MODELLING AND APPLICATION OF A COMPUTER-CONTROLLED LIQUID LEVEL TANK SYSTEM

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ABSTRACT

Liquid level tanks are employed in many industrial and chemical areas. Their level must be keep a defined point or between maximum-minimum points depending on changing of inlet and outlet liquid quantities. In order to overcome the problem, many level control methods have been developed. In the paper, it was aimed that obtain a mathematical model of an installed liquid level tank system. Then, the mathematical model was derived from the installed system depending on the sizes of the liquid level tank. According to some proportional-integral-derivative (PID) parameters, the model was simulated by using MATLAB/Simulink program. After that, data of the liquid level tank were taken into a computer by employing data acquisition cards (DAQs). Lastly, the computer-controlled liquid level control was successfully practiced through a written computer program embedded into a PID algorithm used the PID parameters obtained from the simulations into Advantech VisiDAQ software.

KEYWORDS

Computer-controlled system, Data acquisition card, Level control, PID, Process control

1. INTRODUCTION

Liquid level tanks are used to keep the liquid level a certain point or between particular values in chemical industry. To accomplish this goal, many automatic control methods have been suggested in literature. When these methods carefully inspected, the objective of them are that the changing of the tank level due to the variations of inlet and outlet liquid quantities brings to as quickly and accurately as the defined point [1–12].

A closed loop automatic control system is given in Fig. 1. In practice, some controllers such as computers connected data acquisition cards (DAQs), compact proportional-integral-derivative (PID) devices, programmable logic controllers (PLCs), microcontrollers (μCs) and digital signal processors (DSPs) are commonly utilized.

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The controllers connect the physical and non-physical parts of the systems. Firstly, they take the sensor signal *y*(t) measuring process variables (PV), then compare with a set point *r*(t) (SP) and after that find out an error *e*(t). Lastly, they give an output signal (CV - MV) *u*(t) in order to zeroize the error depending on the used control methods and accumulated errors.

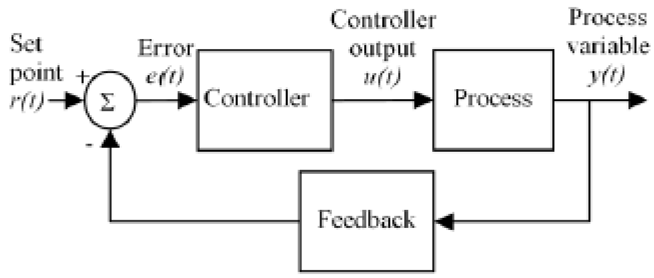


Figure 1. A block diagram of a closed loop automatic control system

The adjusting of the PID parameter values in terms of the used process in controller is essential during the taking into operation. Several methods are used for adjusting of the PID parameter values [1]. There is a specific parameter adjusting for each process. However, the certain adjusting of the PID parameter cannot be achieved to zeroize the error in some cases. The adjusting of parameter values and also the understanding of how each parameter value affects a process are very significant topic for automatic control systems [2].

In this study, in order to turn into application to knowledge, a real computer-controlled liquid level tank control embedded into a conventional PID control algorithm was accomplishedly executed by means of the DAQs. The simulations of the system were performed by MATLAB/Simulink software.

This executed study was presented as follow: In the second section, fundamental control methods were shortly explained. The mathematical model of the system and the simulation practices and results were clarified in the third section. Then, the installation of the developed liquid level control set was displayed in the fourth section. After that, the results and discussion of the experimental applications applied to the mathematical model and the conventional PID algorithm on the system were displayed in the fifth section. Finally, conclusion and future perspectives were given in sixth sections, respectively.

2. FUNDAMENTAL CONTROL METHODS

On-off, proportional (P), proportional-derivative (PD), proportional-integral (PI), and PID controls are fundamental control methods employed to regulate process variable to a specific set point in industrial control systems. These methods were initially realized using mechanical devices and after that, they were designed by pneumatic and analog electronic devices.

In on-off control, a controller opens or closes a final control element in accordance with the case in which the process variable is over or under the set point value. PID control is one of the most basic methods widely used in industrial control systems [3]. The method can be easily applied to the systems with linear and simple structure [4]. In contrast, it is quite difficult to apply nonlinear systems especially when with dead time delays [5]. The general output equations of the PID controller in time and Laplace domains are given as follow:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de}{dt}, \tag{1}$$

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(\tau)\, d\tau + T_d \frac{de}{dt} \right], \tag{2}$$

$$G(s) = K_p + \frac{K_i}{s} + K_d\, s = \frac{K_d s^2 + K_p s + K_i}{s}. \tag{3}$$

Where *u(t)* is the controller output signal fed to the process to be controlled, *e(t)* is the error signal: The difference between the set point and the measured process variable ($e(t) = r(t) - b(t)$), K_p, K_i and K_d are the controller gain parameters, T_i is the integral time constant and T_d is the derivative time constant. The gain parameters K_i and K_d in Laplace domain equation are calculated by the equations $K_i = K_p/T_i$ and $K_d = K_p.T_d$, respectively.

PID control accumulates itself all characteristic features of P control, I control and D control and thus, sometimes called three-term control. This type control is usually used more quickly to stabilize the process controlled by PI control.

2.1. Setting of the PID controller gain parameters

In the setting of PID controller parameters by the Ziegler-Nicholas's (Z-N) sustained oscillation method, the sufficient knowledge and experience about the process makes possible more accurate and faster parameter optimization [6]. This method is experimental and subjects the closed loop control system to an experiment through only proportional gain.

As a result of the applying of the processing procedures to the controller connected to the process, the data required for the calculation of gain parameters are obtained experimentally. Then, these data are placed in the equations in Table 1, recommended by Ziegler and Nichols, and the final values are obtained for the gain parameters K_p, K_i and K_d.

Table 1. According to the Z-N's sustained oscillation method.

Control type	K_p	K_i	K_d
P	0.50 K_u	-	-
PD	0.45 K_u	-	$K_p P_u/8$
PI	0.45 K_u	$1.2K_p/P_u$	-
PID	0.60 K_u	$2K_p/P_u$	$K_p P_u/8$

3. MATHEMATICAL MODEL AND SIMULATION

Before proceeding to the implementation stage, the knowing of how to exhibit a dynamic behavior of liquid level control systems is vital in terms of the determining of a number of parameters related to the system in the design stage [7]. The dynamic behavior of a system can be observed and analyzed through some simulation studies after the obtaining of the mathematical model to the system [8]. As in many physical systems, liquid level control systems also exhibit a non-linear dynamic behavior due to the inherent characteristics [9].

Nevertheless, the theories and theorems in control systems, the most of which can be only applied to linear systems, necessitates to be modeled nonlinear systems as a linear system [10]. When considering small changes in the level control system, the system can be modeled with linear differential equations. In this section, the linearization of a nonlinear liquid level control system model has been discussed. The schematic diagram of the first order liquid level control system is shown in Fig. 2.

This system consists of a tank with an inlet (control) valve and outlet (load) vane and represents a single input single output (SISO) control system. In the system, while the outflow liquid from the tank is manually controlled through the load vane, the inflow liquid into the tank is adjusted by a proportional valve. Normally, the outflow liquid from the tank is a load which is needed by process and continuously changes due to reasons beyond control. Therefore, the inflow liquid into the tank represents a manipulated variable (MV) depending on the liquid level [11]. The outflow liquid from the tank refers to a load or a disturbance. The top of the liquid tank is open and it has a cylindrical structure. The dimensions and some calculations of the liquid level control tank are given in Table 2. The liquid level control system has been modeled taking into account the change in the liquid level, which results from the difference between the inlet flow rate and outlet flow rate of the liquid in the tank. This system can be considered as a simple circuit including a capacity and a resistance.

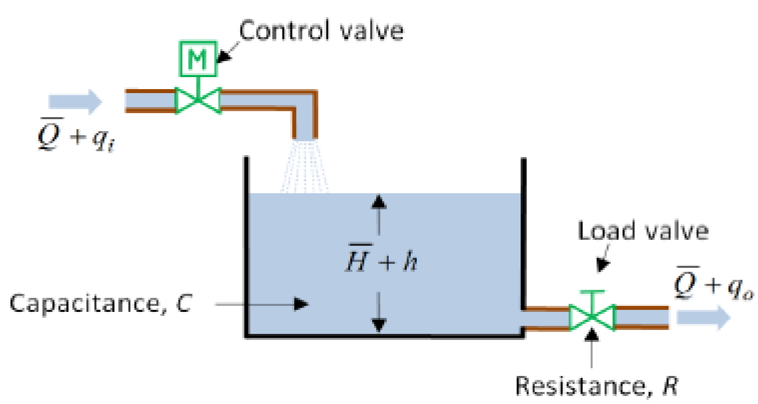


Figure 2. A schematic diagram of the liquid level control system

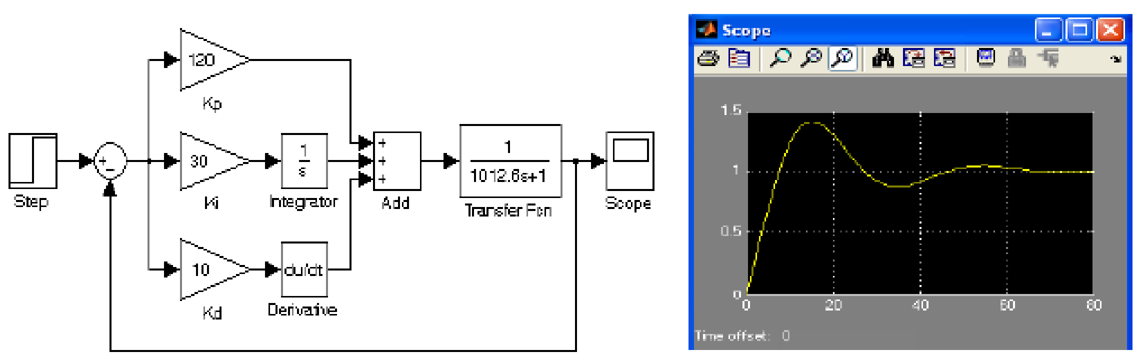
Table 2. The dimensions of the tank

Properties	**Values**
The height of the tank, h (m)	1
The diameter of the tank, d (m)	0.15
The cross sectional area of the tank, A (m^2)	0.5063
The capacitance of the tank, C (m^3/m)	0.5063
The volume of the tank, V (m^3)	0.0176
The maximum liquid flow, Q_o (l/s)	0.5
The maximum liquid flow, Q_o (m^3/s)	0.0005
Resistance, R (s/m^2)	2000

The characteristic equation of the obtained transfer function, simply the denominator of this function, is first order. Therefore, the dynamic behavior of the system is defined in form of time constant [12]. When the calculated the resistance of the liquid level system R and the capacitance C (m^3/m) values in Table 2, the transfer function of the liquid level control system is achieved by:

$$G(s) = \frac{Q_o(s)}{Q_i(s)} = \frac{1}{1012.6s+1} \tag{4}$$

The Simulink model of the whole system, which consists of the mathematical model derived for the liquid level control system and the PID controller with the tuned gain parameters, is given in Fig 3a. The step response of the system is shown in Fig. 3b.



(a) (b)

Figure 3. (a) MATLAB-Simulink model of the liquid level control system with PID controller and (b) Step response of the system

4. APPLICATION

The liquid level set whose experimental setup has been constituted on a prototype and its DAQs are shown in Fig. 4.

(a) (b)

Figure 4. (a) The liquid level control system with computer-controlled and (b) DAQs

The communication between the DAQ cards and the SCADA software on the PC is done by ATS A-4520L DAQ RS232-RS484 converter The RS232 communication protocol is employed in the data communication from the PC to the DAQ cards. Besides, the RS485 communication protocol is used to transfer the data from the DAQ cards to the PC. The DAQ cards are fed by Meanweal power supply of 24 V DC and 100 W. The computer-based PID control algorithm is carried out over the DAQ SCADA program developed by the authors.

The liquid level in the tank is sensed through Foxboro differential pressure transmitter. The transmitter has a measurement range of 0-6.6 kPa. The high pressure input of the transmitter P_H is connected to the bottom side of the cylindrical tank ($P_H = P_{atm} + P_{liquid}$). Also, the low pressure input of the transmitter P_L is left open to the atmospheric pressure ($P_L = P_{atm}$). Since both the top of the tank and the low pressure input of the transmitter are left open to the atmospheric pressure, the transmitter output changes depending on the height of the liquid level in the tank ($P_{difference} = P_H - P_L = P_{liquid}$). Water is used as the process variable to be controlled in the system. The specific gravity of water is about 998.2 kg/m^3 at 1 atm and 20°C. The laboratory temperature, in which there exists the experimental set, is about 20°C.

5. SOFTWARE OF THE DAQ-SCADA SYSTEM

The software of the SCADA system with the DAQ card has been realized by the Advantech VisiDAQ software which is a Windows-based data acquisition, control, analysis and presentation development package. The feedback control algorithm with PID controller is executed on this software developed for the computer-based control. The block diagram of the developed software is given in Fig. 5. In the diagram, while the level information from the A-4011L card is taken by the AI1 block, the output command is sent by the AO1 block to the proportional vane over the A-4021L card The data from the flow transmitter, which is only utilized in monitoring the flow rate of the liquid, is taken by the CTFQ1 block. NTCL1, SPIN1, SPIN2 and SPIN3 tags are used to enter the values of set point, K_p, K_i and K_d, respectively. The PID1 block includes the PID control algorithm which is required to obtain the control signals. The output position of the system is regulated by PRG2 and PRG3 user programs. Preview image of the DAQ-SCADA window which appears on the computer screen when running the software is shown in Fig. 6

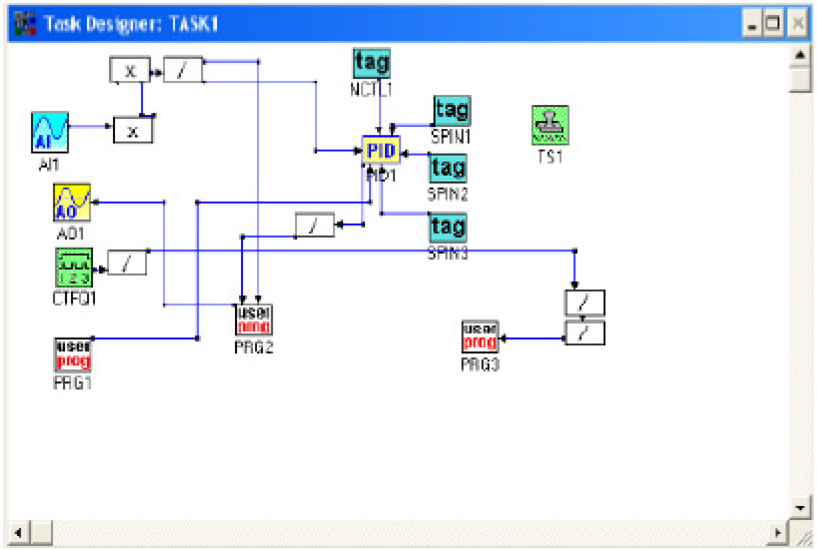


Figure 5. The block diagram of the DAQ-SCADA software

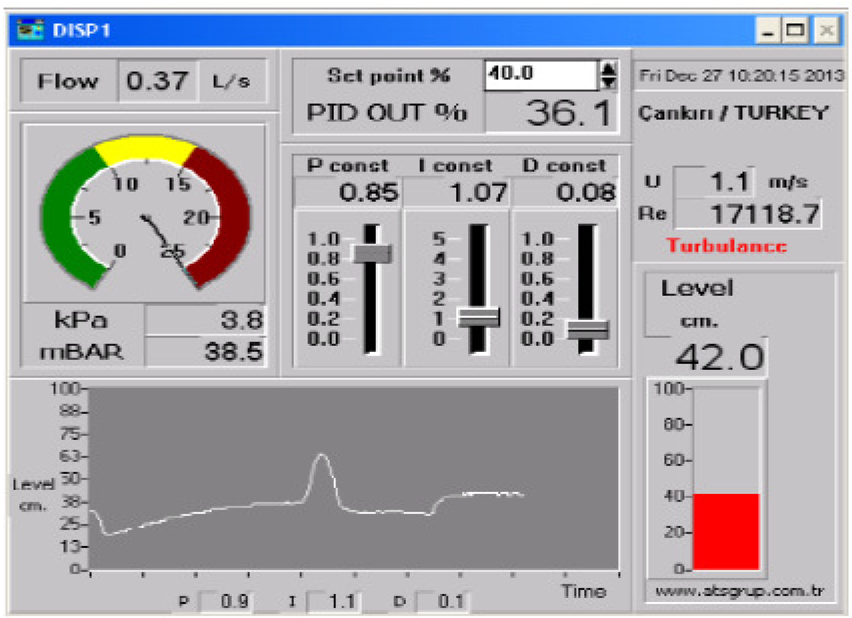
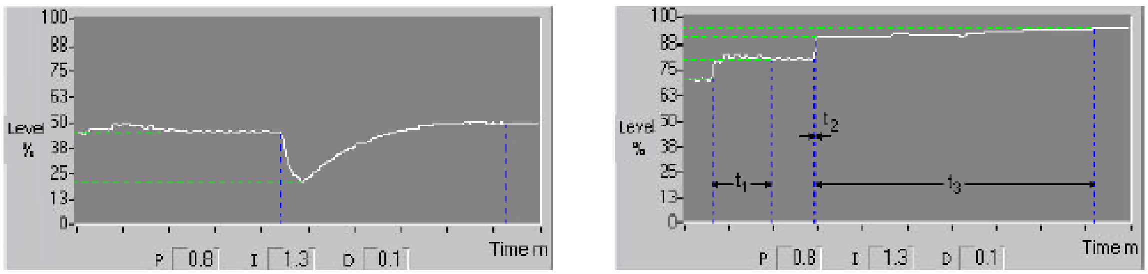


Figure 6. Preview image of the DAQ-SCADA window

6. RESULTS AND DISCUSSION

A SCADA system with DAQ card developed by authors has been used in control of the system, as a computer-based controller. In the system, the PID controller gain parameters have been determined by fine tuning to the gain parameters, which have been previously obtained by the Z-N method, on the SCADA screen given in Fig. 6. According to the mentioned procedure, the tuned optimum controller gains have been obtained as $K_p = 0.80$, $Ki = 1.27$ and $K_d = 0.11$ for the set value of 40% of the process variable. On the SCADA screen, the chart at the bottom of the window shows the change of the process variable versus time and this change is also monitored by a bar graph which is located at the right side of the chart. The vertical and horizontal axes on the chart are scaled as percent (%) and minute, respectively. The maximum deviation of the process variable from the set value, which occurs before the system comes to the steady state, has been measured as 15% in negative direction. The system has reached the steady state at 4 min and the steady state error has been obtained as 0%. The transient response to the parameter changes of the system has been tested over the set point, the output load and the input load. Fig. 7 shows the transient responses to these changes of the liquid level control system which is controlled by the computer-based SCADA system.



(a) (b)

Figure 7. Transient responses for $K_p = 0.80$, $K_i = 1.27$ and $K_d = 0.11$.

For the case that the output load is abruptly dropped while the system is working with the last steady state conditions in last case, the measured transient response is illustrated in Fig. 7a. In that case, a deviation of 23% has happened in the process variable and this has been corrected at about 5 min. The steady state error has been obtained as 0%.

In Fig. 7b, the transient response is illustrated for the cases that the set value of the system is changed from 70% to 80%, from 80% to 90% and from 90% to 95%, consecutively. In the case of the change from 70% to 80% of the set value, the transient response of the system is obtained as about t_1 = 1.20 min and the steady state error has been 2%. When the set value is changed from 80% to 90%, the process variable has come the steady state in a very short time of about t_2 = 5 sec along with the zero steady state error. The system has reached the steady state in a long time about t_3 = 6.20 min along with the zero steady state error when the set value is changed from 90% to 95%.

7. CONCLUSION AND FUTURE PERSPECTIVE

In this study, modeling and application of a computer controlled liquid level tank system was executed for practical applications of conventional PID control method. The results of the experimental studies were clearly carried out the fundamental control algorithms on the liquid level process. By means of the DAQ-SCADA software containing a visual and flexible interface, the process could be controlled by the computer-based control structures and analyzed under the different operating conditions in detail.

For next studies, other control algorithms would be applied on the installed liquid level process. Then the results of these algorithms would be compared with each other as simulation results and experimental results.

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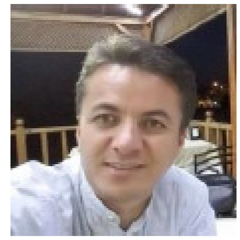

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