DATA ACQUISITION AND CONTROL SOFTWARE FOR THE EDUCATIONAL KIT FESTO (LEVEL AND TEMPERATURE CONTROL)

Gabriela CANURECI, Camelia MAICAN, Matei VINATORU

Automation Department, University of Craiova, Str. A. I. Cuza nr. 13, Craiova, ROMANIA
Tel. +40-251-437541; gabrielacanureci_aut@yahoo.com, camelia@automation.ucv.ro

Abstract **– In this paper presents the study of the educational kit FESTO, a flexible lab kit that can be used for a series of process control applications. A LabView program was developed for control and simulation of the plant parameters data acquisition (temperature, flow and level control) from the FESTO kit.**

Keywords: *FESTO, level and temperature control AXIOM 5411 board.*

1. INTRODUCTION

The educational kit FESTO is a flexible lab kit that can be used for a series process control applications. Using a data acquisition board the analogue or digital data from different sensors can be processed or analysed. There are a lot of possibilities to realise the control process structure for temperature, flow and level control. Using proper computer programs, it is possible to develop some control algorithms to study and simulation the dynamics of complex industrial processes with interdependence between controlled variables. In this paper it is presented some possibilities of utilisation of the educational kit FESTO in laboratory activities of students in didactical and research activities.

2. KIT DESCRIPTION

The educational kit FESTO is a flexible lab kit, which can be used for a series process control applications. The technological process provided by the kit has the following characteristics:
- The system is modular with step by step extension possibilities; authenticity due to industrial original components use;
- The kit is easy transportable;
- The kit is using water as working medium eliminate-ting any operational danger;
- The process is open for new technologies such as process visualisation and technologic control.

2.1. Kit Components

The basic components of the kit are: reservoirs, pumps, control valves, heater, plastic tubes with elbows, sensors for temperature, level and flow measurement, electrical components, mechanical components. The kit allows level, temperature and flow control contains individual modules that can be combines in different configurations. The kit may be equipped with multiple levels.

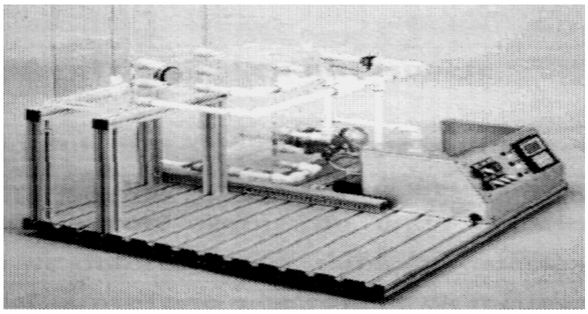

Figure 1: Plant FESTO

2.2. Signal adaptation from FESTO kit to AXIOM board

For data acquisition from the kit sensors the data acquisition board AXIOM 5411 was used. The board has 16 analogue 0-10V DC inputs and 2 analogue 0- -10V DC outputs. Due to the fact that the analogue inputs of AXIOM board accept a 0-10V DC signal we realised some adaptation of transducers, signals and connection system of kit FESTO to data acquisition board.

a) The ultrasonic level sensor.

The level is measured using an ultrasonic sensor. The sensor is generating an ultrasonic wave, which is reflected by the water surface and received back by the sensor. The atmospheric air is used as propagation medium for the ultrasonic waves. The sensor output is proportional with the travailing time of the ultrasonic wave between the sensor and the water surface and is generated by an electronic module connected to the sensor. The output signal is a 4-20 mA current signal. The analogue inputs of AXIOM board accept only voltage input. The sensor output was converted to voltage signal using a 500 ohms reference resistor in parallel with the sensor. The 4-20 mA range was converted to a 2-10 V signal that is accepted by the

AXIOM board. The level calibration was performed with the resistor connected in the circuit and the level-voltage characteristic of the converter is presented in figure 2.

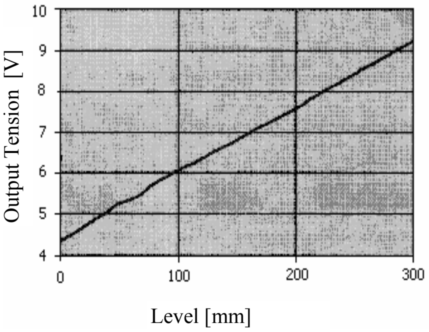

Figure 2: The level-voltage dependence

b) Temperature sensor PT100.

For temperature measurement was implemented a temperature sensor PT100 with the given rezistivity-temperature dependence. In order to convert the resistivity of the sensor in a useful signal for the AXIOM board a range converter F75, manufactured by IEA Bucharest was used. This converter has a current output; therefore a Kohm-calibrated resistor was used to convert the current in voltage. This combination generates a linear tension dependence of temperature. See figure 3:

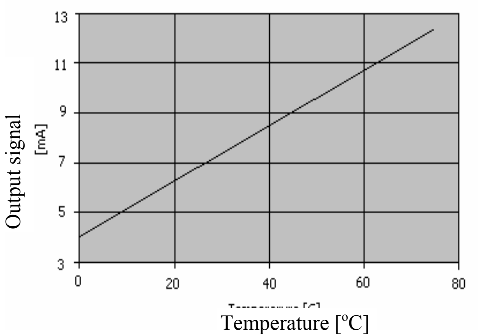

Figure 3: The level-voltage dependence temperature for the range converter F75

2.3. Mathematical modelling of the controlled process

In figure 4 is presented the schematic diagram of the kit FESTO. The basic components of the kit are: reservoirs, pumps, control valves, heater, plastic tubes with elbows, sensors for temperature, level and flow transducers, electrical components, mechanical components.

The following notations were used: A_1 -aria of the first reservoir; A_2 -aria of the second reservoir; L_1 -level of the first reservoir; L_2 -level of the second reservoir; F_1 -first flow; F_2 -second flow; S_1 -aria of the valve one; S_2 -aria of the valve two; ρ_1 -water density; P-pump; u_c -actuator control tension; k_1, k_2, k_3, k_4 - linearisation constants.

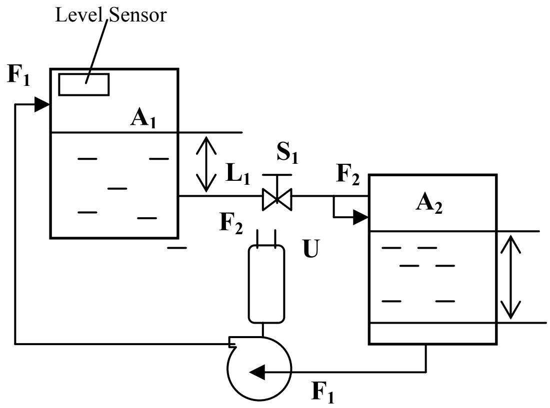

Figure 4: The diagram of the plant

Using the mass balance equations, for the elements of the figure 4, we develop the mathematical model of the plants (equation (1) and (2)).

$$A_1 \frac{\Delta L_1}{dt} = F_1(u_c) - F_2(L_1, S_1) \tag{1}$$

$$A_2 \frac{\Delta L_1}{dt} = F_2(L_1, S_1) - F_1(u_c) \tag{2}$$

The linear model of the plant (3) and (4) was obtained by linearisation of the equation (1) and (2).

$$A_1 \rho_1 \frac{\Delta L_1}{dt} = k_1 \Delta u_c - k_2 \Delta L_1 - k_3 \Delta S_1 \tag{3}$$

$$A_2 \rho_1 \frac{\Delta L_1}{dt} = k_2 \Delta L_1 + k_3 \Delta S_1 - k_1 \Delta u_c \tag{4}$$

The system (3)-(4) can be expressed in Laplace form (5) and (6) for zero initial conditions:

$$(T_1 s + 1)\Delta L_1(s) = \frac{k_1}{k_2} \Delta u_c(s) - \frac{k_3}{k_2} \Delta S_1(s) \tag{5}$$

$$T_2 s \Delta L_2(s) = \Delta L_1(s) + \frac{k_3}{k_2} \Delta S_1(s) - \frac{k_1}{k_2} \Delta u_c \tag{6}$$

Using the notations (5) and (6) results:

$$T_1 = \frac{A_1 \rho_1}{k_2}; \; T_2 = \frac{A_2 \rho_1}{k_2} \tag{7}$$

After simple processing from (5) and (6) or from the block diagram, the transfer functions of the plant has the form (8). The block diagram of the plant has the form from the figures 5:

$$H_{PF}(s) = \frac{k_2}{1 + T_2 s} \cdot \frac{k_1}{k_2} \cdot \frac{k_T}{1 + T_1 s} \tag{8}$$

$$F_2 = CS_1\sqrt{L_1} \tag{9}$$

$$K_2 = \frac{\partial F_2}{\partial L_1} = \frac{CS_1}{2\sqrt{L_1}} = \frac{CS_1\sqrt{L_1}}{2L_1} = \frac{F_{20}}{2L_0} \tag{10}$$

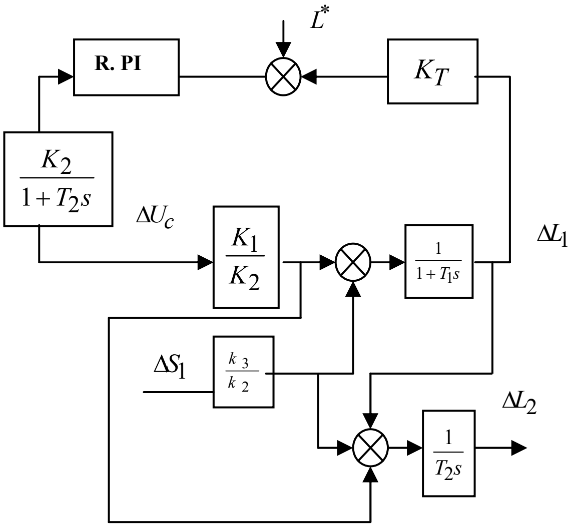

Figure 5: The block diagram of the plant

There is the flow:

$$F_{20} \in 10 \div 25 l/\min = \frac{1 \div 2{,}5 \cdot 10^{-3}}{6} m^3/s \tag{11}$$

$$L \in 0 \div 400$$
$$L_0 = 300\ mm = 0{,}3\,m \tag{12}$$

$$T_1 = \frac{0{,}0675}{(0{,}3 \div 0{,}8)10^{-3}} = 227 \div 86 s \tag{13}$$

$$K_2 \in \frac{1 \div 25 \cdot 10^{-3}}{3{,}5}\left[\frac{m^3/s}{m}\right] = \frac{10 \div 25}{3{,}5} \cdot 10^{-3} = (0{,}3 \div 0{,}8) \cdot 10^{-3} \tag{14}$$

2.4. The wiring diagram

a) The board wiring.

The connection between the FESTO kit and the data acquisition board is made through a connection adapter and a cable with 24-pin connectors. The kit elements are connected to the AXIOM board as follows:

Analogue input channel:
- 0-orange wire-pin CS0-temperature sensor;
- 1-green wire-pin CS1-flow sensor;
- 2-brown wire-pin CS2-level sensor.

Analogue output channel:
- 0-orange wire-pin CD0-heating element;
- 1-green wire-pin CD1-pump;
- Red wire-24V;
- Black wire-0V.

b) The connection adapter diagram.

The connection adapter diagram is presented in figure 6.

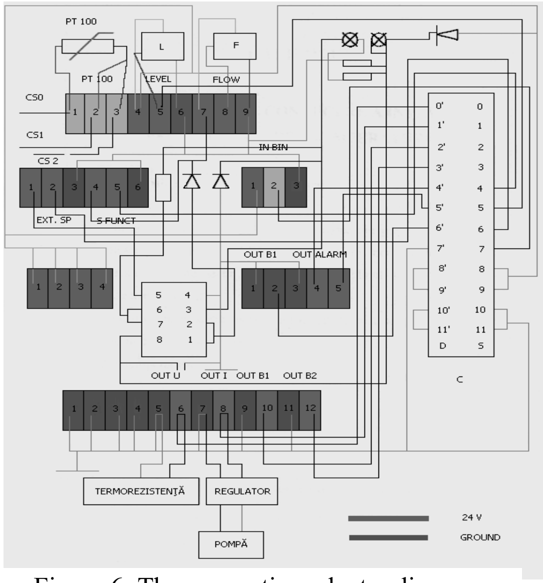

Figure 6: The connection adapter diagram

3. THE CONTROL SYSTEMS DESIGN

The computer control of the plant parameters (temperature and level) is achieved using the control programs developed under LabView software.

3.1. The temperature control systems

a) The structure of temperature control systems.

Generally, the temperature control processes are slow processes with significant transport delay. These processes have big time constants usually in the minutes or even hour's range. Moreover these processes are subjected to important perturbations due to the heat and mass exchange with the environment.

The temperature control loop for the FESTO kit.

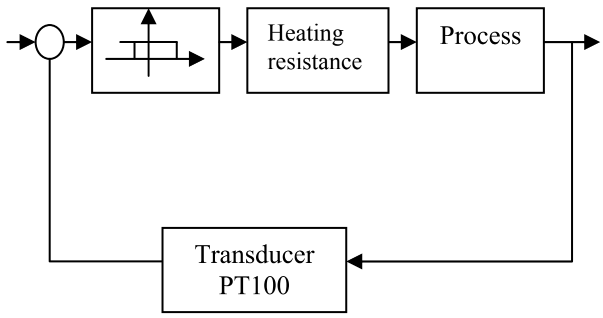

Figure 7: The temperature control loop

For temperature control a bi-positional controller with hysteresis was used.

The controller equations are as follows:

$$\varepsilon_k = v - \theta_k \tag{1}$$

If

$$\varepsilon_k \geq \delta \Rightarrow x_k = 0 \qquad (2)$$

$$\varepsilon_k \leq -\delta \Rightarrow x_k = 0 \qquad (3)$$

$$-\delta \leq \varepsilon_k \leq \delta \Rightarrow x_k = x_{k-1} \qquad (4)$$

where: v- steeping; θ- process variable; ε- error; χ-controller output; δ- control parameter imposed by the required level of performance; k- current step;
A small δ will assure a small error but in the same time will generate fast changes of the controller output between 0 and 1, reducing the life span or even damaging the actuator. Also, δ shall be chosen depending of the process transport delay.

b) The program installation.

The program installation is done with the Open command in the File menu of LabView. The program resides in the LabView folder and has the name temp. The front panel of the virtual controller is presented in the figure 8. After the Open command, the program is launch and the front panel is presented on the screen.

Figure 8: Front panel

3.2. The level control systems

a) The LabView level control program for the FESTO kit.

The level control in the FESTO kit is achieved using the variable flow pump. The water circuit is consists of the upper and lower reservoirs connected through a system of pipes and valves. The controlled variable is the level in the upper reservoir. The level control processes can be divided in two categories.
The first category contains the installations where level is a primary parameter or the level influences directly the process. In this case, the level shall be precisely controlled. The FESTO kit may be included in this category.
The second category contains the installations where level is a secondary parameter and can largely vary. In this case, the precision of the control is not so important and sometime a simple by-positional controller is sufficient.
The input flow or the output flow may control the level. If the installation is part of a process line and the output flow is mandated by the next installation, the input flow is used for level control. If the installation is the last one in a process line and the output flow may be freely modified this flow will be used for level control.

b) The elements of the front panel and user instructions.

The front panel has displays for the process variables and control elements for parameters setting. The process variables are displayed on the left side of the panel: temperature, error and controller output. The variables are presented as graphs and as digital values. Next to each graph there is an LED which displays the following status: -temperature-RED=zero value (possible fault), GREEN (non-zero value) -error- RED (error absolute value is bigger then 0.1), GREEN (error absolute value is smaller than 0.1) –Controller output-RED (output=10V), GREEN (output=0V) (figure 8).

c) Program diagram.

The program is using the voltage for internal calculations. In order to display the temperature, a conversion formula was used:

$$u = 0.1085 * \theta + 4$$

Where: u-voltage [V], θ-temperature [°C]

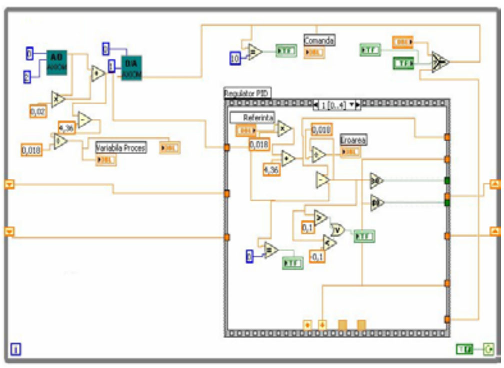

Figure 9 : The program block diagram

The diagram allows also the output values to be changed from 0 and 1 to adapt the program for other installations. After the Open command, the program is launch and the front panel is presented on the screen.

In manual regime the pump is disconnected from the controller and the pump flow can be manually controlled. The reservoir level will be maintained according with other parameters of the system.

d) Experimental identification of the installation.

The dynamic regime of the installation may be determined by probing the installation with step input. The output may be used then to determine the transfer function of the installation. For identification purposes, the level sensor was connected to the acquisition board Cassy that has a digital recorder. An 8V-step signal was applied and the output was recorded every 5 seconds with the Cassy board, used in MultiMate regime until the output reached a steady state. From the step response the transfer function for the installation was determined as being of 1st order and having the following form:

$$H(s) = \frac{k}{T_1 s + 1} \qquad (1)$$

where $k = \frac{\Delta y}{\Delta u} = \frac{7{,}65 - 4{,}82}{8} = 0{,}35$ (2)

and $T_1 \cong 100s$ (3)

The time constant T determined in experimental identification has the value in the interval mentioned in relation (13), induced in theoretical model of the plant.

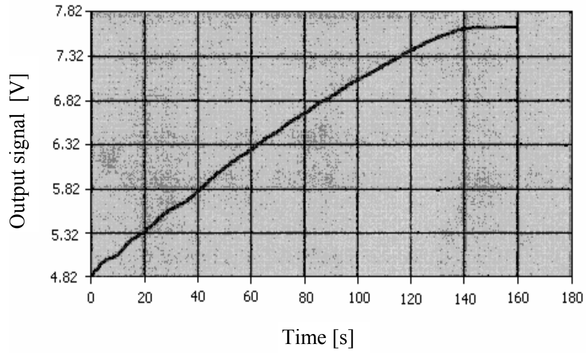

Figure 10 : The installation response for an 8V step input.

e) The controller parameter design.

The dynamic characteristic of the actuator (pump and power amplification) was determined by experimental identification and can be represented with transfer function:

$$H_a(s) = \frac{k_a}{1 + T_a s} = \frac{k_a}{1 + 10s} \qquad (1)$$

where $k_a \cdot k_2 = 0{,}5$. (2)

Using the controller design relations from [2] and [3], it results a PI controller with the following parameters:

$$T_I = T_1 = 100s \qquad (3)$$

$$K_R = \frac{T_I}{2K_p T_a} = \frac{100}{2 \cdot 0{,}5 \cdot 10} = 10. \qquad (4)$$

f) Program installation.

The program installation is done with the Open command in the File menu of LabView. The program resides in the LabView folder and has the name Reglare_nivel.vi.

The front panel of the virtual controller is presented in the next figure:

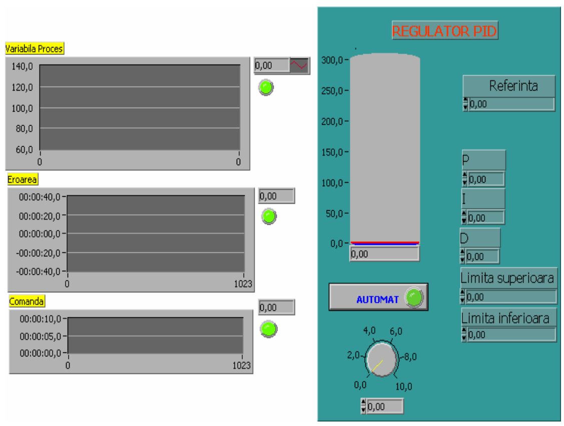

Figure 11 : Level control

g) Experimental results.

The tuning is done experimentally, the parameters being fine-tuned through small changes until the desired response is obtained. This method is using the real operation of all control system elements and can be used regardless the controller type, especially for PID controllers with any interdependence factor.

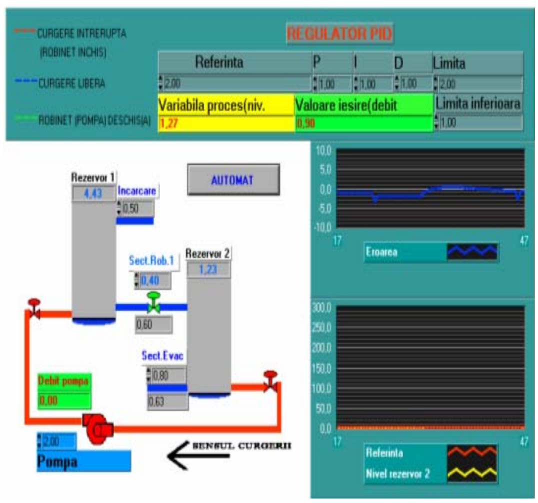

Figure12 : Controller PID

The PID controller tuning is performed as follows:
- The BP and T_i parameters are set at the maximum values and the T_d parameter is set at minimum. BP is lowered until the output oscillates. T_d is raised until oscillation disappears. The process is repeated until T_d raise cannot stop oscillations anymore. In this case, BP is raised to the previous value and T_d is lowered to the previous value to get a stability margin.
- After BP and T_d are set, T_i is lowered until oscillations appear. Then T_i is set at one or two steps higher to get a stability margin. Following this procedure the following parameters were determined for the level controller:

$$K_R=1.5;\ T_i=2;\ T_d=0.02.$$

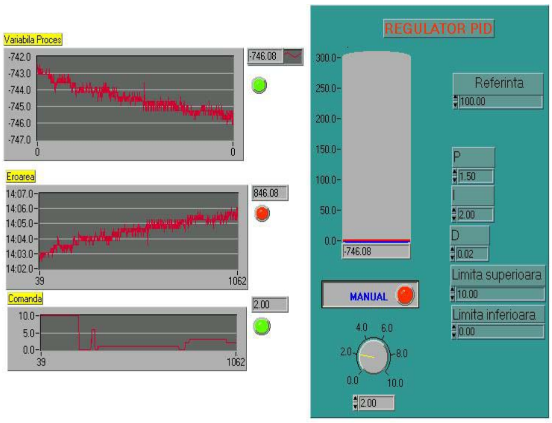

Figure 13 : Controller PID

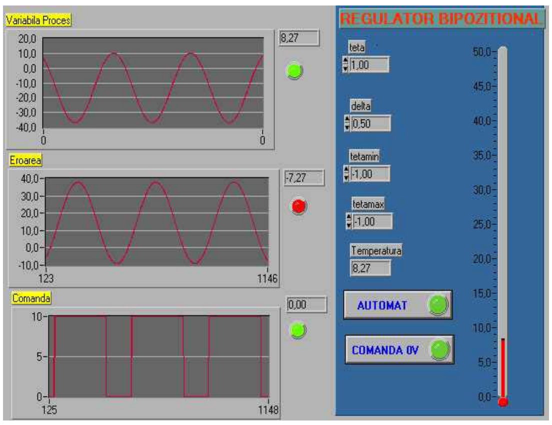

Figure 14 : Controller bi-positional

The variables are presented as graphs and as digital values. Next to each graph there is an LED which displays the following status: -temperature- RED= zero value (possible fault), GREEN (non-zero value) -error- RED (error absolute value is bigger then 0.1), GREEN (error absolute value is smaller than 0.1) – Controller output- RED (output=10V), GREEN (output=0V) (figure 13). The precision of the control is not so important and sometime, a simple bi-positional controller is sufficient.

4. CONCLUSIONS

This paper is presenting the experimental results obtained in the development of some applications for design and implementation of control systems for industrial installations. For that purpose, an educational kit was used manufactured by FESTO-Germany. The kit is provided with necessary sensors for temperature and level. A signal adapter was necessary to connect the sensors to the data acquisition board existent in the lab.

A complex educational system was developed using the FESTO kit, the AXIOM data acquisition board and LabView software. This system may be used for practical work associated with the course Control Systems for Continuous Processes.

Acknowledgments

This paper is part of the research activities from the Automation Department, University of Craiova and the PhD students plan. It was developed during the PhD program of the first two authors.

References

[1] *Cottet, F. Ciobanu, - Bazele programării în LabView, Ed. MatrixRom, Bucureşti, 1998.*

[2] *Vinatoru M., Conducerea automata a proceselor Industriale, Ed. Universitaria, Craiova 2000.*

[3] *Marin C., Structuri si legi de reglare automata, Editor Universitaria, 2000.*

[4] *Marin, C., Structure and automate control law, Ed. Sitech, Craiova, 2000.*

[5] *AX5411 Board – General Description.*

[6] *L.Arsenoiu, T.Savu, A.Szuder; Bazele programa-rii in LabView, Ed. PrinTech, Bucuresti, 1999.*