-t)^K \left[y(t) - Y_0\right] \cdot dt\ , \tag{10}$$

$$X^{(K)}(0) = \int_0^\infty (-t)^K \left[x(t) - X_0\right] \cdot dt\ , \tag{11}$$

with K= 0, 1, . . ., N-1.

The integrals that are obtained from (10) and (11) can be computed on a finite domain, $0 \le t \le T_i$ where T_i represents the limits of integration. Using (9) it was computed successive for the model given by the relation (3):

$$\begin{aligned} &H(0) = K \\ &H'(0) = -K \cdot (T + \tau) \qquad , \\ &H''(0) = K \cdot \left[(T + \tau)^2 + T^2 \right] \end{aligned} \tag{12}$$

These relations permit the evaluation of the model parameters.

$$\begin{aligned} &K = H(0) \\ &T = \sqrt{\frac{H''(0)}{H(0)} - \left(\frac{H'(0)}{H(0)} \right)^2} \;, \\ &\tau = -\frac{H'(0)}{H(0)} - T \;\; . \end{aligned} \tag{13}$$

The performances of this method were determined by choosing a system which has the system function as in equation (3). The values of the parameters model were chosen as in (14), and the values of the test signal parameters were chosen as in (15). The units of all time constants are seconds.

$$T = 7, \;\; K = 5, \;\; \tau = 4 \quad , \tag{14}$$

$$T_0 = 50, \;\; T_i = 100, \;\; T_e = 0.1 \;\; . \tag{15}$$

The influence of the parameters model values was studied by taking different values for one of them and keeping constant the other two. The results are presented in tables 1, 2 and 3. From table 1 it can be observe that amplification coefficient has no influence on computed values, comparative to influence of time constant and delay time, presented in tables 2 and 3. These influences increase as duration of time constant and delay time are increasing referring to test impulse duration and time integration.

In conclusion this identification method has the disadvantage that if the test impulse duration and time integration are not correlated with the real values of the parameters model, the measurements are wrong. The reducing of errors can be obtained by increasing the test impulse duration and time integration.

2.2. Adaptive method of process parameters identification

One of the problems that appear in processes whose model has a time constant and a delayed time, defined by the relation (3) is that of obtaining a transfer function through a dimensionally finite system, which actually means to approximate by a rational function the $e^{-\tau s}$ function (Panoiu et al., 2008 b), (Panoiu et al., 2008 d). The transfer function which approximate $H_\tau(s)$ from relations (2) and (3), is note by $H_{\tau a}(s)$, as in relation (16).

k	k_c	$\varepsilon_{k_c}(\%)$	T_c	$\varepsilon_{T_c}(\%)$	τ_c	$\varepsilon_{\tau_c}(\%)$
1	0,9998	0,0200	6,9324	0,9657	4,0039	0,0975
2	1,9996	0,0200	6,9324	0,9657	4,0039	0,0975
3	2,9994	0,0200	6,9324	0,9657	4,0039	0,0975
4	3,9992	0,0200	6,9324	0,9657	4,0039	0,0975
5	4,9990	0,0200	6,9324	0,9657	4,0039	0,0975
6	5,9988	0,0200	6,9324	0,9657	4,0039	0,0975
7	6,9986	0,0200	6,9324	0,9657	4,0039	0,0975
8	7,9984	0,0200	6,9324	0,9657	4,0039	0,0975
9	8,9982	0,0200	6,9324	0,9657	4,0039	0,0975
10	9,9980	0,0200	6,9324	0,9657	4,0039	0,0975

Table 1. The influence of amplification coefficient on computed values of parameters process with ($T=7$, $\tau=4$).

T	k_c	$\varepsilon_{k_c}(\%)$	T_c	$\varepsilon_{T_c}(\%)$	τ_c	$\varepsilon_{\tau_c}(\%)$
1	5,0000	0,0000	0,9996	0,0400	3,9512	1,2200
3	5,0000	0,0000	2,9999	0,0033	3,9504	1,2400
5	4,9999	0,0020	4,9951	0,0980	3,9544	1,1400
7	4,9990	0,0200	6,9324	0,9657	4,0039	0,0975
9	4,9946	0,1080	8,7054	3,2733	4,1682	4,2050
11	4,9835	0,3300	10,2409	6,9009	4,4733	11,8325
13	4,9632	0,7360	11,5243	11,3515	4,8985	22,4625
15	4,9329	1,3420	12,5771	16,1527	5,4058	35,1450
17	4,8927	2,1460	13,4338	20,9776	5,9585	48,9625
19	4,8438	3,1240	14,1302	25,6305	6,5284	63,2100

Table 2. The influence of time constant on computed values of parameters process, with ($k=5$, $\tau=4$).

τ	k_c	$\varepsilon_{k_c}(\%)$	T_c	$\varepsilon_{T_c}(\%)$	τ_c	$\varepsilon_{\tau_c}(\%)$
1	4,9994	0,0120	6,9520	0,6857	0,9887	1,1300
2	4,9993	0,0140	6,9462	0,7686	1,9932	0,3400
4	4,9990	0,0200	6,9324	0,9657	4,0039	0,0975
6	4,9987	0,0260	6,9151	1,2129	6,0171	0,2850
8	4,9983	0,0340	6,8936	1,5200	8,0334	0,4175
10	4,9977	0,0460	6,8669	1,9014	10,0534	0,5340
12	4,9970	0,0600	6,8337	2,3757	12,0779	0,6492
14	4,9959	0,0820	6,7926	2,9629	14,1079	0,7707
16	4,9946	0,1080	6,7418	3,6886	16,1445	0,9031
18	4,9928	0,1440	6,6791	4,5843	18,1890	1,0500

Table 3. The influence of delayed time on computed values of parameters process, with ($T=7$, $k=5$).

$$H_{\tau a}(s)=\frac{1+c_1\cdot s+c_2\cdot s^2+\cdots+c_n\cdot s^n}{1+d_1\cdot s+d_2\cdot s^2+\cdots+d_n\cdot s^n},\ d_n\neq 0 \tag{16}$$

The coefficients of the transfer function $H_{\tau a}(s)$ can be determined by equalizing the decomposed function $H_{\tau a}(s)$ around the origin with the decomposed function $H_{\tau}(s)$ around the origin. Such an approximation is known as Padé approximation of rank (n + k), where n represent the degree of the polynomial at the denominator and k the degree of the polynomial at the nominator of the $H_{\tau a}(s)$. In (Dumitrache et al., 1993) are present the usual Padé approximation of rank (2 + 0), (2 + 1), (1 + 1) and (2 + 2).

$$\begin{aligned}
&H_{\tau a1}(s)=\frac{1}{1+\tau s+\dfrac{\tau^2}{2}\cdot s^2}, \quad H_{\tau a2}(s)=\frac{1-\dfrac{1}{3}\tau s}{1+\dfrac{2}{3}\tau s+\dfrac{\tau^2}{2}s^2},\\
&H_{\tau a3}(s)=\frac{1-\dfrac{\tau}{2}s}{1+\dfrac{\tau}{2}s}, \quad H_{\tau a4}(s)=\frac{1-\dfrac{\tau}{2}s+\dfrac{\tau^2}{12}\cdot s^2}{1+\dfrac{\tau}{2}s+\dfrac{\tau^2}{12}\cdot s^2}
\end{aligned} \tag{17}$$

The system function of the discrete system is obtained by using one of the Padé approximations of the function $e^{-\tau s}$ and is given by relation (18).

$$H_a(s)=\frac{K}{1+s\cdot T}\cdot H_{\tau a}(s) \tag{18}$$

The system function of the discrete system is obtained by using an equivalence method for the analog filter with a numeric one. The two methods that we are studied are:
1. The approximation of differential equation by finite difference method, in which the system function is obtained from relation (19)

$$H(z)=H_a(s)\Big|_{s=\frac{1}{T_e}\cdot\left(1-z^{-1}\right)} \tag{19}$$

2. The bilinear transform method, in which the system function is obtained from relation (20)

$$H(z)=H_a(s)\Big|_{s=\frac{2}{T_e}\cdot\frac{1-z^{-1}}{1+z^{-1}}} \tag{20}$$

Irrespective of Padé approximation, the general expression of the system function can be written as:

$$H(z) = \frac{b_0 + b_1 \cdot z + b_2 \cdot z^2 + b_3 \cdot z^3}{1 + a_1 \cdot z + a_2 \cdot z^2 + a_3 \cdot z^3} \tag{21}$$

It was determined the coefficients of the system function in the case of using both methods of equivalence and all the 4 Padé approximations. In case if is used the first approximation the coefficients value are presented in table 4.

$s=\frac{1}{T_e}\left(1-z^{-1}\right)$	$H_{\tau_1}(s)$ Pade′ $(1+1)$	$H_{\tau_2}(s)$ Pade′ $(2+0)$	$H_{\tau_3}(s)$ Pade′ $(2+1)$	$H_{\tau_4}(s)$ Pade′ $(2+2)$
b_0	$-\frac{kT_e(\tau-2T_e)}{(T+T_e)(\tau+2T_e)}$	$\frac{2kT_e^3}{(T+T_e)\left(2T_e^2+2\tau T_e+\tau^2\right)}$	$\frac{2kT_e^2(3T_e-\tau)}{(T+T_e)\left(6T_e^2+4\tau T_e+3\tau^2\right)}$	$\frac{kT_e\left(12T_e^2-6\tau T_e+\tau^2\right)}{(T_e+T)\left(12T_e^2+6\tau T_e+\tau^2\right)}$
b_1	$\frac{k\tau T_e}{(T_e+T)(2T_e+\tau)}$	0	$\frac{2k\tau T_e^2}{(T+T_e)\left(6T_e^2+4\tau T_e+3\tau^2\right)}$	$\frac{kT_e\left(6\tau T_e-2\tau^2\right)}{(T_e+T)\left(12T_e^2+6\tau T_e+\tau^2\right)}$
b_2	0	0	0	$\frac{kT_e\tau^2}{(T_e+T)\left(12T_e^2+6\tau T_e+\tau^2\right)}$
a_1	$-\frac{2\tau T+2T_eT+T_e\tau}{(T_e+T)(2T_e+\tau)}$	$-\frac{2T(T_e+\tau)^2+4\tau T_e^2}{(T_e+T)\left(2T_e^2+2\tau T_e+\tau^2\right)}$	$-\left(\frac{4\tau T_e+6\tau^2}{6T_e^2+4\tau T_e+3\tau^2}+\frac{T}{T_e+T}\right)$	$-\left(\frac{T}{T_e+T}+\frac{6\tau T_e+2\tau^2}{12T_e^2+6\tau T_e+\tau^2}\right)$
a_2	$\frac{\tau T}{(T_e+T)(\tau+2T_e)}$	$\frac{\tau\left(2T_e^2+3\tau T_e+\tau^2\right)}{(T_e+\tau)\left(2T_e^2+2\tau T_e+\tau^2\right)}$	$\frac{3\tau^2(T_e+T)+T\left(4\tau T_e+6\tau^2\right)}{(T_e+T)\left(6T_e^2+4\tau T_e+3\tau^2\right)}$	$\frac{T\left(6\tau T_e+2\tau^2\right)+\tau^2(T_e+T)}{(T_e+T)\left(12T_e^2+6\tau T_e+\tau^2\right)}$
a_3	0	$-\frac{T\tau^2}{(T_e+T)\left(2T_e^2+2\tau T_e+\tau^2\right)}$	$\frac{-3\tau^2T}{(T+T_e)\left(6T_e^2+4\tau T_e+3\tau^2\right)}$	$-\frac{\tau^2T}{(T_e+T)\left(12T_e^2+6\tau T_e+\tau^2\right)}$

Table 4. The coefficients values of the numerical system function obtained by using approximation of differential equation by finite difference method.

In case if is used the second approximation the coefficients value are presented in table 5.
It was study the filter behaviour for all the four Padé approximations, for different system parameter values and the conclusion is that for assurance convergence of the adaptive filter coefficients to the real values is necessary to use a greater value for sampling period as the number of poles is greater (Panoiu et al., 1996). From tables 4 and 5 it can be observed that the only approximation that gave the system function with only 2 poles is the Padé approximation (1+1), this approximation being used in the following actions.
In tables 6 and 7 are presented the relations which offer the system parameters values starting from the numerical filter coefficients. There are presented also the situations in which are not found such kind of relations.
In conclusion, this method of determining the system parameters value has the advantage that if the system parameters value is changing during the process, the adaptive filter can permit to determine the instantaneous parameters value.

$s=\frac{2}{T_e}\left(\frac{1-z^{-1}}{1+z^{-1}}\right)$	$H_{\tau_1}(s)$ Pade′ $(1+1)$	$H_{\tau_2}(s)$ Pade′ $(2+0)$	$H_{\tau_3}(s)$ Pade′ $(2+1)$	$H_{\tau_4}(s)$ Pade′ $(2+2)$
b_0	$\frac{kT_e(T_e-\tau)}{(T_e+2T)(T_e+\tau)}$	$\frac{kT_e^3}{(T_e+2T)\left[(T_e+\tau)^2+\tau^2\right]}$	$\frac{kT_e^2(3T_e-2\tau)}{(T_e+2T)(3T_e^2+4\tau T_e+6\tau^2)}$	$\frac{kT_e(3T_e^2-3\tau T_e+\tau^2)}{(T_e+2T)(3T_e^2+3\tau T_e+\tau^2)}$
b_1	$\frac{2kT_e^2}{(T_e+2T)(T_e+\tau)}$	$\frac{3kT_e^3}{(T_e+2T)\left[(T_e+\tau)^2+\tau^2\right]}$	$\frac{kT_e^2(9T_e-2\tau)}{(T_e+2T)(3T_e^2+4\tau T_e+6\tau^2)}$	$\frac{kT_e(9T_e^2-3\tau T_e-\tau^2)}{(T_e+2T)(3T_e^2+3\tau T_e+\tau^2)}$
b_2	$\frac{kT_e}{T_e+2T}$	$\frac{3kT_e^3}{(T_e+2T)\left[(T_e+\tau)^2+\tau^2\right]}$	$\frac{kT_e^2(9T_e+2\tau)}{(T_e+2T)(3T_e^2+4\tau T_e+6\tau^2)}$	$\frac{kT_e(9T_e^2+3\tau T_e-\tau^2)}{(T_e+2T)(3T_e^2+3\tau T_e+\tau^2)}$
b_3	0	$\frac{kT_e^3}{(T_e+2T)\left[(T_e+\tau)^2+\tau^2\right]}$	$\frac{kT_e^2(3T_e+2\tau)}{(T_e+2T)(3T_e^2+4\tau T_e+6\tau^2)}$	$\frac{kT_e}{T_e+2T}$
a_1	$\frac{2(T_e^2-2T\tau)}{(T_e+2T)(T_e+\tau)}$	$\frac{T_e-2T}{T_e+2T}+\frac{2(T_e^2-2\tau^2)}{(T_e+\tau)^2+\tau^2}$	$\frac{T_e-2T}{T_e+2T}+\frac{6(T_e^2-2\tau^2)}{(3T_e^2+4\tau T_e+6\tau^2)}$	$\frac{T_e-2T}{T_e+2T}+\frac{2(3T_e^2-\tau^2)}{3T_e^2+3\tau T_e+\tau^2}$
a_2	$\frac{(T_e-2T)(T_e-\tau)}{(T_e+2T)(T_e+\tau)}$	$\frac{T_e-2T}{T_e+2T}\cdot\frac{2(T_e^2-2\tau^2)}{(T_e+\tau)^2+\tau^2}+\frac{(T_e-\tau)^2+\tau^2}{(T_e+\tau)^2+\tau^2}$	$\frac{6(T_e-2T)(T_e^2-2\tau^2)}{(T_e+2T)(3T_e^2+4\tau T_e+6\tau^2)}+\frac{(T_e-2\tau)^2+2(T_e^2+\tau^2)}{(3T_e^2+4\tau T_e+6\tau^2)}$	$\frac{2(T_e-2T)(3T_e^2-\tau^2)}{(T_e+2T)(3T_e^2+3\tau T_e+\tau^2)}+\frac{3T_e^2-3\tau T_e+\tau^2}{3T_e^2+3\tau T_e+\tau^2}$
a_3	0	$\frac{(T_e-2T)\left[(T_e-\tau)^2+\tau^2\right]}{(T_e+2T)\left[(T_e+\tau)^2+\tau^2\right]}$	$\frac{(T_e-2T)(3T_e^2-4\tau T_e+6\tau^2)}{(T_e+2T)(3T_e^2+4\tau T_e+6\tau^2)}$	$\frac{2(T_e-2T)(3T_e^2-3\tau T_e+\tau^2)}{(T_e+2T)(3T_e^2+3\tau T_e+\tau^2)}$

Table 5. The coefficients values of the numerical system function obtained by using bilinear transform method.

$s=\frac{1}{T_e}(1-z^{-1})$	τ	T	k
$H_{\tau_1}(s)$ Pade′ $(1+1)$	$\frac{2T_e}{\frac{b_0}{b_1}+1}$	$\frac{T_e}{-\frac{a_1}{a_2}-2-\frac{2T_e}{\tau}}$	$\frac{b_1}{a_2}\cdot\frac{T}{T_e}$
$H_{\tau_2}(s)$ Pade′ $(2+0)$	-	-	-
$H_{\tau_3}(s)$ Pade′ $(2+1)$	$\frac{3T_e}{\frac{b_0}{b_1}+1}$	$\frac{-T_e}{1-\frac{3\tau^2}{(6T_e^2+4\tau T_e+3\tau^2)\cdot a_3}}$	$-\frac{3}{2}\cdot\frac{b_1}{a_3}\cdot\frac{T}{T_e^2}\cdot\tau$
$H_{\tau_4}(s)$ Pade′ $(2+2)$	$\frac{3T_e}{\frac{1}{2}\frac{b_1}{b_2}+1}$	$\frac{-T_e}{\frac{\tau^2}{(12T_e^2+6\tau T_e+\tau^2)\cdot a_3}+1}$	$\frac{b_0(T_e+T)(12T_e^2+6\tau T_e+\tau^2)}{T_e(12T_e^2-6\tau T_e+\tau^2)}$

Table 6. The relations between system parameters value and numerical coefficients value obtained by using approximation of differential equation by finite difference method.

$s=\frac{2}{T_e}\left(\frac{1-z^{-1}}{1+z^{-1}}\right)$	τ	T	k
$H_{\tau_1}(s)$ Pade' $(1+1)$	$\left(1-\frac{2b_0}{b_1}\right)T_e$	$\frac{T_r}{2}\cdot\frac{2a_2T_e-a_1T_e+a_1\tau}{2a_2\tau-a_1T_e+a_1\tau}$	$\frac{2b_0\left(T_e^2-2T\tau\right)}{a_1T_e\left(T_e-\tau\right)}$
$H_{\tau_2}(s)$ Pade' $(2+0)$	-	-	-
$H_{\tau_3}(s)$ Pade' $(2+1)$	$\frac{3}{2}T_e\frac{\frac{b_1}{b_0}-3}{\frac{b_1}{b}-1}$	$\frac{T_e}{2}\cdot\frac{1-a_1+\frac{6\left(T_e^2-2\tau^2\right)}{\left(T_e+2\tau\right)^2+2\left(T_e^2+\tau^2\right)}}{1+a_1-\frac{6\left(T_e^2-2\tau^2\right)}{\left(T_e+2\tau\right)^2+2\left(T_e^2+\tau^2\right)}}$	$\frac{b_0\left(T_e+2T\right)\left[\left(T_e+2\tau\right)^2+2\left(T_e^2+\tau^2\right)\right]}{T_e^2\left(3T_e-2\tau\right)}$
$H_{\tau_4}(s)$ Pade' $(2+2)$	-	$\frac{T_e}{2}\cdot\frac{b_0-b_1a_3}{b_0+b_1a_3}$	$b_3\frac{T_e+2T}{T_e}$

Table 7. The relations between system parameters value and numerical coefficients value by using bilinear transform method.

3. Study of characteristics of the IIR-OSLMS filters

Since the values of the parameters of the system model can be finding by knowing the values of the adaptive filter, it was had to choose the optimal identification algorithm with respect to the convergence rate, as well as to stability. It was also had to choose the form of implementation, direct or lattice, as well as the method of equivalence for the analogical filter with a numeric one (Regalia, 1992), (Myuma, 2003), (Punchalard, 2006).
Towards, there were tested 3 identification algorithms: the gradient algorithm, the Steiglitz Mc-Bride algorithm and the SHARF one, each of them being implemented both in direct and lattice form, by using one of the two methods of equate for the analogical filter with a numerical filter. For this, the authors identified the parameters of the unknown system with the transfer function and tested the algorithms in identical conditions. The value chose for the simulated system were: $\tau = 4$ seconds, K=5 and sampling period T_e=2 seconds. The tests were made considering that the unknown system is a fixed filter, with the coefficients obtained based on relations presented in tables 4 and 5.
The three identification algorithms implemented in two equivalence method are presented in hypothesis of using the (1+1) Padé approximation. The tested structures were filter implementation in direct form and filter implementation in lattice form (Regalia, 1991).

3.1. Gradient algorithm

In figure 2 is presented the structure of an adaptive filter based on gradient algorithm. The implementation can be done in direct form and in lattice form (Haykin, 1991).
a) Gradient algorithm in direct form of implementation is described by the equation (22).

$$\begin{pmatrix}\mathbf{a}(n+1)\\ \mathbf{b}(n+1)\end{pmatrix}=\begin{pmatrix}\mathbf{a}(n)\\ \mathbf{b}(n)\end{pmatrix}+\mu\cdot\begin{pmatrix}-\mathbf{Y}_A(n)\\ \mathbf{X}_A(n)\end{pmatrix}\cdot e(n) \tag{22}$$

In (22) μ is the adaptation coefficient, e(n) is the output error, **a** and **b** are the matrix coefficients of nominator and denominator (Chen & Gibson, 1992), (Miao et al., 1994). In figure 3 is represented the coefficients form variations for direct form of implementation.

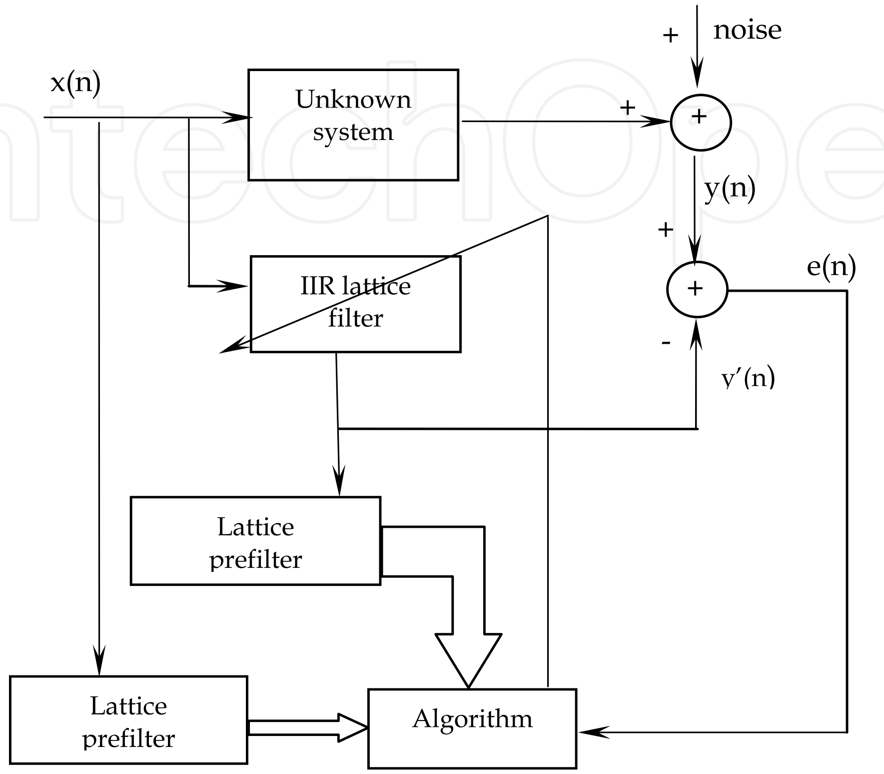


Fig. 2. Implementation of adaptive filter based on gradient algorithm.

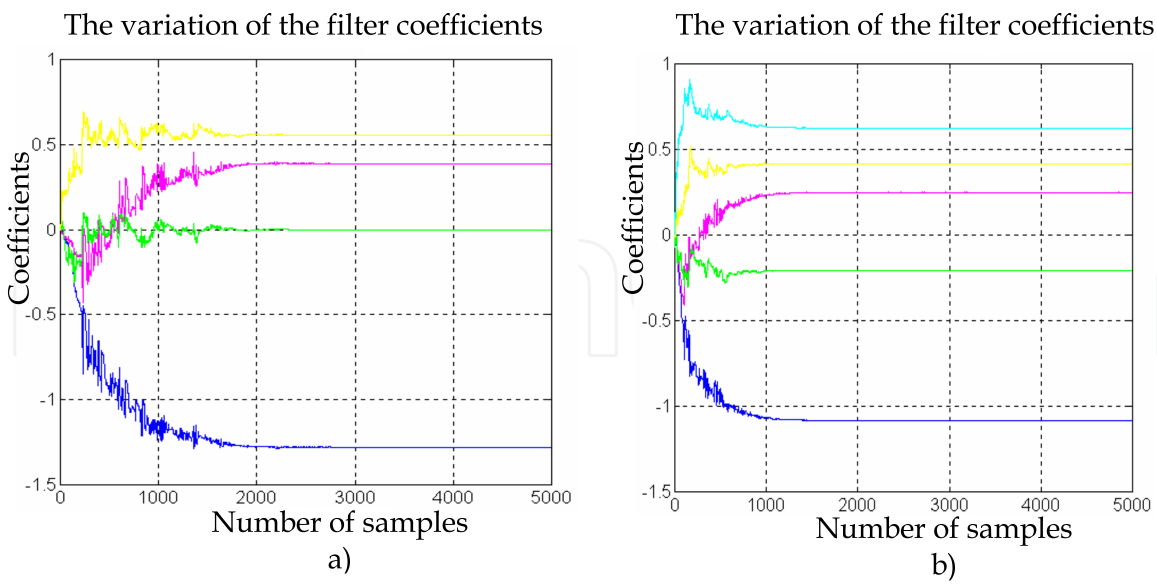


Fig. 3. The variation of adaptive filter coefficients using (1+1) Padé approximation, gradient algorithm implemented in direct form ($\alpha = 0.2$; $T_e = 2s$): a) using approximation of differential equation by finite difference method; b) using bilinear transform method.

b) Gradient algorithm in lattice form of implementation is described by the equation (23).

$$\begin{pmatrix} \mathbf{k}(n+1) \\ \mathbf{b}(n+1) \end{pmatrix} = \begin{pmatrix} \mathbf{k}(n) \\ \mathbf{b}(n) \end{pmatrix} + \mu \cdot \begin{pmatrix} -\mathbf{U}_A(n) \\ \mathbf{X}_A(n) \end{pmatrix} \cdot e(n) \tag{23}$$

In (23) **k** and **b** are the matrix coefficients of lattice implementation structure. In figure 4 is represented the coefficients form variations for lattice form of implementation.

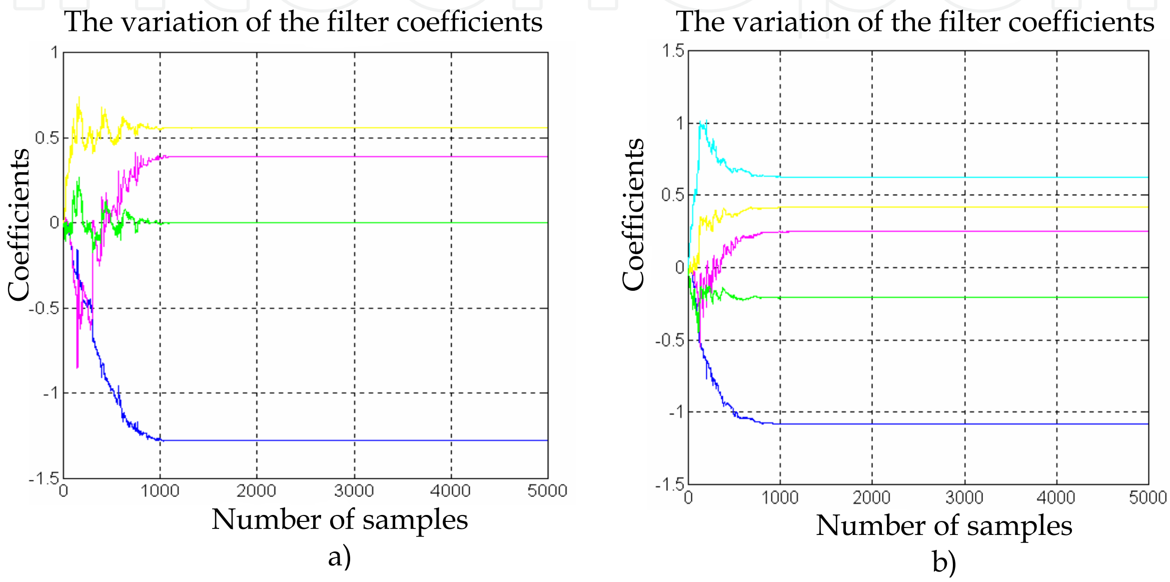


Fig. 4. The variation of adaptive filter coefficients using (1+1) Padé approximation, gradient algorithm implemented in lattice form ($\alpha = 0.2$; $T_e = 2s$): a) using approximation of differential equation by finite difference method; b) using bilinear transform method.

3.2. Steiglitz-McBride algorithm

In figure 5 is presented the structure of an adaptive filter based on Steiglitz-McBride algorithm. The implementation can be done also in direct form and in lattice form.

a) Steiglitz-McBride algorithm in direct form of implementation is described by the equation (24). In figure 6 is represented the coefficients form variations for direct form of implementation.

$$\begin{pmatrix} \mathbf{a}(n+1) \\ \mathbf{b}(n+1) \end{pmatrix} = \begin{pmatrix} \mathbf{a}(n) \\ \mathbf{b}(n) \end{pmatrix} + \mu \cdot \begin{pmatrix} -\mathbf{D}_A(n) \\ \mathbf{X}_A(n) \end{pmatrix} \cdot e(n) \tag{24}$$

b) Steiglitz-McBride algorithm in lattice form of implementation is described by the equation (25). In figure 7 is represented the coefficients form variations for lattice form of implementation.

$$\begin{pmatrix} \mathbf{k}(n+1) \\ \mathbf{b}(n+1) \end{pmatrix} = \begin{pmatrix} \mathbf{k}(n) \\ \mathbf{b}(n) \end{pmatrix} + \mu \cdot \begin{pmatrix} -\mathbf{U}_A(n) \\ \mathbf{X}_A(n) \end{pmatrix} \cdot e(n) \tag{25}$$

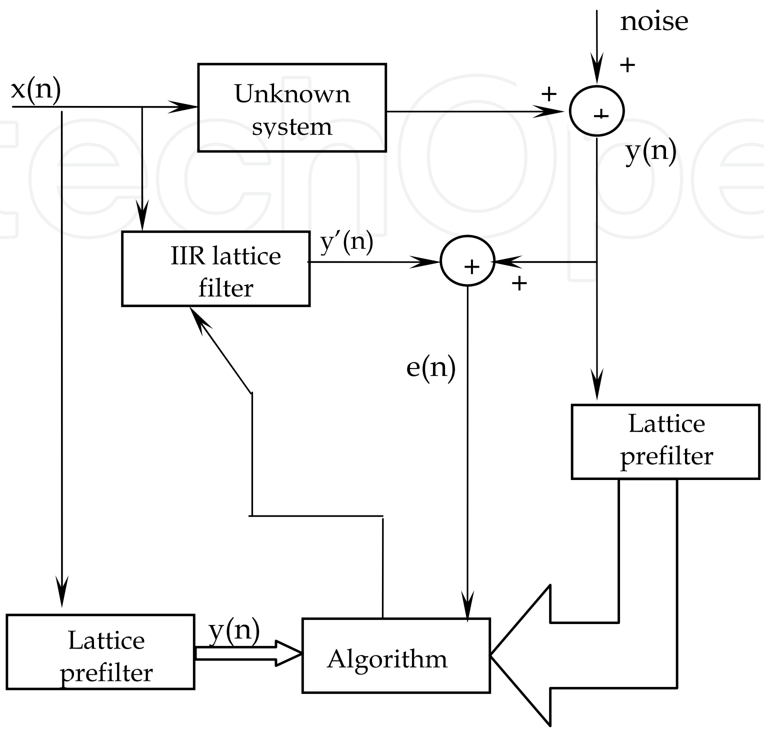


Fig. 5. Implementation of adaptive filter based on Steiglitz-McBride algorithm.

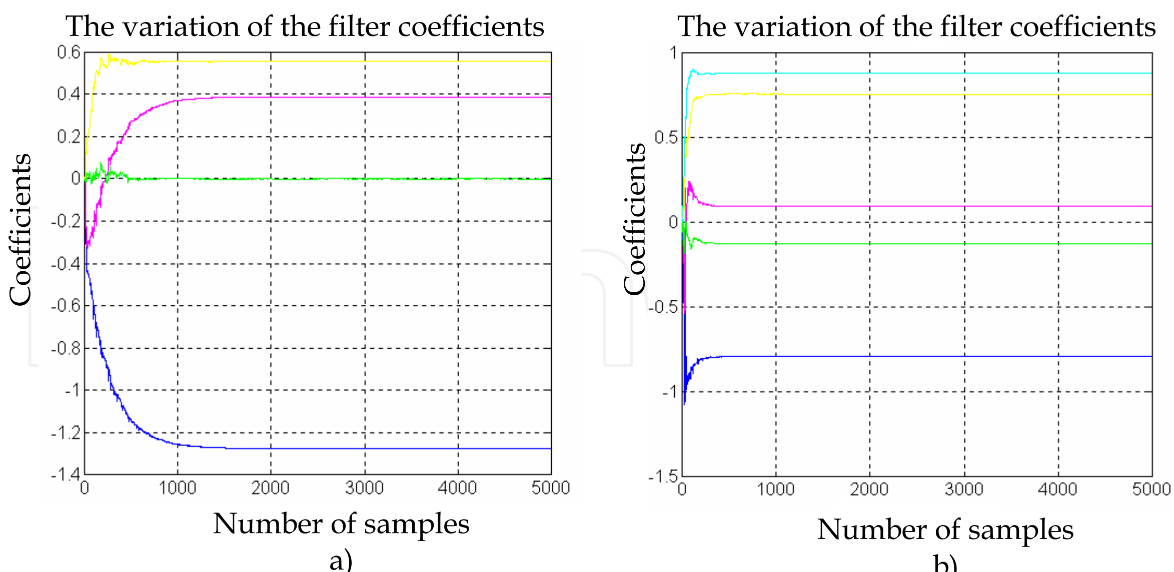


Fig. 6. The variation of adaptive filter coefficients using (1+1) Padé approximation, Steiglitz-McBride algorithm implemented in direct form ($\alpha = 0.2$; T_e = 2s): a) using approximation of differential equation by finite difference method; b) using bilinear transform method.

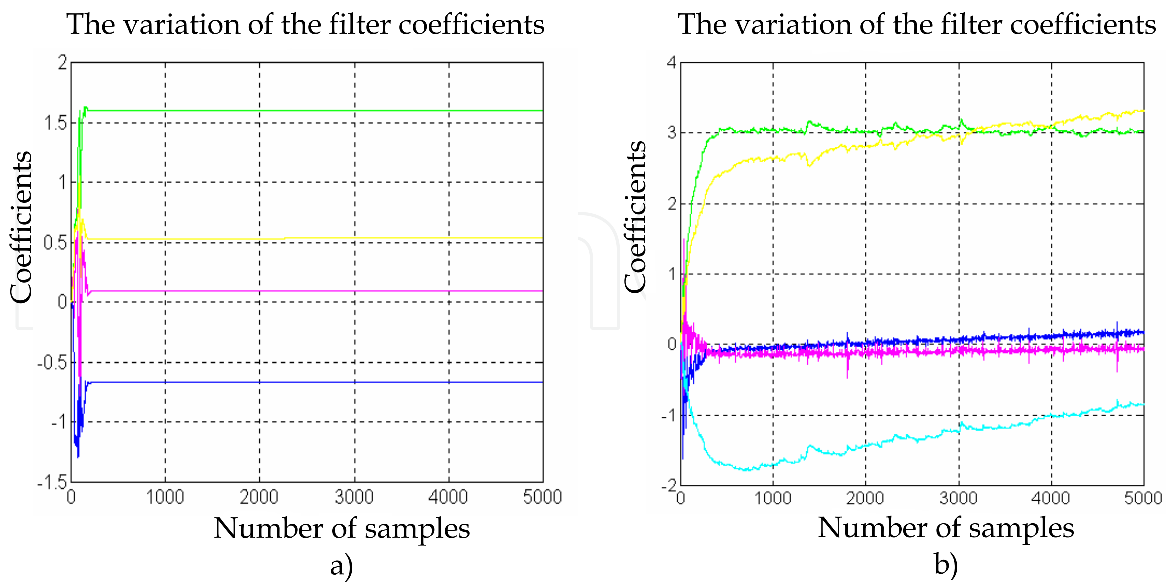


Fig. 7. The variation of adaptive filter coefficients using (1+1) Padé approximation, Steiglitz-McBride algorithm implemented in lattice form ($\alpha = 0.2$; T_e = 2s): a) using approximation of differential equation by finite difference method; b) using bilinear transform method.

3.3. SHARF algorithm

In figure 8 is presented the structure of an adaptive filter based on SHARF algorithm. The implementation can be done also in direct form and in lattice form.

a) SHARF algorithm in direct form of implementation is described by the equation (26). In figure 9 is represented the coefficients form variations for direct form of implementation.

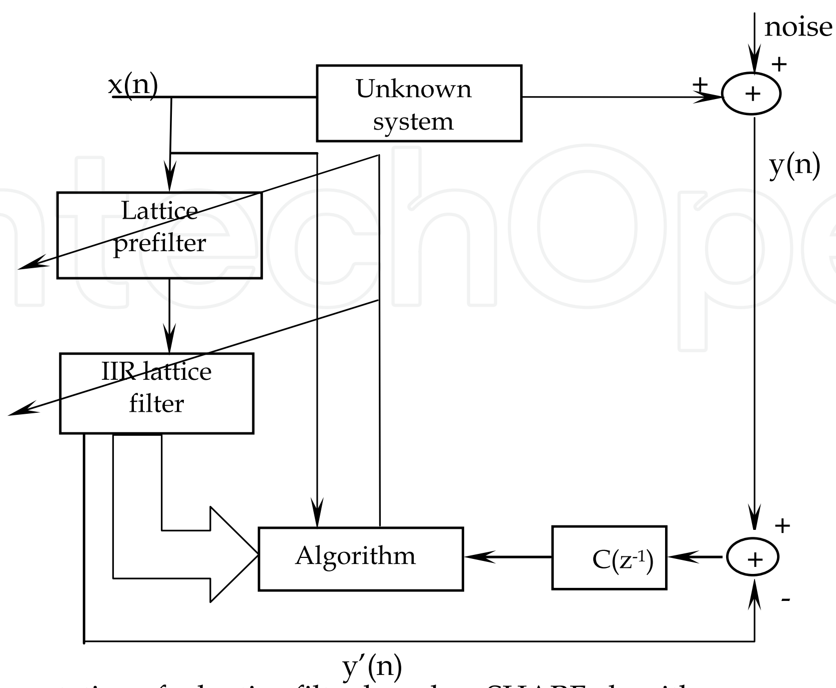


Fig. 8. Implementation of adaptive filter based on SHARF algorithm.

$$\begin{pmatrix} \mathbf{a}(n+1) \\ \mathbf{b}(n+1) \end{pmatrix} = \begin{pmatrix} \mathbf{a}(n) \\ \mathbf{b}(n) \end{pmatrix} + \mu \cdot \begin{pmatrix} -\mathbf{y}(n) \\ \mathbf{x}(n) \end{pmatrix} \cdot c(n) \tag{26}$$

where

$$c(n) = e(n) - 0.6 \cdot e(n-1) \tag{27}$$

b) SHARF algorithm in lattice form of implementation is described by the equation (28), where c(n) is the same as in (27). In figure 10 is represented the coefficients form variations for lattice form of implementation.

$$\begin{pmatrix} \mathbf{k}(n+1) \\ \mathbf{b}(n+1) \end{pmatrix} = \begin{pmatrix} \mathbf{k}(n) \\ \mathbf{b}(n) \end{pmatrix} + \mu \cdot \begin{pmatrix} -\mathbf{u}(n) \\ \mathbf{x}(n) \end{pmatrix} \cdot c(n). \tag{28}$$

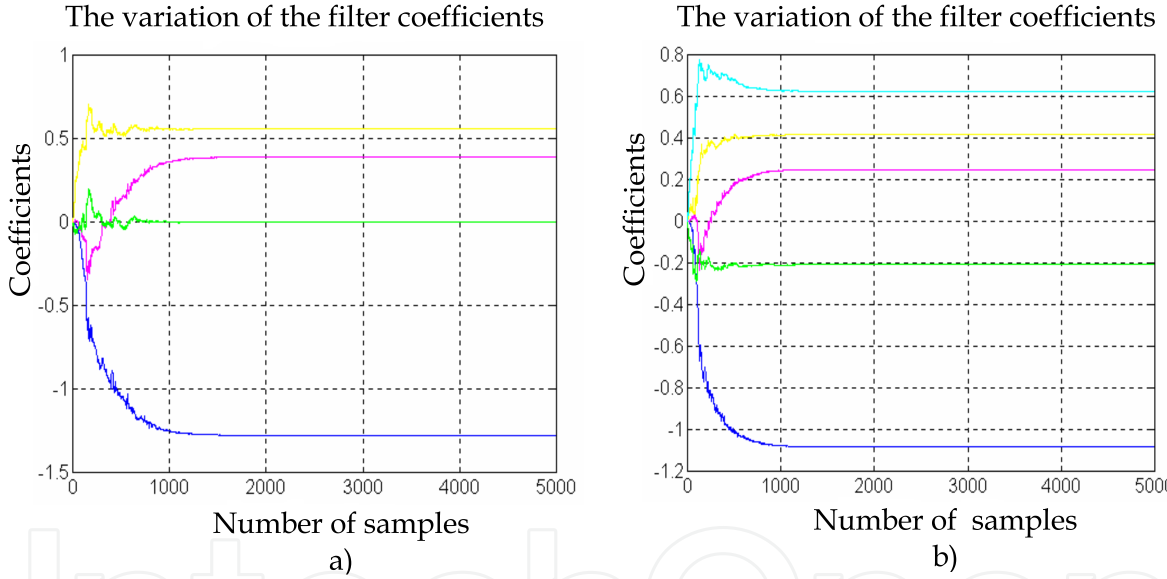
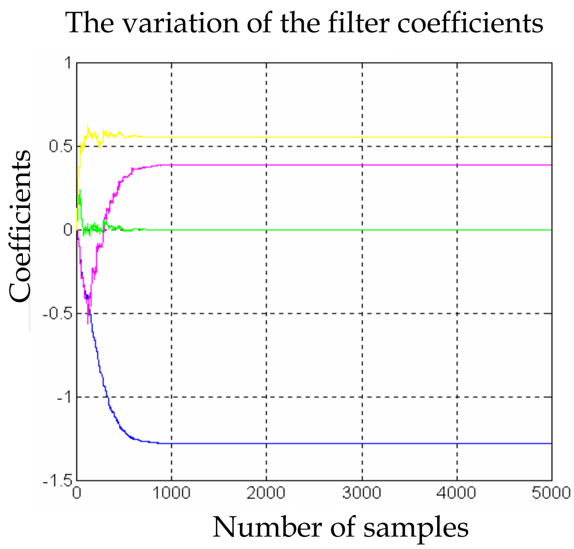
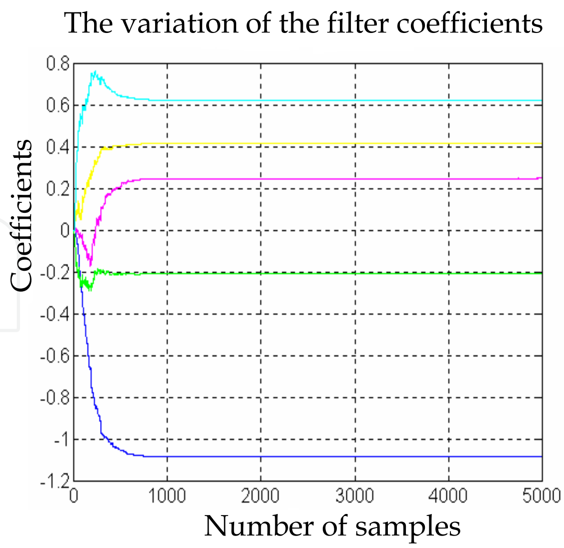


Fig. 9. The variation of adaptive filter coefficients using (1+1) Padé approximation, SHARF algorithm implemented in direct form ($\alpha = 0.2$; T_e = 2s): a) using approximation of differential equation by finite difference method; b) using bilinear transform method.

The results of the tests presume to identify the heating process of the furnace, lead us to the conclusion that the Padé (1+1) approximation allows the easiest determination once the coefficients of the numeric adaptive filter are known (Pomsathit, 2006).
We also determined experimentally that the most efficient algorithm of identification is the SHARF algorithm, implemented in its lattice form, the equivalence of the analogous filter with a numeric one being done by the method of the approximation of the differential equation with finite differences.



a)



b)

Fig. 10. The variation of adaptive filter coefficients using (1+1) Padé approximation, SHARF algorithm implemented in lattice form ($\alpha = 0.2$; T_e = 2s): a) using approximation of differential equation by finite difference method; b) using bilinear transform method.

4. Adaptive controllers

4.1. The used criteria in tuning controllers

The process of temperature control can be accomplished by choosing the type of controller according to particular criteria. Choosing and tuning the controllers for cool time processes represents one of the most difficult problems in the practice of automatic control both because of the difficulties in precisely determining the cool time characterizing the process, and due to the adverse influence of the cool time on the transitory behaviour of an automatic controlling system. The criteria that can be used for the tuning of cool time controlers are:

- Criteria based on the method of stability limit;
- Criteria based in the results of identification;
- Experimental criteria considering the functioning process.

Since the temperature adaptive controlling method is based on the identification of process parameters, are presented four criteria based on the results of identifying the process parameters, criteria which are used for slow process (Dumitrache et al., 1993).

a) The Ziegler - Nichols relations

- for P – controllers

$$K_{R\ opt} = \frac{T}{K \cdot \tau}; \tag{29}$$

- for PI – controllers

$$K_{R\ opt} = \frac{0.9T}{K \cdot \tau}, \quad T_{i\ opt} = 3.3\tau \tag{30}$$

b) The Oppelt relations:
- for P – controllers

$$K_{R\ opt} = \frac{T}{K \cdot \tau} \tag{31}$$

- for PI – controllers

$$K_{R\ opt} = \frac{0.8T}{K \cdot \tau}, \quad T_{i\ opt} = 3\tau \tag{32}$$

c) The Kopelovitch relations

Controller type	Aperiodic answer with minimal duration	Oscillatory answer at $\sigma = 20\%$
P	$K_{R\ opt} = \frac{0.3 \cdot T}{K \cdot \tau}$	$K_{R\ opt} = \frac{0.7 \cdot T}{K \cdot \tau}$
PI	$K_{R\ opt} = \frac{0.6 \cdot T}{K \cdot \tau}$ $T_{i\ opt} = 0.8\ \tau + 0.5\ T$	$K_{R\ opt} = \frac{0.7 \cdot T}{K \cdot \tau}$ $T_{i\ opt} = \tau + 0.3\ T$

Table 8. The values of tuning parameters, according to Kopelovitch.

d) The Chien, Hrones, Roswich relations

Controller type	Aperiodic answer with minimal duration	Oscillatory answer at $\sigma = 20\%$ with minimal duration
P	$K_{R\ opt} = \frac{0.3 \cdot T}{K \cdot \tau}$	$K_{R\ opt} = \frac{0.7 \cdot T}{K \cdot \tau}$
PI	$K_{R\ opt} = \frac{0.35 \cdot T}{K \cdot \tau}$ $T_{i\ opt} = 1.2\ \tau$	$K_{R\ opt} = \frac{0.6 \cdot T}{K \cdot \tau}$ $T_{i\ opt} = \tau$

Table 9. The optimal values of the tuning parameters for a step variation of the input.

Controller type	Aperiodic answer with minimal duration	Oscillatory answer at $\sigma = 20\%$ with minimal duration
P	$K_{R\ opt} = \frac{0.3 \cdot T}{K \cdot \tau}$	$K_{R\ opt} = \frac{0.7 \cdot T}{K \cdot \tau}$
PI	$K_{R\ opt} = \frac{0.6 \cdot T}{K \cdot \tau}$ $T_{i\ opt} = 4\ \tau$	$K_{R\ opt} = \frac{0.7 \cdot T}{K \cdot \tau}$ $T_{i\ opt} = 2.3\ \tau$

Table 10. The optimal values of the tuning parameters for a noise variation of the input.

4.2. Implementation of adaptive controllers

As it was presented in the previous paragraph, the P or PI controllers are advisable to be chosen for time constant and time delay process. The system functions of analogical system can be obtained starting from relation between the output controller signals due to his input signal.
In case of using the P controllers, the output equation is given by relation (33) and the analogical system function is given by relation (34).

$$y_R(t) = K_R \cdot x(t), \tag{33}$$

$$H_R(s) = K_R \tag{34}$$

In case of using the PI controllers, the output equation is given by relation (35) and the analogical system function is given by relation (36).

$$y_R(t) = K_R \cdot x(t) + \frac{K_R}{T_i}\int_0^t x(\tau)d\tau, \tag{35}$$

$$H_R(s) = \frac{K_R}{T_i} \cdot \frac{1 + sT_i}{s} \tag{36}$$

Starting from the adaptive filter coefficients at n^{th} iteration it can be computed the process parameters, T, τ and K. Depending on the chosen adaptive controller and also on the used criteria in tuning controller it can be determined the values of controller parameters, based on the process parameters. In this manner it can be obtained the transfer function of the controller.
The system function of the numerical system can be obtained with one of the two equivalence method. Irrespective of the equivalence method of the analog filter with the numeric one and the type of controller, the general relation for determining the output magnitude of the numeric controller is:

$$y(n) = b_0 \cdot x(n) + b_1 \cdot x(n-1) + a_1 \cdot y(n-1) \tag{37}$$

Depending of the kind of controller and of used equivocation method, in table 11 are presented the coefficients relations on equation (37), as functions on parameters controller and sampling period.

4.3. Noise cancellation

It was experimentally determined that during the temperature measurement process appear impulse noises with high amplitude due to functioning of the voltage controller rectifier.

Equivalence method	Controller	b_0	b_1	a_1
Approximation of differential equation by finite difference method	P	K_R	0	0
	PI	$K_R\left(1+\frac{T_e}{T_i}\right)$	$-K_R$	1
Bilinear transform method	P	K_R	0	0
	PI	$\frac{K_R}{2T_i}\left(T_e+2T_i\right)$	$\frac{K_R}{2T_i}\left(T_e-2T_i\right)$	1

Table 11. The coefficients value of numerical controller.

The temperature control process inside the electric resistance furnace presumes to know exactly the instantaneous temperature value that means elimination necessity of the high amplitude and short duration impulse influence (Panoiu & Panoiu, 2007).
To study the possibility of noise cancellation it was applied a test impulse and the temperature values were measured. The impulse duration was 20 minute, the test duration was 40 minutes and sampling period was 0.2 seconds. The results are presented in figure 11.

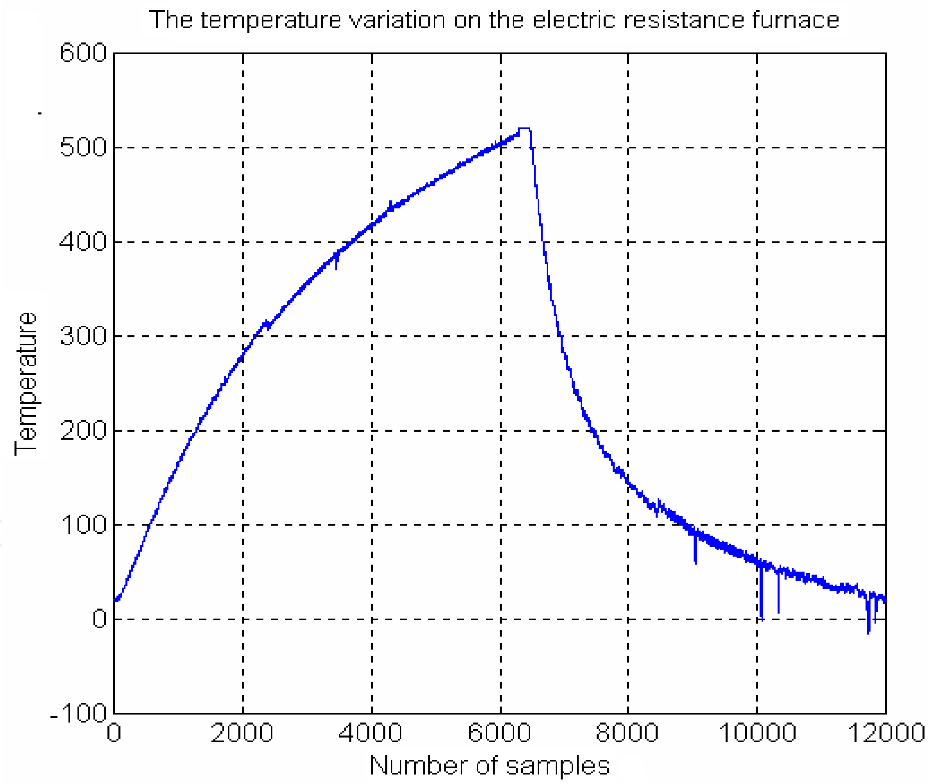


Fig. 11. The variation of the measured temperature.

Taking this fact into consideration, in temperature measurement process was used a MLMS filter with window length of 75 samples. For this filter it was experimentally determined that the temperature can be adjusted on-line and it can be realised an optimal noise rejection. In figure 12 is presented the temperature variation form using MLMS filter.

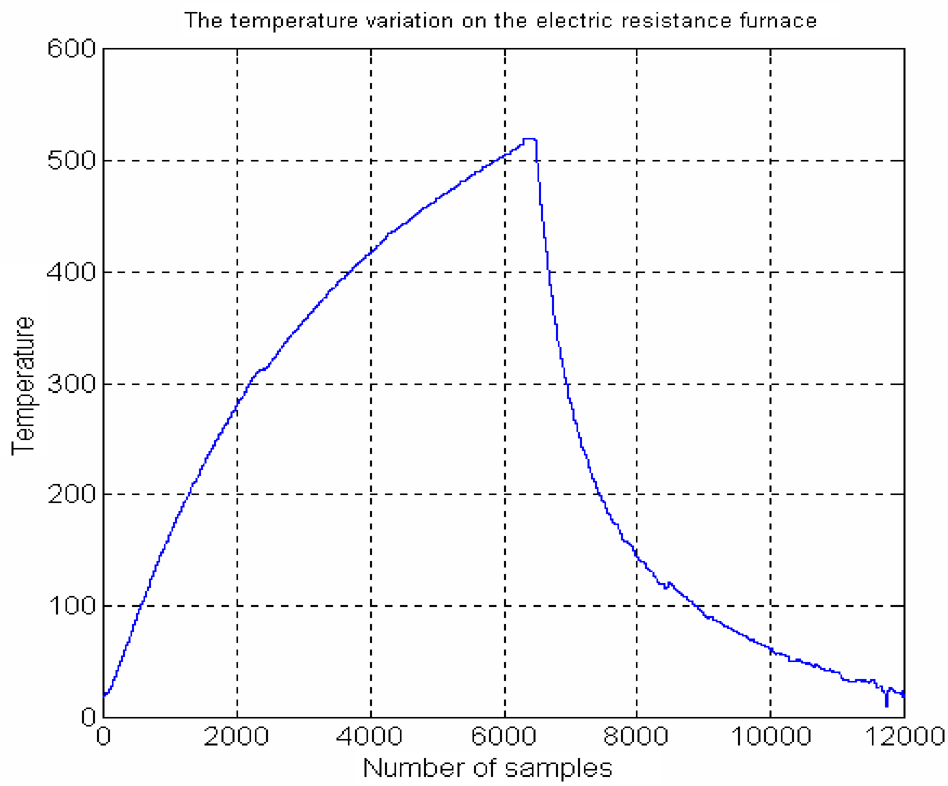


Fig. 12. The variation of the measured temperature after noise cancellation.

4.4. The measurement of the electric resistance furnace parameters using the on-line identification method

Until this point is presented the situation of using an adaptive filter in order to identify the parameters of the slow processes. In this case, using another method, i.e. on-line identification method, is necessary to determine the approximated values of the system parameters. Using these values the initial values of the adaptive filter coefficients will be determined (Panoiu & Panoiu, 2005), (Panoiu et al., 2008 a).

The parameters of the model of the electric resistance furnace heating were determined using the on-line identification method. The experiment consists in applying during the impulse test on the resistance terminals the highest rectifier voltage that produces the furnace heating. During this interval the temperature increases inside the furnace. After this impulse test, the supplying voltage is disconnected and the temperature decrease. The impulse test was 20 minutes duration, the integration period was 40 minutes and sampling period was 0.2 seconds. In order to determine the parameters of the furnace heating model, were made 10 measurements with null initial conditions. The measurements results are presented in table 12.

Taking into consideration the results presented in table 12, the initial values of parameters of the furnace heating model were chose: K=440, $T = 275$ seconds and $\tau = 66$ seconds.

Because the SHARF algorithm present reduced variations of the adaptive filter coefficients, irrespective of the implementation form or of the equivocation method, between an analogical filter with a numeric filter, this algorithm was used in the process of adaptive identification of the parameters of the furnace heating model.

Number of measurement	K_{meas}	T_{meas} (seconds)	τ_{meas} (seconds)
1	442,60	274,22	66,21
2	438,56	272,21	64,87
3	450,88	280,34	65,38
4	443,24	275,33	66,86
5	436,22	271,00	67,12
6	445,78	278,22	66,43
7	436,50	270,29	63,26
8	447,87	279,24	65,96
9	440,26	275,34	67,28
10	438,22	273,37	66,32

Table 12. The parameters of the furnace heating model.

Because the lattice form of implementation present a convergence speed greater than the direct form of implementation, it was used the lattice form of implementation of the adaptive filter (Voltz & Kozin, 1992).
Because the number of the adaptive filter coefficients using Padé approximation (1+1) is more reduced in case of approximation of differential equation by finite difference method then in case of bilinear transform method, the first method was used.
With the initial chosen values of the parameters of the furnace heating model, it was tested the convergence of the adaptive filter coefficients using some of the sampling period values. Experimentally was concluded that the optimal sampling period is 30 seconds, as necessary time interval between two consecutive adjustments of the power discharged by the electric resistance. In figure 13 is presented the variation form of the adaptive filter coefficients using SHARF algorithm, implementing the adaptive filter in lattice form and using the approximation of differential equation by finite difference method.

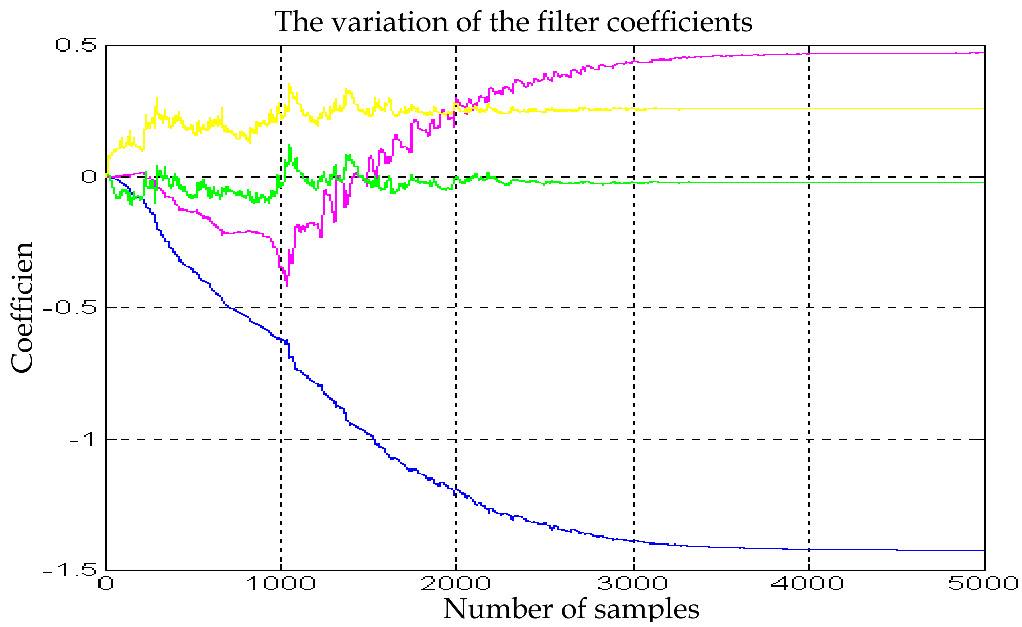


Fig. 13. The variation of adaptive filter coefficients.

5. The adaptive temperature control system

5.1. The structure of the adaptive temperature control system

The implemented adaptive temperature control system has the structure given in figure 14, including the following elements:
- the electric resistance of furnace, representing the system whose output, temperature, is controlled by the modification of the power dissipated over its electric resistance;
- the voltage controller rectifier (VCR) whose role is to allow the controlling of the output voltage value, according to the level of the input DC voltage;
- the temperature transducer (T), used for obtaining a voltage proportional to the temperature. We used a chromel-alumel temperature transducer with the maximum measurable temperature of 1200°C and a maximum output voltage of 48 mV;
- the voltage amplifier (A) used to increase the output voltage of the temperature transducer, in view of obtaining an output voltage of 20 V, corresponding to the range of measurements allowed by the system in use;
- one computer;
- the data acquisition board ADA3100 used both in the output voltage digital to analogous conversion of the amplifier and in the output voltage digital to analogous conversion meant to act upon the voltage-controlled converter. This data acquisition board has the following characteristics:

- 8 analogical input channels that can be used differential or single ended;
- 2 analogical output channels;
- 8 digital input lines and 8 numeric output lines;
- input voltage domain: $\pm 5V$, $\pm 10V$ or 0-10 V , selectable by program;
- output voltage domain: $\pm 5V$, $\pm 10V$, $0-5V$ or 0-10 V , selectable by program;
- possibility to choose the input signal amplification of 1, 2, 4, 8, 16 or adjustable before the analogous to digital conversion.

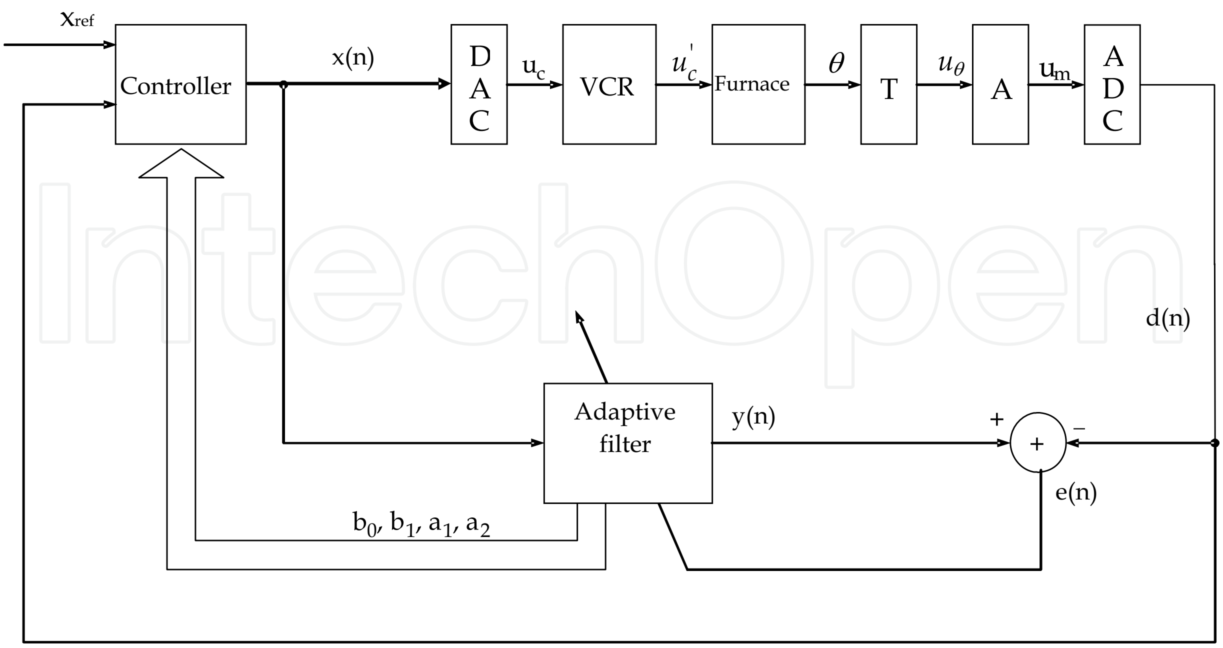
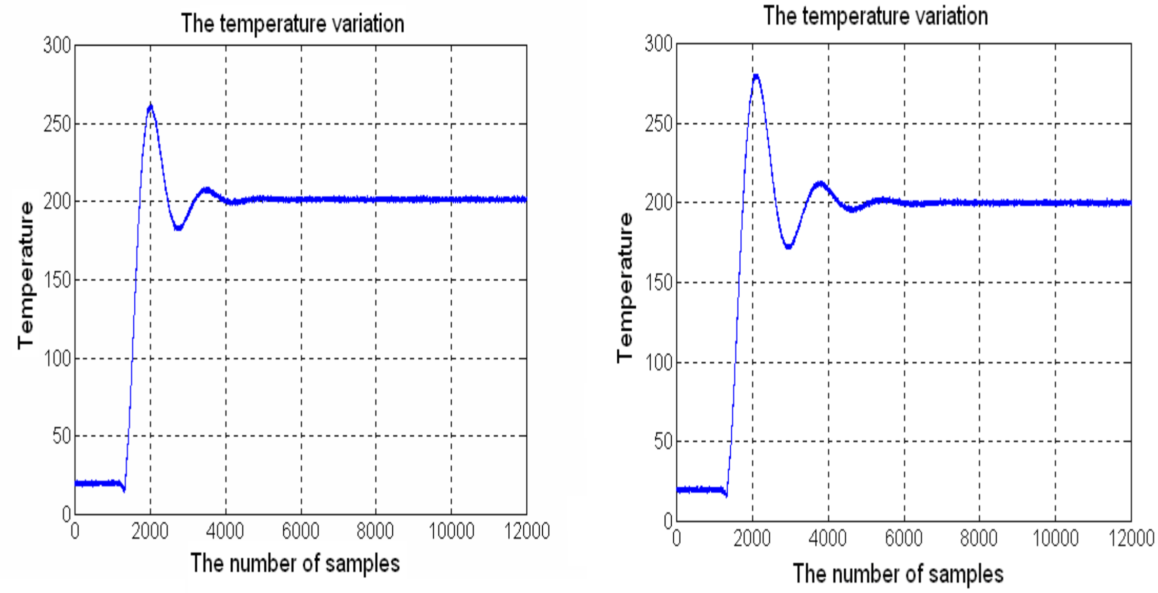


Fig. 14. The temperature adaptive control system.

5.2. Experimentally results

Experiments were realised using the adaptive control system presented in figure 14. All criteria of tuning controllers were tested in the same condition. These are referring to the imposed temperature which is desired to obtain. In all experiments this temperature is 200°C.

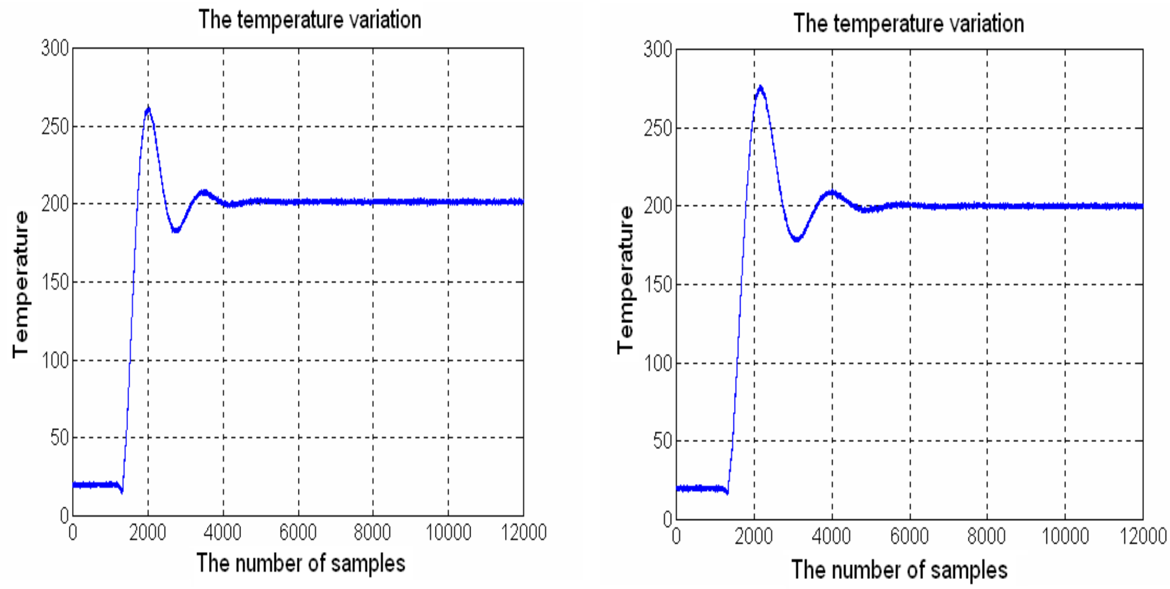
In figures 15 is presented the temperature variation obtained by using Ziegler-Nichols relation with P and PI controller.



a) for P controller b) for PI controller

Fig. 15. The temperature variation using Ziegler-Nichols relations.

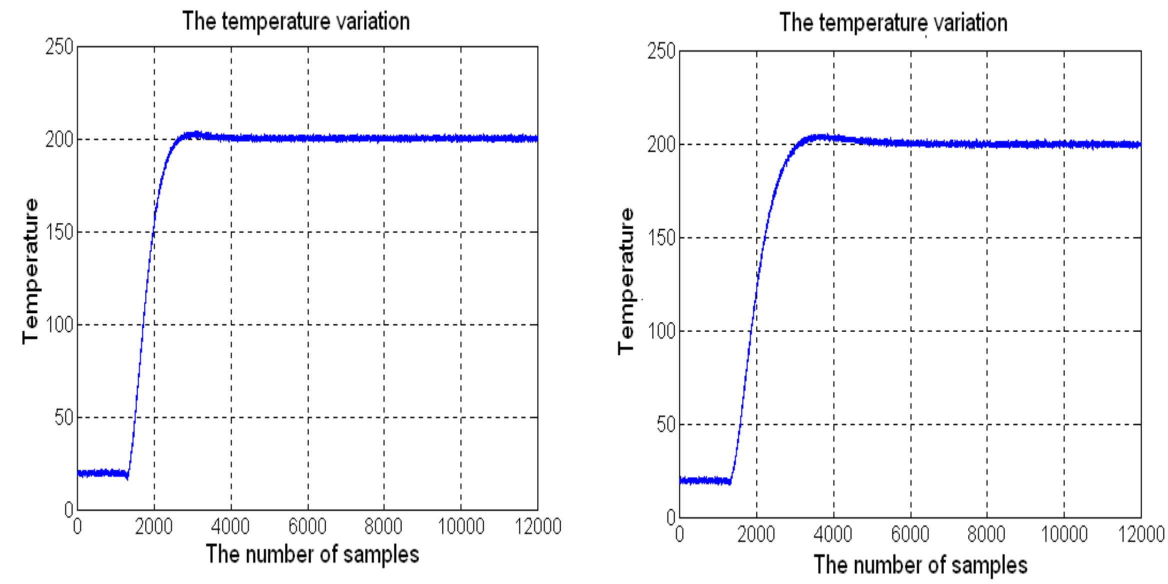
In figure 16 is presented the temperature variation obtained by using Oppelt relation with P and PI controller.



a) for P controller b) for PI controller

Fig. 16. The temperature variation using Oppels relations.

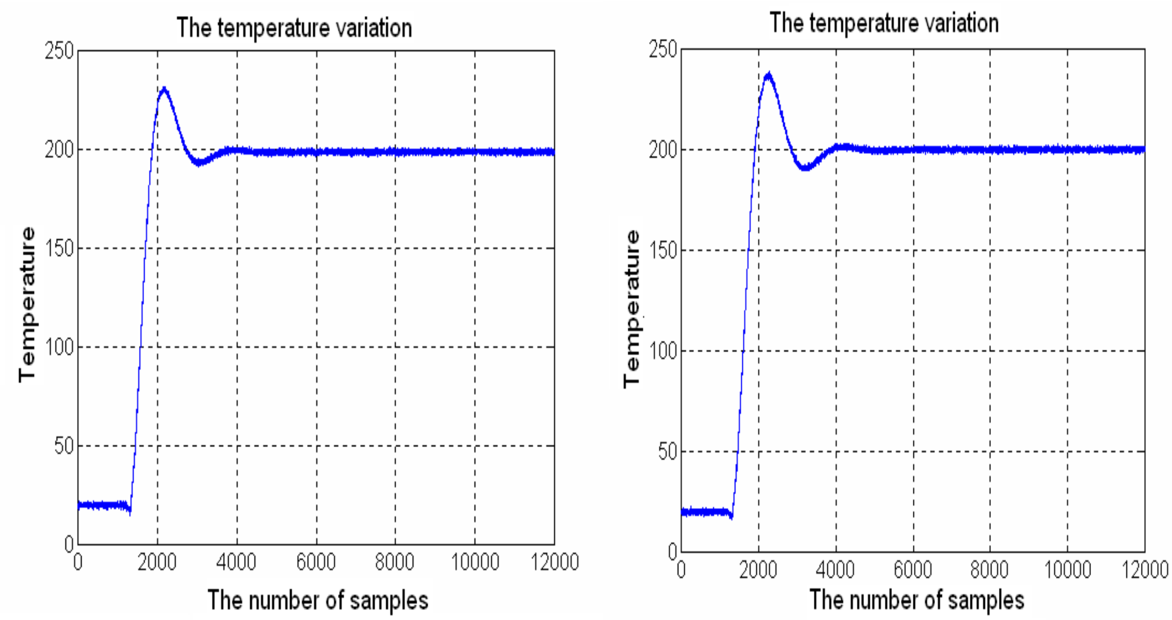
In figure 17 is presented the temperature variation obtained by using Kopelovici relations for aperiodic answer with minimal duration.



a) for P controller b) for PI controller

Fig. 17. The temperature variation obtained by using Kopelovici relations for aperiodic answer with minimal duration.

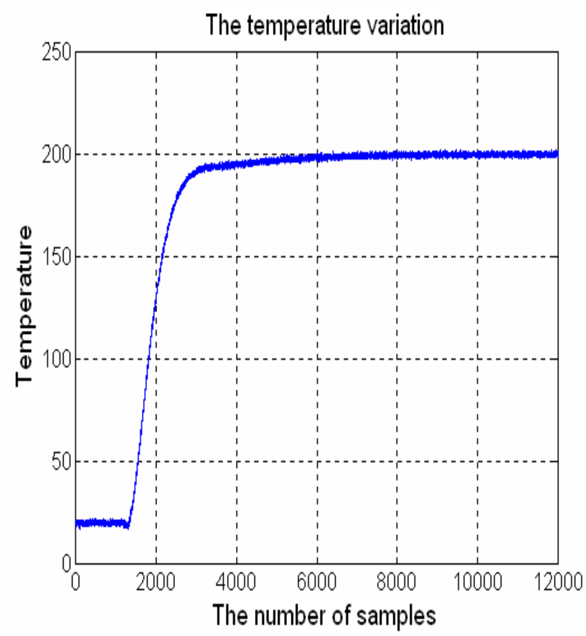
In figure 18 is presented the temperature variation obtained by using Kopelovici relations for oscillatory answer at $\sigma = 20\%$ with minimal duration.



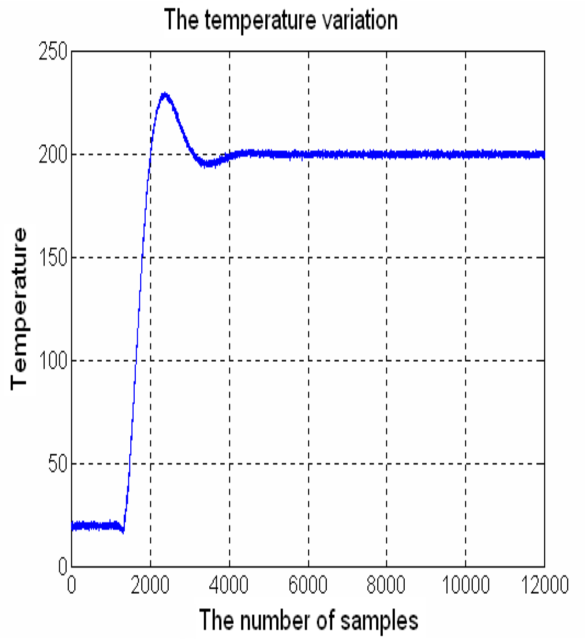
a) for P controller b) for PI controller

Fig. 18. The temperature variation obtained by using Kopelovici relations for oscillatory answer at $\sigma = 20\%$ with minimal duration.

In figure 19 is presented the temperature variation obtained by using Chien, Hrones, and Reswich relations for oscillatory answer at $\sigma = 20\%$ with minimal duration.



a) for P controller



b) for PI controller

Fig. 19. The temperature variation obtained by using Chien, Hrones and Reswich relations for oscillatory answer at $\sigma = 20\%$ with minimal duration.

6. Conclusions

The online identification method has two disadvantages. The first of them consists in the fact that if the test impulse duration and the integration duration are not chosen in correlation with the real values of the process parameters the measured values of the process parameters present high errors. The second disadvantage consists in the fact that for measuring the values of the process parameters the system must be taken out from its steady state and the measured values are considered constant until the next measurement is performed.

The transfer function of the system can be obtained by using a Padé approximation of the transfer function associated to a delayed time process. The system function of the numerical system is obtained by using an equivocation method of the analogical filter with a numerical filter. Two equivalence methods of the analogical filter with a numerical filter were analysed: the approximation of differential equation by finite difference method and the bilinear transform method.

Based on equivalence methods it were determined the computing relations of the filter coefficients knowing the values of the process parameters as well the mutual relations of determining the values of the process parameters knowing the values of the adaptive filter coefficients for the 4 Padé approximations that are treated in the technical literature.

It was studied 3 identification algorithms, implemented in direct form and also in lattice form. The conclusion is that irrespective of the algorithm type, the lattice implementation form presents a convergence speed higher than the direct implementation form. Also, the

SHARF algorithm has the smallest oscillation of the coefficients values, irrespective of the implementation form. Based on the accomplished study, it was used in identification process of the parameters of the furnace heating the SHARF algorithm, implemented in lattice form and using the method of the integral approximation using the rectangle method.
The next step consist in experimentally demonstration that in order the adaptive filter to be availed in identification of the slow processes parameters, is necessary to determine with approximation the values of the system parameters, based on a previous measurement, using another method. Using these values, it has to be determined the initial values set of the adaptive filter coefficients.
In the final part are presented the experimental conclusions that are obtained in the temperature controlling process using the criteria based on the identification results in choosing the controllers parameters.
The experimental results obtained in the process of temperature control, using the criteria based on the results of identification in choosing the controller parameters, confirm the fact that the using of the adaptive method of furnace temperature control presents some advantages, such as:
First advantage consist in the fact that the measurements of the parameters of the electric resistance furnace heating process consists in their calculation after each correction interval of the power given by the electric resistance, knowing the updated values of the adaptive filter coefficients. In this way, it is no longer necessary to take the system out of its steady state, as it is the case with the on-line identification method.
The second advantage consists in that since we practically know at each moment the parameters of the furnace heating process, the values of the numeric controller parameters are chosen in each interval of power control according to the values of the process parameters.
Finally, the performances obtained by this method allow a better control of the temperature, in the sense of reducing the time to reaching the preset temperature value in the case of applying a step signal to the standard input of the controller. Moreover, after the preset temperature value is reached, the oscillations around it are smaller than in the case of using a constant-parameter controller.

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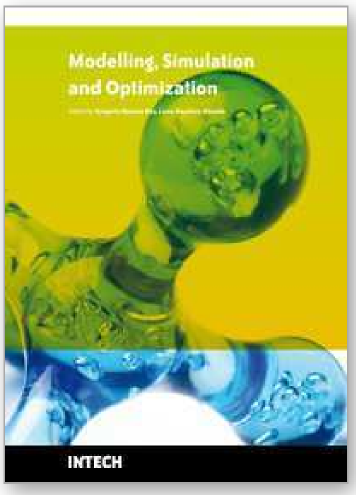

Modelling Simulation and Optimization

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Computer-Aided Design and system analysis aim to find mathematical models that allow emulating the behaviour of components and facilities. The high competitiveness in industry, the little time available for product development and the high cost in terms of time and money of producing the initial prototypes means that the computer-aided design and analysis of products are taking on major importance. On the other hand, in most areas of engineering the components of a system are interconnected and belong to different domains of physics (mechanics, electrics, hydraulics, thermal...). When developing a complete multidisciplinary system, it needs to integrate a design procedure to ensure that it will be successfully achieved. Engineering systems require an analysis of their dynamic behaviour (evolution over time or path of their different variables). The purpose of modelling and simulating dynamic systems is to generate a set of algebraic and differential equations or a mathematical model. In order to perform rapid product optimisation iterations, the models must be formulated and evaluated in the most efficient way. Automated environments contribute to this. One of the pioneers of simulation technology in medicine defines simulation as a technique, not a technology, that replaces real experiences with guided experiences reproducing important aspects of the real world in a fully interactive fashion [iii]. In the following chapters the reader will be introduced to the world of simulation in topics of current interest such as medicine, military purposes and their use in industry for diverse applications that range from the use of networks to combining thermal, chemical or electrical aspects, among others. We hope that after reading the different sections of this book we will have succeeded in bringing across what the scientific community is doing in the field of simulation and that it will be to your interest and liking. Lastly, we would like to thank all the authors for their excellent contributions in the different areas of simulation.

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