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LABVIEW SOFTWARE IMPLEMENTATION FOR LIQUID-LEVEL CONTROL IN TANK SYSTEMS

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Abstract

The paper discusses using LabVIEW software to enhance teaching in Automatic Control, emphasizing visualization and intuitiveness. It focuses on an example involving liquid level control in a nonlinear tank system with two and three horizontally arranged tanks. The paper outlines the advantages of LabVIEW over MATLAB, which is commonly used in control systems, especially regarding process visualization. The system model is linearized using Taylor series development. An analysis of the system's behavior in the time domain includes responses in both open-loop and closed-loop configurations and PID controller design. Additionally, the paper presents frequency domain analysis through Nyquist plots and Bode diagrams to assess system stability and frequency response characteristics.

Keywords: LabVIEW, tank system, PID controller design, Nyquist plots, Bode diagrams.

NOMENCLATURE

A [m^2]	Tank cross-section;
a [m^2]	Cross-section of the tank's outlet pipe;
Q_i [m^3/s]	Flow rate into the tank;
Q_{is} [m^3/s]	Steady-state flow rate into the tank;
q_i [m^3/s]	Deviation of the flow rate into the tank from the steady-state value;
Q_0 [m^3/s]	Liquid flow rate out of the tank, i.e., between tanks
H [m]	Liquid height in the tank;
H_s [m]	Steady-state liquid level in the tank;
h[m]	Deviation of the liquid height in the tank from the steady-state value;
g [m/s^2]	Acceleration due to gravity;

INTRODUCTION

Nowadays, teaching a course on Automatic Control Systems would be quite callenging without the use of MATLAB software [1-7]. The tools provided by MATLAB, enable a comprehensive analysis of automatic control systems, covering all fundamental elements and enhancing theoretical understanding. However, MATLAB does not provide a way to visually model a real physical system while simultaneously controlling desired parameters and system behavior.

For these purposes, LabVIEW software has proven to be highly beneficial [2-4,8]. It can be used not only for simulation, but also for relevant measurements, making it an excellent substitute when appropriate laboratory exercises are unavailable. This is crucial for demonstrating a wide range of practical examples in student courses, therefore ultimately better-preparing students for their future careers.

LabView software uses graphical programming, allowing users to easily create a customized Front Panel by applying controls, indicators, and functions. This enables the user to design an interface that visually represents the entire system, can adjust parameters, monitors outputs, and more [3,4,8]. This offers a clear visual representation of the control flow within an automated system. Any problem can be set, control implemented, and system synthesis and analysis performed.

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This paper demonstrates the application of LabVIEW software through examples involving liquid level control in coupled tank (CT) and three-tank (TT) systems. The study covers system modeling, open-loop control, frequency analysis, and PID control. These case studies are chosen because liquid level control is a frequent industrial practice, making it an ideal practical example for educating future students.

SYSTEM MODELLING

The paper discusses two non-linear systems made up of two and three horizontally placed tanks, Fig.1. and Fig. 2. To analyze these systems, it was necessary to develop appropriate mathematical models using relevant linearization techniques. The linearization method employed was based on the Taylor series expansion [5-7].

The mathematical models of the tank systems are derived using the mass balance equation. A detailed description of the linearization process of these equations is provided in the papers [6] and [7].

The CT system comprises two vertical tanks connected by a channel (Fig. 1), with each tank having its own independent pump for liquid inflow.

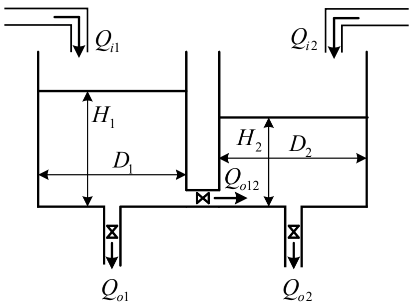

Fig. 1. *CT system*

The nonlinear equations describing the dynamics of each tank of the CT system are as follows:

$$A_1 \frac{\mathrm{d}H_1}{\mathrm{d}t} = Q_{i1} - Q_{o1} - Q_{o12}, \quad A_2 \frac{\mathrm{d}H_2}{\mathrm{d}t} = Q_{i2} - Q_{o2} + Q_{o12}, \tag{1}$$

where

$$Q_{ok} = a_k \sqrt{2gH_k}, \; k=1,\; 2; \quad Q_{oj(j+1)} = a_{j(j+1)} \sqrt{2g(H_j - H_{j+1})}, \; j=1. \tag{2}$$

After linearization, the following relationships can be written in the Laplace domain:

$$h_1(T_1 s + 1) = q_{i1} k_{11} + k_{12} h_2, \quad h_2(T_2 s + 1) = q_{i2} k_{21} + k_{22} h_1, \tag{3}$$

where

$$B_1 = a_1 \sqrt{\frac{g}{2H_{1s}}} + a_{12} \sqrt{\frac{g}{2(H_{1s} - H_{2s})}}, \quad T_1 = \frac{A_1}{B_1}, T_2 = \frac{A_2}{B_2}, \quad B_2 = a_2 \sqrt{\frac{g}{2H_{2s}}} + a_{12} \sqrt{\frac{g}{2(H_{1s} - H_{2s})}}, \tag{4}$$

and

$$k_{11} = \frac{1}{B_1}, \quad k_{12} = \frac{1}{B_2}, \quad k_{21} = \frac{a_{12} \sqrt{\frac{g}{2(H_{1s} - H_{2s})}}}{B_1}, \quad k_{22} = \frac{a_{12} \sqrt{\frac{g}{2(H_{1s} - H_{2s})}}}{B_2}. \tag{5}$$

The TT system consists of three vertical tanks connected by a channel (Fig. 2), where each tank is equipped with its own independent pump to control liquid inflow.

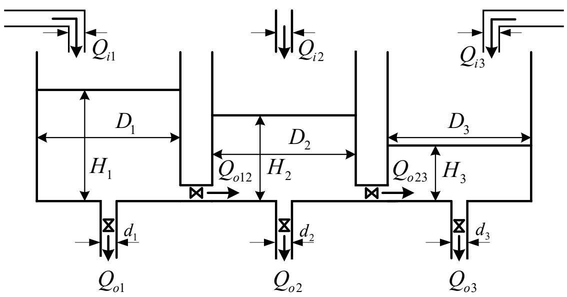

Fig. 2. *TT system*

The nonlinear equations governing the dynamics of each tank in the TT system are as follows:

$$A_1 \frac{\mathrm{d}H_1}{\mathrm{d}t} = Q_{i1} - Q_{o1} - Q_{o12},$$
$$A_2 \frac{\mathrm{d}H_2}{\mathrm{d}t} = Q_{i2} - Q_{o2} + Q_{o12} - Q_{o23}, \quad (6)$$
$$A_3 \frac{\mathrm{d}H_3}{\mathrm{d}t} = Q_{i3} - Q_{o3} + Q_{o23},$$

where

$$Q_{ok} = a_k \sqrt{2gH_k},\ k=1,\ 2,\ 3,$$
$$Q_{oj(j+1)} = a_j \sqrt{2g(H_j - H_{j+1})},\ j=1,\ 2. \quad (7)$$

The linearized MIMO TT model in Laplace domain is

$$h_1(T_1 s + 1) = q_{i1}k_{11} + k_{12}h_2,$$
$$h_2(T_2 s + 1) = q_{i2}k_{21} + k_{22}h_1 + k_{23}h_3, \quad (8)$$
$$h_3(T_3 s + 1) = q_{i3}k_{31} + k_{32}h_2,$$

where the time constants and gains in (8) are given in [7].

In this study, inputs 2, i.e. 3 (relations (3) and (8)), are assumed to be equal to zero, thereby forming SISO CT and TT systems,

$$q_{i2} = 0,\ i.e.\ q_{i3} = 0. \quad (9)$$

LABVIEW IMPLEMANTATION

The LabVIEW software is used to analyse the behaviour of the tank system in both the time and frequency domains. For that purpose virtual instruments have been created. The Front Panel of the virtual instruments contains three tabs. The first two tabs are related to open loop control of the tank system and the third tabs are related to the PID control.

The first tab displays the physical appearance of the tank system of interest, allows the user to input tank dimensions, and shows the block diagram of the linearised tank system and obtained values of system gains and time constants. Furthermore, the first tab shows of time responses ($h_1(t)$, $h_2(t)$ for the CT system and additionally $h_3(t)$ for the TT system). These responses are obtained for the given input flow of the first tank $q_{i1}(t)$, where the other inputs are equal to the zero ($q_{i2}(t) = 0$ for the CT system, $q_{i2}(t) = q_{i3}(t)=0$ for the TT system).

The second tab presents the results of the system's frequency analysis in the form of a Nyquist plot and Bode diagrams.

The third tab pertains to the PID control of the tank system in closed-loop feedback. It consists of a structural block diagram, controls that allow the selection of PID controller parameter values, and displays the system's response to a specified reference input.

During realisation of the LabVIEW appliaciation it was necessary to use MathScript code. MathScript has been used to form linearized transfer functions based on the specified tank dimensions, calculate poles and zeros, and determine appropriate gains. All these values are passed to the corresponding sections of the LabVIEW code, which creates open-loop system models, plots Nyquist and Bode diagrams, and control structures for the purpose of PID control of the systems.

Figs. 3-8 display the layout of the corresponding tabs for CT and TT systems. The program enables the selection of tank dimensions, filling rate (using the Knob button), and PID control parameters, providing students with an enhanced understanding of theoretical concepts through result analysis. For instance, in Fig. 4, it is observed that for specified tank dimensions, both phase margin and gain margin approach infinity, indicating absolute CT system stability. Meanwhile, the Bode plots in Fig. 7, show a positive finite value of the gain margin. System stability in both cases can also be validated using Nyquist curves. By adjusting PID parameters, students can explore the individual effects of each parameter on system behaviour during transient and steady-state phases. In this example, PID control of the liquid level in the third tank is achieved.

The implemented LabVIEW programs further enable the visual monitoring of tank filling and the establishment of steady-state conditions in the system with both open and closed feedback loops.

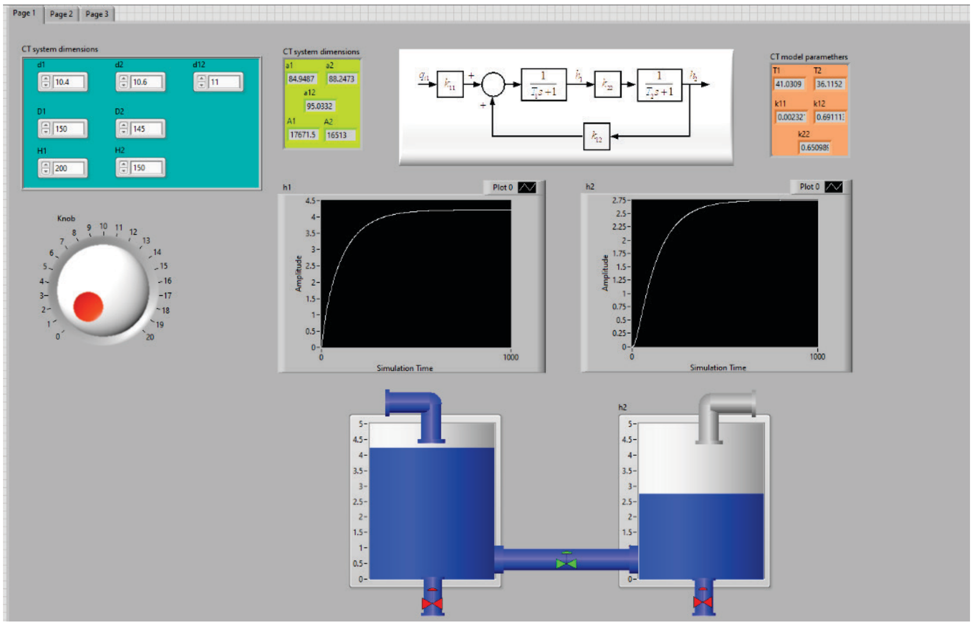

Fig. 3. *The first tab of the LabVIEW Front Panel of CT system*

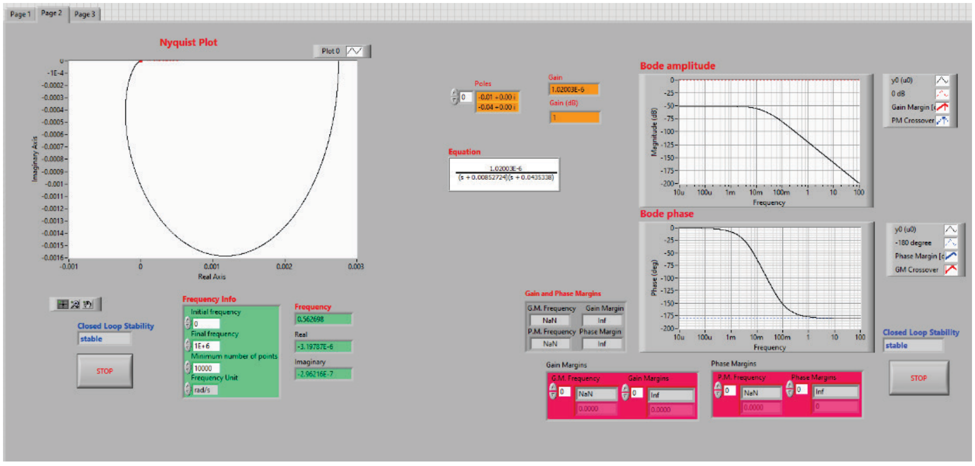

Fig. 4. *The second tab of the LabVIEW Front Panel CT system*

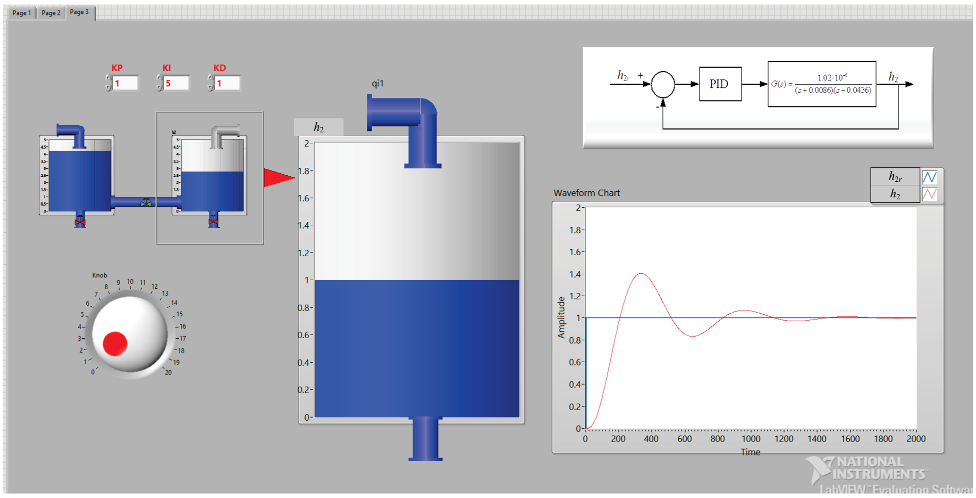

Fig. 5. *The third tab of the LabVIEW Front Panel of CT system*

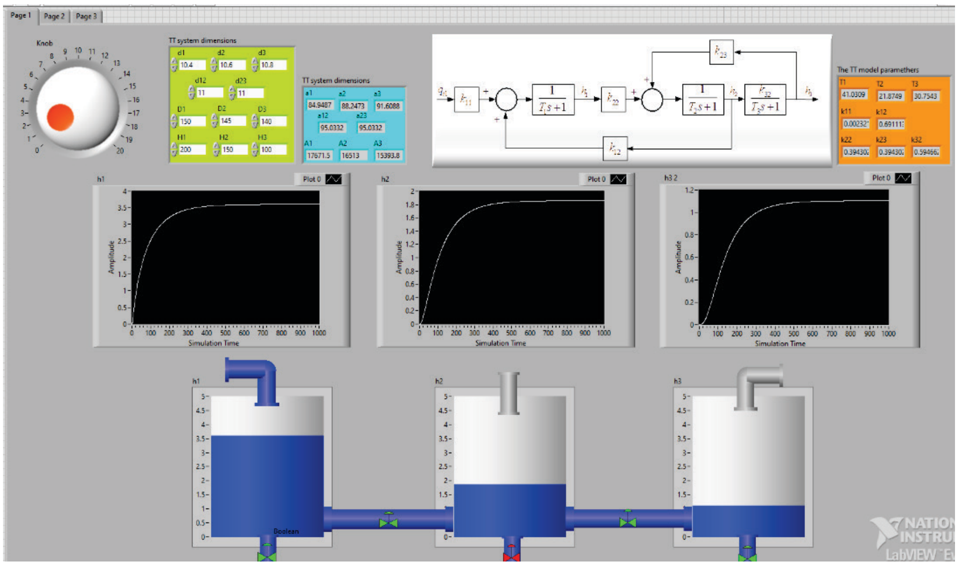

Fig. 6. *The first tab of the LabVIEW Front Panel of TT system*

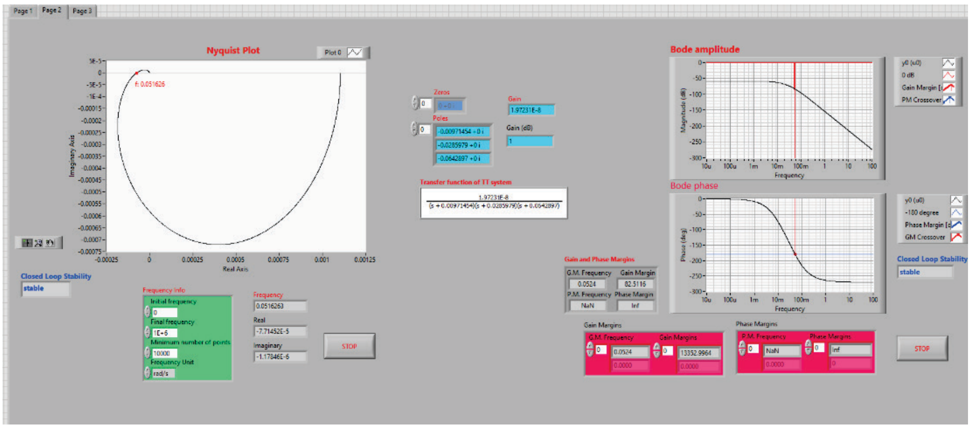

Fig. 7. *The second Tab of the LabVIEW Front Panel of TT system*

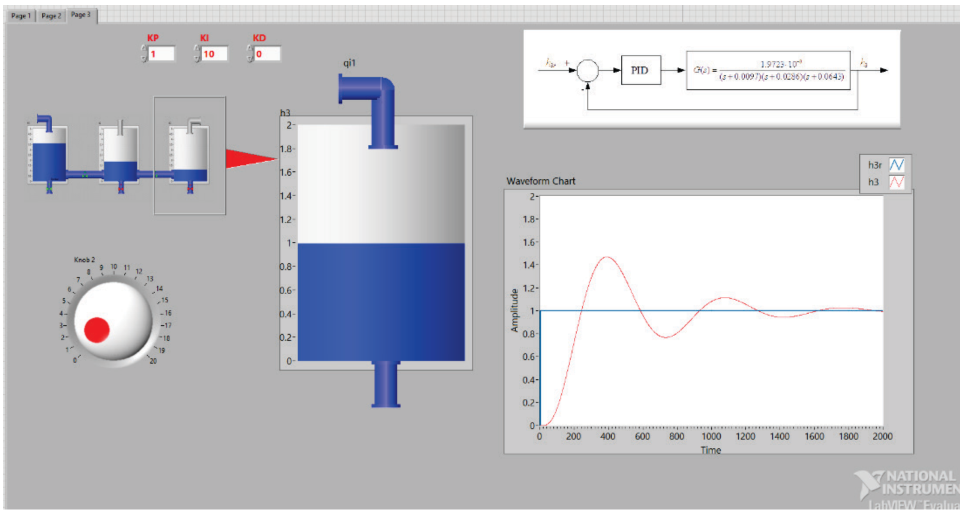

Fig. 8. *The third tab of the LabVIEW Front Panel of TT system*

CONCLUSION

This paper demonstrates how LabVIEW software can be successfully applied in courses on control systems. As an example, it has been used to analyze and control coupled and three-tank systems, to visually represent the filling of the tanks, to form graphical charts of achieved tank levels, followed by frequency analysis of the systems and PID control.

Compared to MATLAB [6, 7], which is most often used for system analysis and synthesis, the authors of this paper are slightly in favor of the application of LabVIEW. In addition to the features already mentioned (visual representation of the system and real-time control monitoring), LabVIEW can also be directly integrated with MATLAB. All code created in MATLAB can be implemented in the corresponding LabVIEW program, thus leveraging all the advantages that MATLAB offers.

The virtual instruments displayed in this paper are effective teaching tools that can serve as laboratory exercises in automatic control courses.

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