TELKOMNIKA, Vol.16, No.5, October 2018, pp.2465~2473
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v16i5.9074

An Adaptive Liquid Level Controller Using Multi Sensor Data Fusion

Santhosh K. V., Bhagya R Navada*
Department of Instrumentation and Control Engineering, Manipal Institute of Technology
Manipal Academy of Higher Education, Manipal, India
*Corresponding author, e-mail: kgbagya@gmail.com

Abstract

This paper describes a design of adaptive liquid level control system using the concept of Multi Sensor Data Fusion (MSDF). Purpose of the work is to design a controller for accurately controlling the level of liquid in a process tank with liquid temperature changes. The proposed objective is obtained by i) implementing a MSDF framework using Pau's framework for measuring liquid level and temperature, ii) analyzing the behavior of actuator output for variation in liquid temperature, and iii) designing a suitable adaptive controller which will produce desired control action for controlling liquid level accurately using neural network algorithms. Outputs from sensors are fused to obtain the fluid level output and also relation of level transmitter output for change in temperature. This information is used by controller to train the neural network so as to tune the controller parameters (proportional gain, integral constant, and differential constant), to drive the actuator. Results obtained show that the system is able to control liquid level within range of 1.915% of set point even with variations in liquid temperature.

Keywords: *labVIEW, level process, MSDF, PID controller*

Copyright © 2018 Universitas Ahmad Dahlan. All rights reserved.

1. Introduction

Industries like pharmaceutical, food, dairy, paints, etc. often involve processes where one or more elements are mixed to obtain a product. It is often seen that these processes need to be carried out in a very controlled manner. The control might be in terms of the external environment or in terms of the elements which are to be mixed. In case of a process involving liquid mixtures, some of the parameters which need to be controlled are, liquid level, flow rate, density, viscosity, and temperature.

Several researchers have reported controller technique for controlling the above discussed parameters like in [1], an algorithm is reported for controlling the temperature change in a gas turbine. Various controllers used in chemical reactors are discussed in [2]. Liquid level in a simulated model of a conical tank is controlled using a Proportional Integral (PI) controller is reported in [3]. In [4], a controller model is designed in simulation for control of pH with disturbances in a chemical process. A system for controlling feed load changes in alcohol fermentation is designed using a PID controller in [5]. In [6], a design for controlling flow of air in wings by modelling the variation in structure using an optimization function is discussed. A control system for control of liquid level in a nuclear plant using a PI controller is reported in [7]. In [8], a technique is designed for control of liquid level in a coupled tank system using a sliding mode control system.

Switching type of liquid level controller for casting plant is reported in [9]. A control algorithm for the modelled beer fermentation process in a multi-stage process is discussed in [10]. A control algorithm is designed to control flow in a microfluidic system using model reference dscontrol system in [11]. In [12], liquid level control system implementation using a PID controller is reported. Design of a nonlinear predictive controller for controlling level of liquid in a coke fractionation tower is reported in [13]. In [14], a controller design technique for both liquid level and temperature in a spherical shape tank is reported. In [15], a control algorithm for a nonlinear liquid level system using ANN based reinforcement technique is reported. Implementation of a PID controller for liquid level control in an interacting tank system is discussed in [16].

Received February 23, 2018; Revised July 27, 2018; Accepted August 10, 2018

Design of controller for a multivariable liquid level process is reported in [17]. A neural network based switching controller design for evaporation system is reported in [18]. Design of predictive proportional control system for control of liquid level in industrial coke fractionation tower using state space analysis is reported in [19]. Different adaptive control techniques have been reported on recent research articles some of the work have been reported here. An adaptive method of disturbance compensation using state observer technique is reported in [20] for a permanent magnet motor.A disturbance control technique using disturbance observer and neural network is reported in [21] for a nonlinear and uncertain system. An adaptive control technique is developed in [22] for nullifying the effect of variation in unknown parameters. Disturbance rejection in non linear system is achieved by developing an adaptive control technique using output feedback in [23]. An adaptive technique with fuzzy tracking is reported in [24] for controlling of uncertain disturbaces using adaptive observer.

This paper proposes a technique for design of controller using the data of both the process variable (liquid level) and disturbance variable (temperature). The data of process parameters derived from different sensors are fused using multi sensor data fusion framework. Fusion framework is used to analyze the effect of temperature on the process and produce the tuned values of PID controller coefficients (K_P, K_I, and K_D) to control liquid level independent of any variations in liquid temperature.

Organization of the paper is done with discussion on introduction in first Section. In second Section description of experimental setup of proposed technique is reported. In third section problems faced with available liquid level control is analyzed, followed by proposed solution. Analysis of results obtained is discussed in fifth section. Finally, conclusion is reported in the last section.

2. Experimental Setup

A laboratory setup for liquid level control system is designed. The designed model works on the principle of varying inlet liquid flow rate keeping the outlet flow constant (i.e. to increase liquid level, inlet flow rate should be more than outlet and decrease inlet flow rate for decreasing level). Process inlet flow rate is controlled by a pneumatic control valve. The control signal for the pneumatic control valve is standard 3-15psi signal, derived from an I/P converter. I/P converter is actuated from the signal of controller which is 4-20mA. In the proposed work a standard PID controller is used for this purpose. The controller designed is a soft controller developed on LabVIEW platform. Process variable for controller is given from the level transmitter present in the tank, whose liquid level is controlled. MODBUS connector is used to communicate between the PC and process station.

3. Process Analysis

Analysis of the liquid level process system in open loop shows that it behaves as a first order system with a delay [10]. General representation of a first order system with delay is as shown in equation 1.

$$G(s) = \frac{K}{Ts+1} e^{-\tau s} \quad (1)$$

where; K=System gain

T=Time constant of the first order system

T=Time delay at which variable begins to change for the input provided.

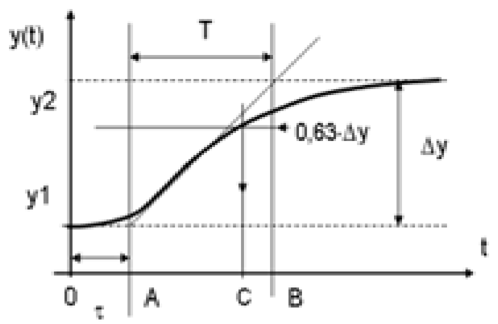
The first step in analyzing the system would be to identify the values of the system parameters (K, T, and τ) for the system considered in this experiment. Several researchers have reported many system identification approaches based on black box design (identification without any information about the system), white box design (first principle model), and grey box design (with some information about the system). In the proposed technique we prefer to go ahead with grey box design as we know that the system is first order system. Many techniques are available for identification of system parameters in a grey box design, in the proposed technique widely used [26] two point methods is followed to compute the system parameters.

3.1. Two Point Method

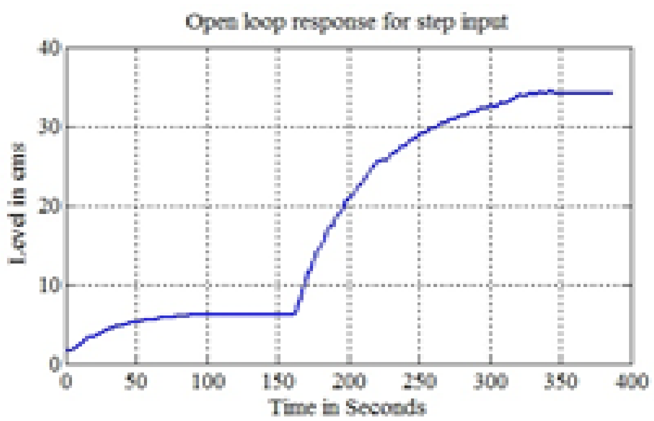
Two point method can be best explained using the step response for the system. Let us consider step response of a first order system, it is typically of the form shown in Figure 1. It is said that the constants K, T can be computed by considering the process times at 28.3% and 63.2% of output [25-29] as shown in equation 2.

$$T=1.5(T2-T1)\ s \tag{2}$$

Now, the open loop step response is analyzed to find the transfer function of the given system. The step response plot of the open loop system obtained is as shown in Figure 1(b). The system is subjected to step input at 154s. Further the graph shows the responses similar to that of standard characteristics. On comparing Figure 1 (a) and Figure 1 (b) the model derived is represented as G(s)=4.76/(51s+1).



(a)



(b)

Figure 1. Step response of (a) generic first order system, (b) actual system

3.2. PID Tuning

The next step will be to design a controller for control of flow. From the basic idea of the system it is understood that the system is a quick process, and PID is a suitable controller. The design of controller involves the task of finding the proportional gain (K_P), Integral gain (K_I), and Differential gain (K_D). Tuning of the controller parameters are carried on by Zeigler Nicholas method [30-31]. Once the controller parameters are computed it is subjected to test in real time. The result obtained from the designed controller is shown with the set point variation in Figure 2. From the Figure 2(a) it is seen that the controller output was able to track the given set point in level accurately, with a very small offset. The condition shown was for a constant liquid at room temperature. Now, if the temperature of liquid is varied from room temperature to 20 ^oC, will the system performance be same/ altered?

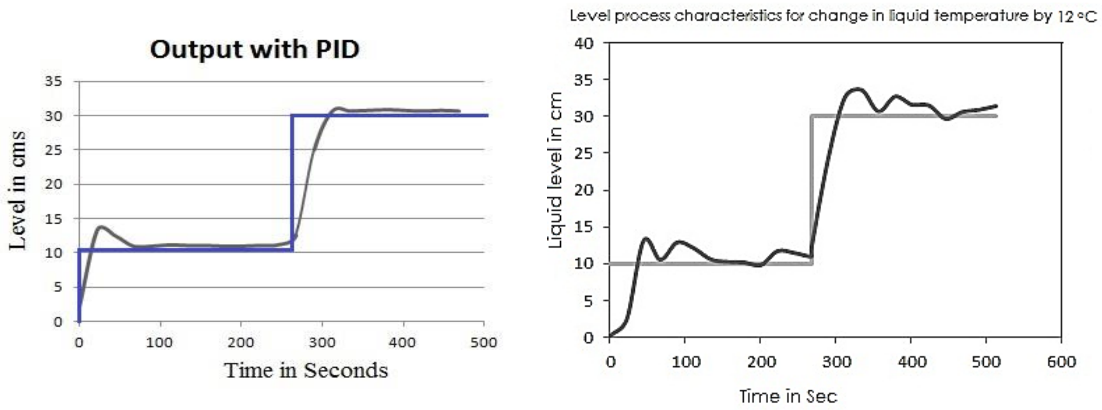
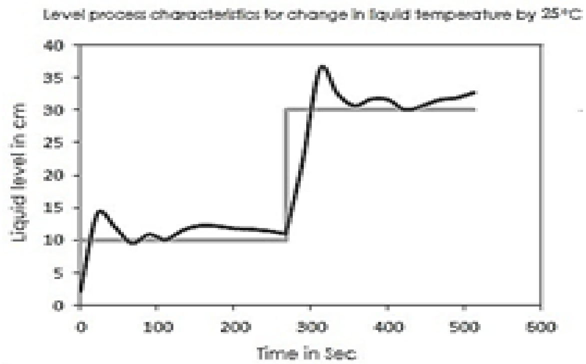
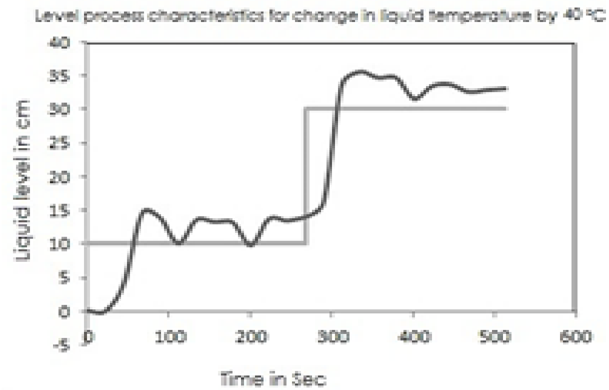


Figure 2. Process characteristics for step response with a) tuned PID controller b) for varying liquid temperature to 12 oC

To check the performance of the designed liquid level control system for variation of liquid temperature, liquid of varying temperature is used. From the graphs shown in Figure 2 (b) and Figure 3 it is evident that, the controller fails to track the set point on variation of liquid temperature. Secondly the error produced is also large as compared to the output at 20 ^{o}C. An efficient robust controller is one which tracks the process variable even with variations in noise [32]. Considering the effect of temperature as noise on the liquid level control system, a controller is designed which would control the output even when the liquid temperature is varied.



(a)



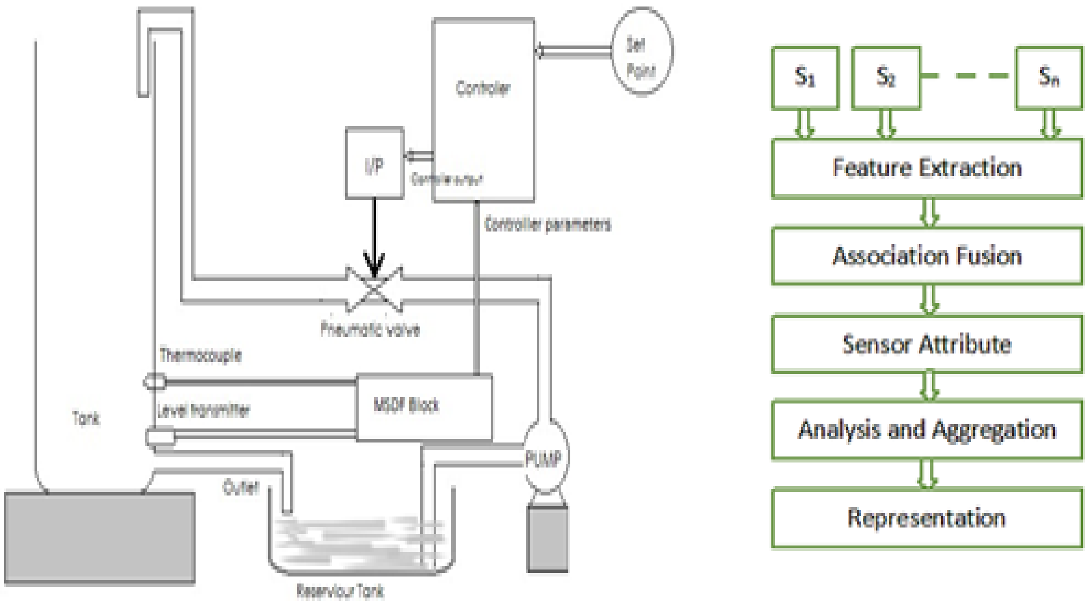
(b)

Figure 3. Process characteristics at liquid temperature of (a) 25 oC, (b) 40 oC

4. Problem Solution

The next step of the work is to design an adaptive controller using the concept of MSDF. Adaptive controller is designed in a way to produce coefficients of PID controllers which tune dynamically with variation in liquid temperature. An additional temperature sensor thermocouple is used along with orifice flow sensor. Fusion process uses Pau's framework. Modified schematic diagram of the proposed level process is as shown in Figure 4(a).

The first step towards execution of proposed work is to design a multi sensor data fusion framework with thermocouple and level transmitter. Pau's framework is followed in this paper to achieve the desired changes in PID coefficient gain based on variation of liquid temperature as measured using thermocouple. The schematic of Pau's framework is shown in Figure 4(b). Pau's framework is considered here because it is a behavioral model, which can be made dynamically adaptive.



(a) (b)

Figure 4. (a) Schematic diagram of proposed controller design, (b) Pau's framework

4.1. Feature Extraction

In this stage the feature from both the sensor is extracted, the data extracted from thermocouple and level transmitter will all be of different type and magnitude. Both the sensor data are arranged to a common representation format. Radiometric normalization technique is used in this work to convert the output from both the sensor to a value of 0 to 1 [33].

4.2. Association, Analysis and Aggregation

Neural network algorithm is used to for the purpose of association and analysis. The first step in developing a neural network model is to create a database. Database consists of both input and target vectors. Input vector is the output of the level transmitter and temperature for variation in liquid temperature, for different values of liquid level. The target matrix is the values of PID coefficients for variations in temperature.

4.3. Training

For training a multi-layer, perceptron based neural network model is considered. Back propagation network architecture with Artificial Bee Colony algorithm is used for the purpose [34, 35]. Table 1 shows the data matrix used for training. Training is carried out to achieve least mean square error.

Table 1. Data Matrix for Training Neural Network

Input data set			Target data set			
	Thermocouple o/p	Level transmitter o/p at liquid level of 50%		K_p	K_I	K_D
30 °C	0.02	0.028	30 °C	34.6	189	0.01
32 °C	0.058	0.079	32 °C	34.0	192	0.01
34 °C	0.89	0.142	34 °C	33.5	194	0.01
⋮	⋮	⋮	⋮	⋮	⋮	⋮
90 °C	0.999	0.978	90 °C	31.6	207	0.01

4.4. Front Panel VI of Proposed Work

The front panel is configured to acquire data from the process through MODBUS. Further the user can choose between manual and auto mode. In manul mode, user needs to feed the controller parameters to obtain the desired output. The proposed work is designed to function while the system is in auto mode. Under this setting, a neural network programming of MSDF architecture is developed for having sensor output adaptive for variations in liquid temperature. In the last stage tuning of K_P, K_I, and K_D is done for controlling of liquid level. The front panel of VI for proposed work is as shown in Figure 5 [36].

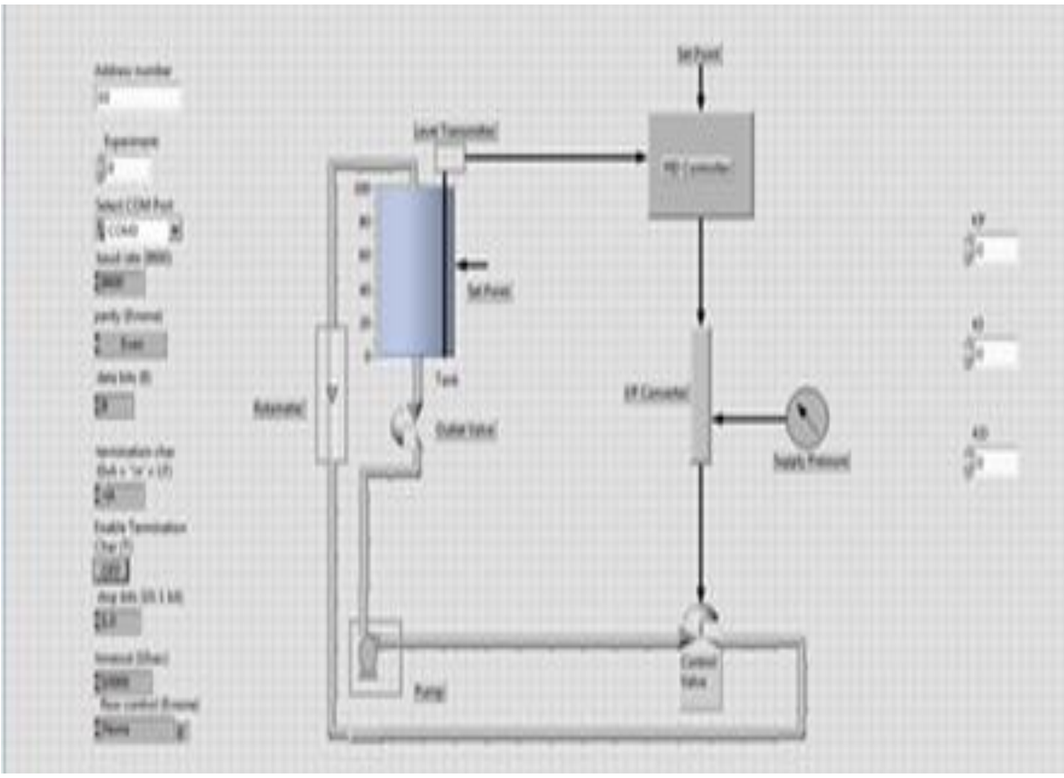


Figure 5. Front panel VI of proposed work

5. Results and Analysis

Designed technique was tested with several test cases by varying the set-point, and liquid temperature within the desired range. The results obtained from the proposed technique are tabulated in Table 2. Response characteristics for a step input change with variation in liquid temperature for a test case is plot and shown in Figure 6. The percentage error obtained for every test case is tabulated along with set-point Vs Output characteristics is plot in Figure 6. The root mean square of percentage error thus obtained from proposed system is found to be 1.915%.

Table 2. Results Obtained from Real Life Testing of Proposed Technique

Sl. No.	Set point in mm	Liquid temperature in ^oC	Output level obtained in mm	% Error
1	30	27	32	-6.67
2	30	48	31	-3.33
3	30	66	31	-3.33
4	80	35	79	1.25
5	80	20	80	0.00
6	80	50	78	2.50
7	95	55	94	1.05
8	95	22	94	1.05
9	95	80	96	-1.05
10	140	40	143	-2.14
11	140	60	143	-2.14
12	140	27	142	-1.43
13	185	38	188	-1.62
14	185	55	187	-1.08
15	220	70	218	0.91
16	220	20	217	1.36
17	255	35	254	0.39
18	255	85	257	-0.78
19	290	70	294	-1.38
20	290	24	293	-1.03
21	290	95	294	-1.38
22	340	22	342	-0.59
23	340	55	338	0.59
24	340	77	341	-0.29
25	385	64	388	-0.78
26	385	35	384	0.26
27	400	44	400	0.00
28	400	58	397	0.75

6. Conclusion

In the reported paper an attempt was made to design an adaptive controller for controlling level of liquid in a tank even with variations in liquid temperature. Controllers are designed to make the process variable equal to the set point. In the reported paper, Proportional +Integral+ Derivative (PID) controller scheme is considered for control of liquid level in tank. Tuning of controller coefficient is performed using Ziegler Nicholas tuning technique based on open loop response of process. Once tuned, the controller was able to track the set point given by user. But if the liquid temperature is varied, controller was unable to track the desired set point.

An adaptive controller using concept of multi-sensor data fusion was designed to vary the tuning coefficient with respect to variation in liquid temperature so as to track the liquid level accurately. Designed system was tested with varying input conditions, and it was found that proposed controller was able to track liquid level accurately with a root mean square error of 1.915% for varying liquid temperature. It is very clear that the reported work achieved the objective of set point tracking with noise interference.

References

[1] Khalilpour M, Valipour K, Shayeghi H, Razmjooy N. Designing a robust and adaptive PID controller for gas turbine connected to the generator. *Research Journal of Applied Sciences, Engineering and Technology*. 2013; 5(5): 1544-51.

[2] Smets IY, Claes JE, November EJ, Bastin GP, Van Impe JF. Optimal adaptive control of (bio) chemical reactors: past, present and future. *Journal of process control*. 1 Oct 2004; 14(7): 795-805.

[3] Ram AG, Lincoln SA. A model reference-based fuzzy adaptive PI controller for non-linear level process system. *International Journal of Research and Reviews in Applied Sciences*. Feb 2013; 4(2):477-86.

[4] Vijayakumar P, Unnikrishnan PC. Intelligent Control Using Adaptive Pid Controller. *International Journal of Engineering Science and Technology*. 1 Feb 2014; 6(2): 32-39.

[5] Folly R, Berlim R, Salgado A, França R, Valdman B. Adaptive Control of Feed Load Changes in Alcohol Fermentation. *Brazilian Journal of Chemical Engineering*. Dec 1997; 14(4).

[6] Cattafesta L, Tian Y, Mittal R. Adaptive control of post-stall separated flow application to heavy vehicles. In The Aerodynamics of Heavy Vehicles II: Trucks, Buses, and Trains. Springer, Berlin, Heidelberg. 2009: 151-160.
[7] Yongsheng Q, Yong W, Nan S. *Design of liquid level control system of nuclear power plant. InElectronic Measurement & Instruments (ICEMI),* IEEE 11th International Conference on 16 Aug 2013; 2: 583-586.
[8] Abbas H, Asghar S, Qamar S. *Sliding mode control for coupled-tank liquid level control system. InFrontiers of Information Technology (FIT),* 10th International Conference IEEE on 17 Dec 2012: 325-330.
[9] Krajewski W, Miani S, Morassutti AC, Viaro U. Switching policies for mold level control in continuous casting plants. *IEEE Transactions on Control Systems Technology.* Nov 2011; 19(6): 1493-503.
[10] Shujiao BI, Feng D. *Modeling for liquid-level control system in beer fermentation process*. In Control Conference (CCC) IEEE, 31st Chinese 25 Jul 2012: 1739-1744.
[11] Wei W, Guo S. *A developed microfluidic system with model reference adaptive control. In Mechatronics and Automation (ICMA),* International Conference IEEE on 5 Aug 2012: 403-408.
[12] Mehta SA, Katrodiya J, Mankad B. *Simulation, design and practical implementation of IMC tuned digital PID controller for liquid level control system*. In Engineering (NUiCONE), Nirma University International Conference IEEE on 8 Dec 2011: 1-5.
[13] Zhang R, Xue A, Wang S. Modeling and nonlinear predictive functional control of liquid level in a coke fractionation tower. *Chemical engineering science*. 1 Dec 2011; 66(23): 6002-13.
[14] Xiong M, Gong H, Qian Z, Zhao CL, Dong X. Simultaneous measurement of liquid level and temperature based on spherical-shape structures and long period fiber grating. *Sensors and Actuators A: Physical.* 1 Mar 2016; 239: 196-200.
[15] Noel MM, Pandian BJ. Control of a nonlinear liquid level system using a new artificial neural network based reinforcement learning approach. *Applied Soft Computing*. 1 Oct 2014; 23: 444-51.
[16] Kadu CB, Patil CY. Design and Implementation of Stable PID Controller for Interacting Level Control System. Procedia Computer Science. 1 Jan 2016; 79: 737-46.
[17] Dulău M, Dulău TM. *Multivariable System with Level Control.* Procedia Technology. 1 Jan 2016; 22: 614-22.
[18] Wang Y, Chai T, Fu J, Sun J, Wang H. Adaptive decoupling switching control of the forced-circulation evaporation system using neural networks. *IEEE Transactions on Control Systems Technology.* May 2013; 21(3): 964-74.
[19] Zhang R, Cao Z, Lu R, Li P, Gao F. State-space predictive-p control for liquid level in an industrial coke fractionation tower. *IEEE transactions on automation science and engineering*. Oct 2015; 12(4):1516-24.
[20] Wu YJ, Li GF. Adaptive disturbance compensation finite control set optimal control for PMSM systems based on sliding mode extended state observer. *Mechanical Systems and Signal Processing*. 1 Jan 2018; 98: 402-14.
[21] Li R, Chen M, Wu Q. Adaptive neural tracking control for uncertain nonlinear systems with input and output constraints using disturbance observer. *Neurocomputing*. 26 Apr 2017; 235: 27-37.
[22] Zhang C, Gan M, Chen J, Chen C. Adaptive Optimal Control Based on Parameter Estimation for Servomechanisms. IFAC-PapersOnLine. 1 Jul 2017; 50(1): 7064-9.
[23] Wang Z, Yuan J, Wei J. Adaptive output feedback disturbance attenuation control for nonlinear systems with non-harmonic multisource disturbances. *Optik-International Journal for Light and Electron Optics.* 1 May 2017; 137: 85-95.
[24] Cui Y, Zhang H, Qu Q, Luo C. Synthetic adaptive fuzzy tracking control for MIMO uncertain nonlinear systems with disturbance observer. *Neurocomputing*. 2 Aug 2017; 249:191-201.
[25] Sundaresan KR, Prasad CC, Krishnaswamy PR. Evaluating parameters from process transients. Industrial & Engineering Chemistry Process Design and Development. 1978 Jul; 17(3): 237-41.
[26] Chen CT. Analog and digital control system design: transfer-function, state-space, and algebraic methods. Oxford University Press, Inc.; 1995 Oct 1.
[27] Bi Q, Cai WJ, Lee EL, Wang QG, Hang CC, Zhang Y. Robust identification of first-order plus dead-time model from step response. *Control Engineering Practice.* 1 Jan 1999; 7(1): 71-7.
[28] Chen CL. A simple method for on-line identification and controller tuning. *AIChE journal.* 1 Dec 1989; 35(12): 2037-9.
[29] Oldenbourg RC, Sartorius H. The dynamics of automatic controls. American Society of Mechanical Engineers; 1948.
[30] Rake H. Step response and frequency response methods. InSystem Identification 1981: pp. 519-526.
[31] Xiaoping H, Chao W, Wenhui Z, Jing M. Self-learning PID Control for XY NC Position Table with Uncertainty Base on Neural Network. *TELKOMNIKA (Telecommunication Computing Electronics and Control).* 1 Jun 2014; 12(2): 343-8.
[32] Balaji V, Maheswari E. Model Predictive Control Strategy for Industrial Process. Bulletin of Electrical Engineering and Informatics. 5 Mar 2012; 1(3): 191-8.

[33] Liu X, Jiang S. Research on DS evidence reasoning improved algorithm based on Data Association. *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*. 1 Sep 2013; 11(9): 5037-5043.
[34] Golub GH, Van Loan CF. Matrix computations. JHU Press; 27 Dec 2012.
[35] Kelley CT. Iterative methods for optimization. Siam; 1999.
[36] Chakravarthi MK, Venkatesan N. Experimental validation of a multi model PI controller for a non linear hybrid system in LabVIEW. *TELKOMNIKA (Telecommunication Computing Electronics and Control).* 1 Jun 2015; 13(2): 547-55.