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Flow and level control of coupled four tanks system using artificial neural network

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Abstract
This paper presents a nonlinear artificial neural network (ANN) control design for the nonlinear coupled four tanks system. The objective is to control the level of the four tanks at desired values and to isolate the uncertainties of the nonlinear tank system. A leakage factor is also considered in the system model. The robustness of the proposed control against the disturbances is considered. The ANN is highly nonlinear, has more flexibility and robust to tackle the undesired disturbances of the coupled four tank system. The simulation results show that the ANN has good stability performance.

1. Introduction

Every system in today world has many applications especially industrial applications. The liquid level control has also industrial application and has somehow got extreme importance especially in petrochemical industries, pharmaceutical and food processing industries. The basic task of controller is to provide proper output. Due to this reason when the level controller works well then final product will be error free and will be accurate, hence the quality of the final product depends on the accuracy of the level controller. In industries there is problem of controlling some specific system, so in industries the level control systems with large dead time are difficult to control. For the controller a point is to be set which we call set point and the controller track that set point and the controller improve their ability to adopt a new set point values automatically [1].

There are different controllers that operate in the world. The proportional-integral-derivative (PID) controller operates the majority of the control system. It is cleared that PID is simple and clear because it is reported that more than 95% of the controllers in the industrial process control applications are of PID type as no other controller match the simplicity, clear functionality, applicability and ease of use offered by the PID controller. The PID controller is used for a wide range of problems like motor drives, automotive, flight control, instrumentation, etc.,[15]. PID controller involves three tuning parameters K_p, K_i and K_d. Proportional gain K_p is selected based on the present error, integral gain depends upon on the accumulation of the past error and derivative gain K_d depends on the prediction of the future errors, based on the rate of change of error. All together are used to affect the process via a final control element to meet the process requirement [1, 2]. In order to overcome some problems that faced by PID controller, the other type of control methods can be developed such as Linear-Quadratic Regulator (LQR) optimal control. LQR is one of the best techniques in a sense of performance. It overcomes the error of PID. It is such a control scheme that gives the best possible performance with respect to some given measure of performance. Level control of coupled tanks using sliding mode control is presented in [15]. The performance measure is a quadratic function composed of state vector and control input. LQR also a linear controller and our system is nonlinear so the only way to achieve better performance is to use artificial neural network controller instead of conventional controllers. The neural network controller is developed based on the human skill and experiences about the system [3, 4]. There are some advantages due to which we use artificial neural network controller approach:

- Neural network have a built-in capability to adapt their synaptic weights to changes in the surrounding environment.
- It exhibits a graceful degradation in performance rather than catastrophic (extremely harmful) failure.
- Mapping input signal to desired response – supervised learning.
- An ANN can create its own organization or representation of the information it receives during learning time (Unsupervised Learning).

Artificial Neural Network controller is such type of controller that can modify its behavior in response to changes in the dynamics of the process and the disturbances[13]. Recently, level control of coupled tank using neural network is presented by [9-6]. Also, the fuzzy logic is very powerful tool to control level of coupled tanks system [10]. So in short artificial neural network controller is a very common and important techniques used for coupled four tanks system. It is a lot more different from the other techniques. The main difference between artificial neural controller and PID controller is that PID is a controller used for the linear system but the artificial neural network logic controller is used for the nonlinear systems. The main advantage of the artificial neural network controller is that it updates its parameter by itself. We need to change the learning rate only and the parameters will be change by itself. Artificial neural network controller doesn't need to understand the physics or modeling of plant [12].

In this study, ANN control strategy is developed for the level control of coupled four tanks system. This paper is divided into five sections. Section II gives the brief description of coupled four tank system. In section III discuss the detail modeling of ANN control scheme. Finally, sections IV and V give the simulation results and conclusion of the study work.

2. Coupled Four Tank Model

Our adapted system is coupled four tank system. The schematic diagram of tank system is shown figure 1.

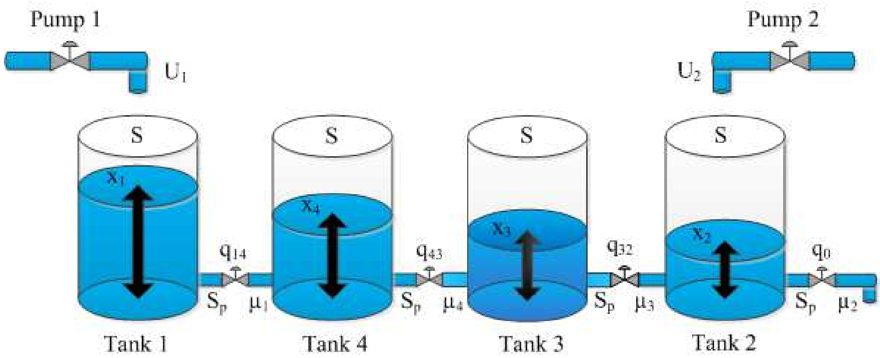

Figure 1. *Coupled four tanks system*

Figure 1 is the system diagram of the coupled four tank system. It has two inputs which are coming from pump1 and pump2 and one output which is going out from tank2. Our system has four levels. S is the cross sectional area of the tanks which is equal for the four tanks. S_p is the surface area of the pipes which is equal for all pipes. u_1 and u_2 are input flow rates which are coming from the two pumps. x_1 , x_2, x_3 and x_4 are levels in four tanks. μ_1, μ_2, μ_3, and μ_4 are the flow coefficients or viscosity of the liquid.

The mass balance equations for the above system is

$$U_1(t) - q_{14}(t) = S\frac{dh_1}{dt} \quad (1)$$

$$U_2(t) + q_{32}(t) - q_0(t) = S\frac{dh_2}{dt} \quad (2)$$

$$q_{43}(t) - q_{32}(t) = S\frac{dh_3}{dt} \quad (3)$$

$$q_{14}(t) - q_{43}(t) = S\frac{dh_4}{dt} \quad (4)$$

Flow rate equation for Coupled Four Tank system can be expressed as [5, 6]:

$$q_{ij} = \mu_i S_p sign(x_i - x_j)\sqrt{2g\left|x_i - x_j\right|} \quad (5)$$

Equation 5 is the general flow equation for tanks.

Similarly the flow from tank 1 to 4, tank 4 to 3, 3 to 2 and outflow from tank2 can be expressed as [9: 6].

$$q_{14} = \mu_1 S_p sign(x_1 - x_4)\sqrt{2g\left|x_1 - x_4\right|} \quad (6)$$

$$q_{43} = \mu_4 S_p sign(x_4 - x_3)\sqrt{2g\left|x_4 - x_3\right|} \quad (7)$$

$$q_{32} = \mu_3 S_p sign(x_3 - x_2)\sqrt{2g\left|x_3 - x_2\right|} \quad (8)$$

$$q_0 = \mu_2 S_p sign(x_2)\sqrt{2g\left|x_2\right|} \quad (9)$$

From these flow rates equation we create the nonlinear equation for our system.

$$\dot{x}_1 = -C_1 sign(x_1 - x_4)\sqrt{2g\left|x_1 - x_4\right|} + \frac{U_1 + w_1}{S} \quad (10)$$

$$\dot{x}_2 = C_3 sign(x_3 - x_2)\sqrt{2g\left|x_3 - x_2\right|} - C_2 sign(x_2)\sqrt{\left|x_2\right|} + \frac{U_2 + w_2}{S} \quad (11)$$

$$\dot{x}_3 = C_4 sign(x_4 - x_3)\sqrt{2g\left|x_4 - x_3\right|} - C_3 sign(x_3 - x_2)\sqrt{\left|x_3 - x_2\right|} \quad (12)$$

$$\dot{x}_4 = C_1 sign(x_1 - x_4)\sqrt{\left|x_1 - x_4\right|} - C_4 sign(x_4 - x_3)\sqrt{\left|x_4 - x_3\right|} \quad (13)$$

Above equations show the change in levels of tanks 1, 2, 3 and 4 respectively.

2.1. Parameters for Coupled Four Tanks Model

The coupled four tanks system has different parameters like surface area of tanks, surface area of pipes, input flow rates, maximum level in Tanks and viscosity [11]. The integral values which we used in our simulation are narrated in the table below.

***Table 1.** Parameters of coupled tanks*

Parameter Values Of Three Tanks System			
Parameter	**Description**	**Units**	**Nominal Values**
S	Surface area of tanks	m^2	0.01540
S_p	Surface area of pipes	m^2	0.00005
$u_{1\max}, u_{2\max}$	Input flow rates	m3/sec	0.00012
x1 , x2, x3, x4	Maximum level in Tanks	m	0.62
μ1, μ2, μ3, μ4	Viscosity or flow coefficients	-------	0.5,0.675,0.5

3. Artificial Neural Network

The neural network is adaptive and nonlinear in nature which provides robust performance for the parameter variations and load disturbances. To efficiently An artificial neural network commonly known as "neural network" has been motivated right from its inception by the recognition that the brain works in a completely different way from the conventional digital computer. The brain is a parallel computer system very complex and non-linear information processing system). The brain has the ability to organize their structural components known as neurons and to perform certain tasks (such as pattern recognition, motor control and perception) many times faster than the fastest digital computer in existence today. For example, human vision, this is a task of processing information. And the function of the visual system to provide a representation of the environment that surrounds us and, above all, to provide the information needed to interact with the environment. To be more specific, the brain performs routinely reconnaissance of perception (for example, recognize a familiar face embedded in an unknown scene) in approximately 100 to 200 ms, while the much less complex tasks can take days on a conventional computer. In summary, the artificial neural networks process information differently than traditional computers. Calculation is performed in parallel through a large number of simple processing units, rather than in the way traditional serial computer architectures. Similarly, information is distributed throughout the network, instead of being located in a place or a specific address. In fact, neural computing is sometimes called parallel distributed processing to emphasize how it differs from traditional computing. In addition, learning algorithms can be defined simply change the connections between the units (and hence processing), as a result of an experience. For scientists and engineers, neural networks are a paradigm for solving problems; it is often a great success, especially in domains that are not well understood or subject to uncertainty. For linguists, cognitive scientists, psychologists and philosophers, neural networks offer a metaphor for how the cognitive processes occur such as perception, attention, learning, memory, language, reasoning and thinking. And neuroscientist's mathematical simplification of the physiological processes allows the analysis of large networks of unity and gives an idea of how the myriad interactions of neurons produce the behavior.

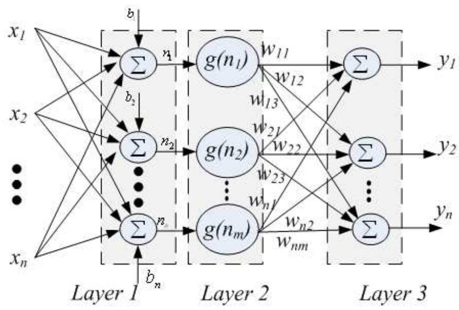

***Figure 2.** Neural network structure*

- Layer 1:It represents the input x_i ; i=1,2,3
- Layer 2: it is hidden layer where bias (b_i) is added with input x_i ; $n_i = \sum_{i=1}^{3} x + b_i$; j=1,2,3.

It also represents the activation layer (sigmoid function) $g(n_i) = \frac{1}{1+e^{-nj}}$

And layer 2 is fully connected to each node of the layer 3 though weights.

- Layer 3: it represents the output layer of the neural network. $y_k = \sum_{j=1}^{3} w_{jk} \left(\frac{1}{1+e^{\left(\sum_{i=1}^{3} x+b_j\right)}} \right)$

and w_{jk} is the weight connection where jk shows the strength of the neuron j on neuron k.

The closed loop law of the proposed control along with steam boiler is shown in figure 3. The parameters of ANN control are updated online and adaptively by using gradient descent algorithm.

Update parameter rules

The activation function which is used in this proposed multi-layer neural network is sigmoid function which limits the desired output values between [0,1] and the bias value used is according to standards (bias value of 1).

The error signal at the input of neural network (neuron in figure 2 is defined by

$$e_k(n) = d_k(n) - x_k(n) \quad (14)$$

Where $d_k(n)$ is the targeted output and $y_k(n)$ is the computed output.

The mean square error is given by:

$$E(n) = \frac{1}{2}\sum_{i=1}^{n} e_k^2(n)$$

The weight equation is given by:

$$w_{kj}(n+1) = w_{kj}(n) + \eta\delta_j(n)x_i(n) \quad (15)$$

Where

$$\delta_j(n) = \varphi'(\upsilon_j(n))\sum_k e_k(n) w_{kj}(n)$$

We can minimize the error or strengthen the weights connections by adjusting learning rate η. We will compare the actual response with our desired response and will adjust η until we get our desired response.

The closed loop diagram for the ANN control scheme is shown in figure 3 below.

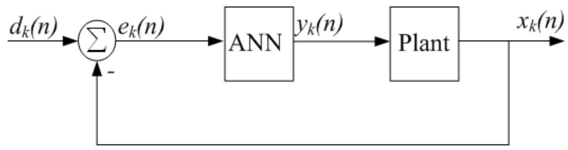

Fig 3. *Closed loop of proposed control design*

4. Simulation Results

In this section simulation results for the proposed ANN control strategy are given. First the open loop response of coupled four tanks system is given in figure 4.

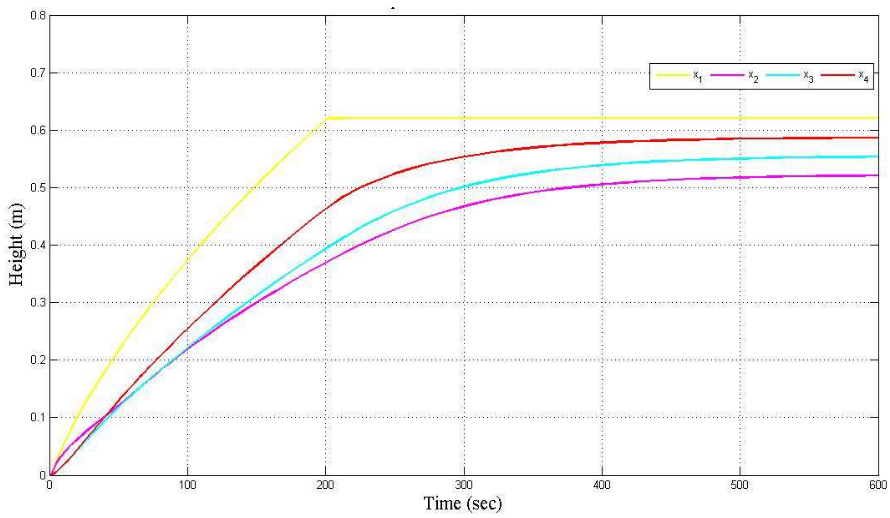

Figure 4. *Liquid level in four tanks*

In figure 4 level in four tanks are shown when input1 is double of input 2 and output valve is open. Tank1 will reach its maximum level first, then tank4 , tank3 and tank2.

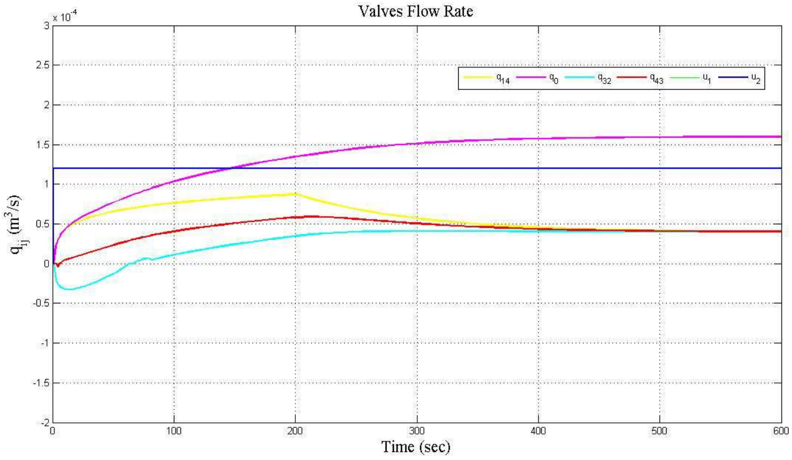

***Figure 5.** Valves flow rate*

In figure 5 valves flow rates of coupled four tank system is shown. The flow rate of tank2 valve is more than the valves between tank1 and tank4, tank4 and tank3, and, tank3 and tank2.

Now results of controller with plant is given in figure 6 and figure 7.

4.1. Case 1

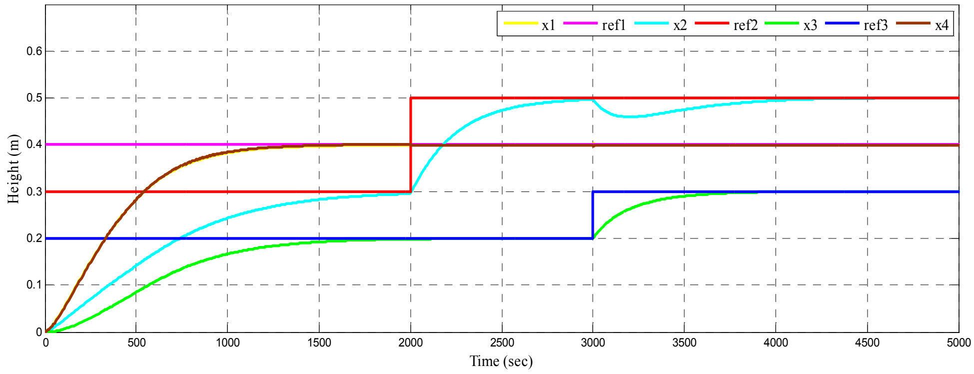

***Figure 6.** Liquid level in four tanks*

In figure 6, it can be seen that the ANN based control system for coupled tank followed the reference values set by the user. The steady state and overshoot response for ANN control strategy is good. The valve between tank1 and tank4 is open and tank1 will have the same level with that of tank4 due to action of gravity. As we can see from the figure that level of the tanks followed the reference and become stable when reference is reached.

4.2. Case 2

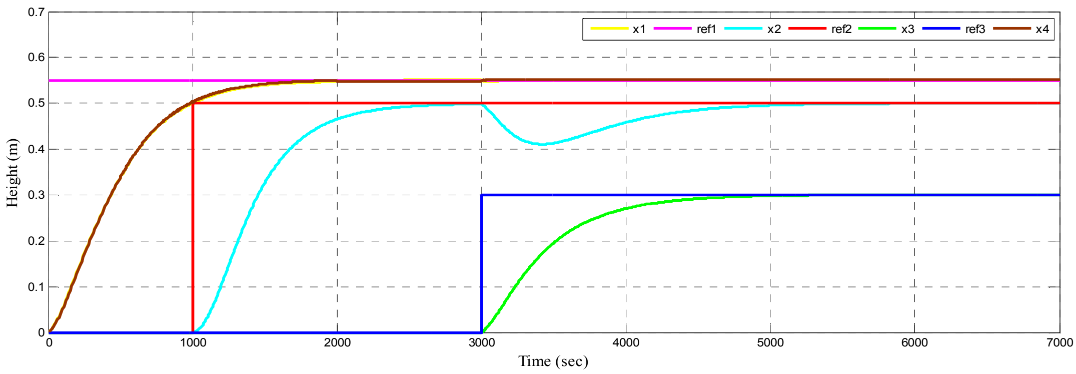

***Figure 7.** Liquid level in four tanks*

In figure 7, the reference value of tank1 is *0.55 m*, tank2 is *0.5 m* at *t=1000 sec* and tank3 is *0.3 m* at *t=3000 sec*, and it is clear from the figure that tank 1, tank2 and tank3 follow reference levels. Tank4 will have same level as that of tank1 because we have set reference for tank1 and designed our system as that tank4 will follow tank1 reference. This showed that the ANN based controlled strategy has better computational ability to reached the reference value of tank level rapidly. Also, ANN is flexible and robust to track any referred value given by the user.

5. Conclusion

In this paper, the ANN control strategy is designed for the level control of coupled four tanks system. The proposed control scheme show better performance for level control of tank system with and without disturbances. Also, simulations results of ANN strategy based level control of four coupled tank shows better performance in all respects.

References

[1] Srinivas, P., PrasadaRao, and P. Durga, Comparative Analysis of Conventional Pid Controller And Fuzzy Controller With Various Defuzzification Methods in a Three Tank Level Control System, International Journal of Information Technology, Control & Automation, vol. 2, no. 4, 2012.

[2] Ho, WengKhuen, Yang Hong, Anders Hansson, HåkanHjalmarsson, and J. W. Deng, Relay auto-tuning of PID controllers using iterative feedback tuning. Automatica, vol. 39, no. 1, pp. 149-157., 2003.

[3] Joseph J. Distefano, Allen R. Stubberud, Ivan J. Williams. “Feedback and Control Systems, McGraw-Hill Professional, 1995, Schaum’s Series.

[4] Spitzer, David W., Advanced regulatory control: Applications and techniques. Momentum Press, 2009.

[5] Dardinier-Maron, V., Hamelin, F., &Noura, H. (1999). A fault-tolerant control design against major actuator failures: application to a three-tank system, Proceedings of the 38th IEEE Conference on Decision and Control, vol. 4, pp. 3569-3574, 1999.

[6] Blažič, Sašo, Igor Škrjanc, and DragoMatko, Globally stable direct fuzzy model reference adaptive control, Fuzzy Sets and Systems, vol. 139, no. 1, pp. 3-33, 2003.

[7] Muhammad HosseinSobhani and JavadPoshtan, Fault Detection and Isolation Using Unknown Input Observers with Structured Residual Generation, 2009.

[8] Ramli, MohdSyakirin, Mohd Ashraf Ahmad, and R. M. T. Raja Ismail, Comparison of Swarm Adaptive Neural Network Control of a Coupled Tank Liquid Level System, ICCTD'09 International Conference on Computer Technology and Development, vol. 1, pp. 130-135, 2009.

[9] Cerda-Villafana, Gustavo, Sergio E. Ledesma-Orozco, and Efren Gonzalez-Ramirez, Tank Model Coupled with an Artificial Neural Network, In MICAI 2008: Advances in Artificial Intelligence, pp. 343-350. Springer Berlin Heidelberg, 2008.

[10] Wu, Dongrui, and Woei Wan Tan, A type-2 fuzzy logic controller for the liquid-level process, Proceedings of IEEE International Conference on Fuzzy System, vol. 2, pp. 953-958, 2004.

[11] Boubakir, Ahcene, Fares Boudjema, and SalimLabiod. "A neuro-fuzzy-sliding mode controller using nonlinear sliding surface applied to the coupled tanks system." International Journal of Automation and Computing vol. 6, no. 1, pp. 72-80, 2009.

[12] Han Rucheng Wang Yahui Li and XiaofengTianQichuan, An Intelligent Control Method of Thermal Boiler System,” IEEE International Conference on Intelligent Processing System, Beijing, China, pp.28-31, Oct.,1997.

[13] Chu, Chia-Chi, and Hung-Chi Tsa. Application of Lyapunov-Based Adaptive Neural Network Controllers For Transient Stability Enhancement,Power And Energy Society General Meeting, Pp. 1-6, July, 2008.

[14] A. Afzalian, D. A. Linkens, Training Of Neuro-Fuzzy Power System Stabilisers Using Genetic Algorithms,International Journal Of Electrical Power And Energy Systems, vol. 22, no.2, pp. 93-102, 2000.

[15] Hur Abbas, ShahidQamar, Sliding Mode Control For Coupled-Tank Liquid Level Control System, 10th International Conference on Frontiers of Information Technology (FIT), pp. 325-330, Pakistan, 17-19 December, 2012.