AN EDUCATIONAL TOOL WITH REMOTE ACCESS FOR TEACHING MODELLING CONTROL SYSTEMS FOR ENGINEERING COURSES

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ABSTRACT
This paper presents the use of a teaching tool that allows the temperature control and the system identification by Weighted Least Square Method. The system is an application of remote access laboratory, a WebLab, with real equipments and systems that can be remotely controlled by the web. At the approach, the WebLab allows the development of multidisciplinary experiments related to modelling control systems and is used as a tool for engineering education and for research projects.

KEY WORDS
Control system, system identification, modelling control systems, WebLab.

1. Introduction

The continuous evolution of technology of information and the growing of new computational tools provide considerable advances to remote education and research fields. The laboratories using remote access, i.e. the WebLabs, are clear examples of computation use in education, but with a large differential because provide a possibility of a real learning with a distance supervision. This is possible mainly because the WebLabs provide a possibility of developing practical experiments, by accessing the equipment through the net in real laboratories and thus permitting control and data acquisition in real time.

WebLabs have been developed and implanted in several Brazilian universities since last decade, presenting solutions for remote operations [1-4]. Several authors report about experience in utilization of WebLabs for teaching physics, chemistry [5], processes control [6, 7] and robotics [8]. Some WebLabs provide the possibility of development electronics experiments, including simulation tools [9, 10].

This paper presents the implementation of a didactic system, similar to industrial process for teaching modelling temperature control systems and parameters identification. The system is used to teaching process control and instrumentation in engineering courses.

2. Temperature Control System

A computer-based control system is typically formed by digital computer, data acquisition board, interface electronic circuits and software package that allows the user to obtain, analyze and display all the experimental data [11].

The process control system, illustrated at Figure 1, is a didactic heating system, built with wood, including a lamp, where the heating is controlled by adjusting the applied voltage. A thermocouple (PT100) is used as temperature sensor and provides a voltage proportional to temperature. An electrical panel (Figure 2), including electronics signal conditioning circuits provide the conversion of voltage levels of sensor voltage, while a solid state relay produces adequate power in the lamp based on control signal produced by a data acquisition system. Cooling is produced by the control voltage applied to a cooler.

Figure 1. Temperature Control System
The temperature control system was implemented as illustrated at block diagram at Figure 3. The control was developed using ELVIS™ (Educational Laboratory Virtual Instrumentation Suite) toolkit (Figure 4) and LabVIEW™ programming language with a graphical man-machine interface being constituted of one data acquisition board model NI PCI-6251 and one work station equipped with one protoboard where the applications can be developed.

3. Temperature Control System Modelling

The temperature control system can be model by the following differential equation [12]:

\[
RC \frac{d\theta_o}{dt} + \theta_o = Rh + \theta_i
\]

(1)

where \( R \) is the thermal resistance (°C.s/kcal), \( C \) is the thermal capacitance (kcal/°C), \( \theta_o \) and \( \theta_i \) are respectively the deviation of temperature output and input over an operating point in steady state (°C) and \( h \) is the deviation of heating over the operating point in steady state (kcal/s).

Applying the Laplace Transform and assuming \( \theta_o(0) = 0 \):

\[
\Theta_o(s) = \frac{R}{RCs+1} H(s) + \frac{1}{RCs+1} \Theta_i(s)
\]

(2)

Whereas the variation of outside air temperature is a disturbance \( \theta_i = 0 \), ignoring the dynamics of the temperature sensor and assuming the voltage produced by this sensor \( V_i(s) \) is proportional to the temperature, i.e., \( V_i(s) = K_i \theta_i(s) \), and assuming the heating is proportional to the output voltage produced by the data acquisition system, i.e., \( H(s) = K_h V_o(s) \), we have:

\[
V_o(s) = \frac{K_h K_i R}{RCs + 1} V_i(s) = \frac{K_h}{T_s s + 1} V_i(s)
\]

(3)

where \( K_h \) is static gain and \( T_s \) is the time constant of system. Note that the system has heating and cooling system separately driven, respectively to positive and negative control signals \( V_i(s) \) as illustrated at Figure 3.

The discrete state space of (3), using sampling time \( T \):

\[
v_o(K + 1) = e^{-\frac{1}{T}T} v_o(K) + \left[1 - e^{-\frac{1}{T}T}\right] K_h T_s v_i(K)
\]

(4)

Defining \( W \) the array of discrete system parameters:

\[
v_o(K + 1) = \begin{bmatrix} e^{-\frac{1}{T}T} & 1 - e^{-\frac{1}{T}T} \end{bmatrix} K_h T_s v_i(K) = [v_o(K) \ v_i(K)] W(k)
\]

(5)

4. Temperature Control System Identification

The temperature control system (3) is a first order model and its parameters can be determined by the step response, as illustrated at Figure 5, where is considered, in specific case, the initial condition \( V_i(0) = 0V \) and \( V_i(t) = V_{\text{max}} \) para \( t \geq 0 \) s. The parameter \( K_h \) can be obtained by the Final Value Theorem while \( T_s \) corresponds to the time required for the output reaches 63.2% of the output variation after the step applied and up to steady state.

Figure 2. Devices on electrical panel

Figure 3. Temperature control system – block diagram

Figure 4. Data Acquisition System ELVIS™
Other methods are used to determine mathematical model of the discrete system (5), with the advantage of use of application in real time, defining the parameters at each sampling. An example is the Weighted Least Squares Method (WLS Method) [13], an extension of the Least Squares Method that is an efficient and accurate estimation algorithm suitable particularly when the designer has a priori approximation of parameters values.

It should be noted that the estimation in real time allows the determination of the parameters considering variation of operating conditions, for example, due to external disturbances. Additionally, it makes possible the implementation of adaptive control system where the controller parameters can be automatically adjusted in real time from the estimated mathematical model.

The main feature of the WLS Method is the use of initial values for the parameters and the determination of errors on-line. In order to achieve convergence, it uses a gain matrix (Kalman gain) which is automatically adjusted in the algorithm to produce the minimization of errors, considering the previously calculated parameters and those obtained in the current sampling. This is accomplished by adjusting the “forgetting factor” γ and the variable α. By adjusting γ, the user is given greater importance (higher degree of weighting) to the latest measurements, as these contain the most current information and should have greater influence in the estimation. This is enforced in practice by setting $0.9 < \gamma < 1$.

The structure of the estimation algorithm is presented below.

(a) Choose a diagonal weighting matrix $P(k)$, known as “covariance matrix” with order $n \times n$, where $n$ is the number of variables representing the system states whose parameters will be estimated. $P(k)$ reflects the degree of uncertainty in knowledge of the estimated parameters. However, if there is some knowledge about the amounts expected in the estimation, we use a diagonal matrix $P(k)$ with parameters set at low magnitude values. However, if the estimated parameters are completely unknown, the “covariance matrix” should present terms with high values on the main diagonal.

(b) Set a “forgetting factor” γ such that: $0 < \gamma \leq 1$ and $\alpha = (1 - \gamma)$.

(c) Initialize $V_0(k)$, $V_0(k-1)$, $V_0(k-2)$, $V_1(k-1)$, $V_1(k-2)$ and $D(k) = [-V_0(k-1) \ -V_0(k-2) \ V_1(k-1) \ V_1(k-2)]^T$.

(d) Assume initial values for $\hat{W}(k + 1)$ and $\hat{W}(k)$ where $\hat{W}(k)$ is the array of estimated parameters at each sampling time.

Repeat the operations listed from (e) to (i) while max $|\hat{W}(k+1) - \hat{W}(k)| \geq \varepsilon$ where ε is a tolerance for the estimation error. However, if the goal is to develop a control based on the estimated parameters, then the algorithm should be used continuously.

(e) Update $\hat{W}(k)$ = $\hat{W}(k+1)$.

(f) Calculate the Kalman gain of the system by:

$$K(k) = \frac{P(k)}{\gamma} D(k) \left[ \frac{1}{\alpha} + D^T(k) \frac{P(k)}{\gamma} D(k) \right]^{-1}$$

(g) Estimate a new value of $\hat{W}(k+1)$ using:

$$\hat{W}(k + 1) = \hat{W}(k) + K(k) \left( V_0(k) - D^T(k) \hat{W}(k) \right)$$

(h) Calculate the new weighting matrix by:

$$\hat{D}(k) = \frac{1}{\gamma} \left[ I - K(k) D^T(k) \right] \hat{D}(k)$$

(i) Update: $V_0(k) = V_0(k+1)$; $V_0(k-1) = V_0(k)$; $V_0(k-2) = V_0(k-1)$; $V_1(k-1) = V_1(k)$; $V_1(k-2) = V_1(k-1)$; $D(k) = [V_0(k-1) V_0(k-2) V_1(k-1) V_1(k-2)]^T$

Setting the tolerance is made if the goal is estimate the system parameters to achieve their convergence. However, if the goal is to identify the parameters in real time, the algorithm, considering the operations (e) to (i) can be repeated continuously.

5. WebLab for Modelling the Temperature Control System

The man machine interface in order to identify the model of temperature control system was developed by using LabVIEW™ and html codes. Basically, three steps were required: (i) create LabVIEW™ applicative as an appropriate man-machine interface to the user; (ii) enable the WebServer option to obtain remote access and thus to configure the access managing panel; (iii) modify the html code, inserting text containing introduction and fundamentals, specific information about the school and general instructions to the user.

The initial html page of WebLab is presented at Figure 6. Using this application the user select the operation system of your computer and download the plugin file for access the Web Server.

Considering the choice of adequate set of initial settings, it is possible make access to the experiment. To do this, the user must select the desired method: based on step response or MLS method.

The first choice is presented at Figure 7. Using the interface the user can adjust the set point and monitoring the temperature measured by sensor.
The second choice (MLS method), illustrated at Figures 8 and 9 has two algorithms: simulation and practical application. Using either applications, the user obtain the discrete and continuous model of temperature control system. However, at the simulation algorithm, the results are obtained using a simulation of system with ideal parameter.

6. Experimental Results Obtained Using the Approach

The temperature control system was modelled using the approaches proposed.

Using (3) and the WebLab presented at Figure 7 and adjusting set point 10 V, the results obtained were:

\[
\frac{V_o(s)}{V_i(s)} = \frac{K_s}{T_s s + 1} = \frac{0.11}{425 s + 1}
\]  

(9)

Note that, the equivalent discrete parameters of the system (9) are:

\[
v_o(K+1) = [v_o(K) v_i(K)]^T \begin{bmatrix} W_1(k) \\ W_2(k) \end{bmatrix} = \\
= [v_o(K) v_i(K)] \begin{bmatrix} 0.9976498 \\ 0.258519 \times 10^{-3} \end{bmatrix} \]

(10)

Using (5), the simulation WebLab presented at Figure 8, and adjusting \( \gamma = 0.96 \), \( P(k) \) with diagonal terms 10000, and initial values to \( W_1(0) \) and \( W_2(0) \) respectively 0.9 and 0.2, the MLS method resulting the following discrete parameter:

\[
v_o(K+1) = [v_o(K) v_i(K)]^T \begin{bmatrix} 0.99765 \\ 0.25851 \times 10^{-3} \end{bmatrix} \]

(11)

Note that the values are equivalent to those produced using the step response, as expected, because were used the parameter of equation (9) at simulation. The convergence of parameters is presented at Figure 10. The results is the same presented at Figure 8, but inverting colors in order to improve the waveforms display.
Temperature Control System

This application allows tests using the temperature control system manufactured by the CONTEMP. The control can be performed remotely, including graphical data acquisition in real time.

Status in operation
Development: Dr. Wanderson de Oliveira Assis

Introduction

Temperature Control System

In this experiment we use a teaching kit for temperature control, illustrated at Figure 1, and the kit ELVIS™ (Educational Virtual Instrumentation Suite) a multidisciplinary tool by National Instruments focused on the development of control applications. The data acquisition and the control algorithm was introduced using the LabVIEW software.

![Figure 1 – Temperature Control System and Detail of Electric Panel](image)

Application - Step Response - Temperature Control System

Instructions

1. To request access to the experiment, click the right mouse button on the screen and make the access request in the Request Control of VI. To release control, select Release Control of VI.

Figure 7. Step response HTML page
The practical results was obtained using the WebLab presented at Figure 9, and either adjusting $\gamma = 0.96$, $P(k)$ with diagonal terms 10000, and initial values to $W_1(0)$ and $W_2(0)$ respectively 0.9 and 0.2. At this case the MLS method resulting a relative variation at estimated parameter, as illustrated at Figure 11.

The last estimated discrete and continuous parameters are the following:

$$v_0(K+1) = \begin{bmatrix} v_1(K) \\ v_2(K) \end{bmatrix} \begin{bmatrix} 0.997034 \\ 0.40186 \times 10^{-3} \end{bmatrix}$$

$$V_0(s) = \frac{K_s}{T_s s + 1} = \frac{0.1355}{336,654 s + 1}$$
The results, obtained in practical tests, although presents relative variation, are similar to those obtained at simulation, as presented at Table 1, where the results using step response and MLS method are compared, getting the relative deviation between the simulation and real system. The differences is acceptable and feasible, considering not only the inaccuracies in the system identification, but mostly due to the different operating conditions conducted in the step response model (and consequently in the simulation). Obviously, the input values applied to the step response method and the temperature are different than those carried out for testing the method of least squares. Thus, values in MLS method represent the real time system parameters identification, even considering changes in the characteristics and system operating conditions.

### Table 1
Results using step response method, simulation of MLS method and MLS method in real system

<table>
<thead>
<tr>
<th>Methods / Parameters</th>
<th>Ks</th>
<th>Ts (s)</th>
<th>w1</th>
<th>w2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step response</td>
<td>0.11</td>
<td>425</td>
<td>0.9976498</td>
<td>0.258519 x 10⁻³</td>
</tr>
<tr>
<td>MLS (Simulation)</td>
<td>0.11</td>
<td>425</td>
<td>0.99765</td>
<td>0.258519 x 10⁻³</td>
</tr>
<tr>
<td>MLS (real system)</td>
<td>0.1355</td>
<td>336,654</td>
<td>0.997034</td>
<td>0.40186 x 10⁻³</td>
</tr>
<tr>
<td>Deviation</td>
<td>0.0255</td>
<td>-88,346</td>
<td>-3.1 x 10⁻⁴</td>
<td>0.143341 x 10⁻³</td>
</tr>
</tbody>
</table>

### 7. Conclusions

The algorithms and interfaces develop to teaching modelling and estimation of system parameters were used in undergraduate and graduate engineering courses, with a differential because the WebLab could be accessed remotely, whatever the students wants, and thus producing better evaluating of results.

The developed interfaces are easy to use and the algorithms are efficient. But, a major disadvantage is the need of installing a LabVIEW™ tool, requiring a procedure, which relatively consuming time depending on the computer and, consequently, is discouraging, especially for those who have little time to dedicate and access to the experiment.

Even so, after the good results, it is hoped that this work will boost other research projects and experiments related to remote industrial process control, for example, using adaptive control.

### References


