Intelligent Liquid Level Control of a Coupled Nonlinear Three Tank System Subjected to Variable Flow Parameters

Mustefa JIBRIL¹, Messay TADESE¹, Nuriye HASSEN¹
¹School of Electrical & Computer Engineering, Dire Dawa Institute of Technology, Dire Dawa, Ethiopia
E-mail : Mustefa.jibril@ddu.edu.et

Abstract - In this paper, an intelligent control system technique is proposed to model and control of a nonlinear coupled three tank system. Two pumps fed the the tank 1 and tank 2 and a fractional flow of this two pumps fed tank 3. The main aim of this paper is to make a set point tracking experiments of the tanks level using a nonlinear autoregressive moving average L-2 (NARMA L-2) and neural network predictive controllers. The proposed controllers are designed with the same neural network architecture and algorithm. Comparison of the system with the proposed controllers for tracking a step and random level set points for a fixed and variable flow parameters and a promising results have been obtained.

Keywords - Neural network, NARMA L-2, NN Predictive Controller.

I. INTRODUCTION

Water level control in a tank is one of the major control engineering benchmark for understanding the performance behaviour of a controller. One of the major application of this system is for nuclear reactors. Controlling a nonlinear three tank system now a days becomes one of the major control engineering issues.

In this paper, a three tank interconnected system level control is modelled and designed with a variable flow parameter in order to control the level of the three tanks using nonlinear feedback control theory. The controller performance is tested using tracking a reference level of each tanks indivisually. The level accuracy is also tested for different flow parameter of the liquid which enters the tanks.

A neural network based NARMA L-2 and Predictive controllers have been proposed for this system. In order to compare the performance of the controllers, they designed with the same number of layers and algorithm.

II. THREE COUPLED TANK SYSTEM DESCRIPTION

The three coupled tank system design is shown in Figure 1.

The relationship between the flows to the tanks and the flow from pump A and pump B depends on the flow parameters \( \gamma_1 \) and \( \gamma_2 \) as :

\[
q_i = \gamma_i Q_a \\
q_{iD} = (1-\gamma_i) Q_a \\
q_2 = \gamma_2 Q_b \\
q_{2D} = (1-\gamma_2) Q_b
\] (1)

Fig. 1. Three coupled tank system design

In this paper a controller is designed to control the liquid level to the given set point. The level of each tank is designated as \( h \). The flow of the liquid out of the tank through the exit pipe let exits. This flow is representing as \( q \). The flow of a liquid to the tank is done by the pump. The flow of the liquid, \( Q \), will be
adjusted by the proposed controller. The cross sectional area of the three tanks is the same and representing as \( A \). The mass balance equation of this system as a function of time is:

\[
\begin{align*}
A \frac{dh_1}{dt} &= q_1 - q_{13} \\
= &\gamma_1 Q_a - q_{13} \\
A \frac{dh_2}{dt} &= q_2 - q_{23} - q_{20} \\
= &\gamma_2 Q_b - q_{23} - q_{20} \\
A \frac{dh_3}{dt} &= q_{1D} + q_{2D} - q_{13} - q_{23} \\
= &\left(1 - \gamma_1\right) Q_a + \left(1 - \gamma_2\right) Q_b - q_{23} - q_{20}
\end{align*}
\]

The output flow from the tank, \( q \) through the exit pipe let and the manual valve is given as

\[
\begin{align*}
q_{13} &= \Psi_1 A \sqrt{2gh_1} \\
q_{23} &= \Psi_3 A \sqrt{2gh_2} \\
q_{20} &= \Psi_2 A \sqrt{2gh_1}
\end{align*}
\]

where \( \Psi_1, \Psi_2 \) and \( \Psi_3 \) are coefficient of friction of the pipe let exit. The term \( A_{p13}, A_{p23} \) and \( A_{p20} \) represents the cross-sectional area of the pipe let exits.

The system parameters of the three tank system is given in Table 1.

| No | Parameter | Symbol | Value      |
|----|-----------|--------|-----------|
| 1  | Area of the tanks | \( A \) | 6 m\(^2\) |
| 2  | Area of the outflow b/n Tank 1&3 | \( A_{p13} \) | 0.15 m\(^2\) |
| 3  | Area of the outflow b/n Tank 3&2 | \( A_{p23} \) | 0.12 m\(^2\) |
| 4  | Area of the outflow Tank 2 | \( A_{p20} \) | 0.09 m\(^2\) |
| 5  | Coefficient of friction of tank 1 | \( \Psi_1 \) | 0.75 |
| 6  | Coefficient of friction of tank 2 | \( \Psi_2 \) | 0.9 |
| 7  | Coefficient of friction of tank 3 | \( \Psi_3 \) | 0.4 |
| 8  | Gravitational acceleration | \( g \) | 9.8 m/s\(^2\) |

The nonlinear three tank system block diagram is shown in Figure 2.

### III. PROPOSED CONTROLLERS DESIGN

#### A) NARMA L-2 Controller Design

This neuro controller is described by two different names: response linearization control and NARMAL2 control. The feedback linearization control is when the plant model has a particular form. The NARMA-L2 model control is when the system model is approximated by the same model. The main theory of this type of control is to convert the nonlinear system into linear system by eliminating the nonlinearities. In this paper the companion model of the system is done by identifying the system using a neural network model. Then the identified neural network model is used to construct the controller. The main advantage of the NARMA-L2 is that you can adjust the control input signal in order to get the output signal follows efficiently the reference input signals.
B) NN Predictive Controller Design

There are many types of the neural network predictive controller for especially controlled a linear system predictive controllers. In this paper, the neural network predictive controller is used to control a neural network system of a nonlinear model to predict the system performance improvement in futures. The proposed controller will adjust the control input to improve the system performance for a specific future time horizon. The main advantage of the model predictive control is to evaluate the neural network system model and this model is controlled by the controller to predict future improvement.

Fig. 4. Three tank system with NN Predictive controller

Table 2. Neural network Parameters

| Network Architecture                  |
|--------------------------------------|
| Size of hidden layer                 | 4 | Delayed plant input | 2 |
| Sample interval(sec)                 | 0.1 | Delayed plant output | 3 |
| Training Data                        |
| Training sample                      | 100 | Maximum Plant output | 3 |
| Maximum Plant input                  | 2 | Minimum Plant output | 1 |
| Minimum Plant input                  | 1 | Max interval value (sec) | 5 |
| Min interval value (sec)             | 10 |
| Training Parameters                  |
| Training Epochs                      | 100 |

IV. RESULT AND DISCUSSIONS

Here in this section the comparison of the three tank system level control using NARMA L-2 and NN predictive controllers have been done using a step and random reference level signals. The performance of the proposed controllers has been evaluated and the best controller is further evaluated for different flow parameters.

A) Comparison with Predictive Controllers for Tracking Level (h1) using Step Reference Signal

The comparison of the coupled three tank system with NARMA L-2 and NN Predictive controllers is done for assigning a set point level h1 to 2.75 meter and tracking this reference step input level to the two input flows Qa and Qb with a flow parameter gamma 1 assigned as 0.9 and gamma 2 assigned as 0.1. This flow meter values makes more flow in to the tank 1 and tank 3 more and this makes q13 to flow slowly to check the performance of tank 1 level with the proposed controllers. The simulation result is shown in Figure 5 below.

Fig. 5. Step response of tank 1 level h1

The simulation result shows that the three coupled tank system with NARMA L-2 controller tracks the set point level h1 input with small percentage overshoot and less settling time as compared to the three coupled tank system with NN Predictive controller.

B) Comparison with Predictive Controllers for Tracking Level (h2) using Step Reference Signal

The comparison of the coupled three tank system with NARMA L-2 and NN Predictive controllers is done for assigning a set point level h2 to 2.75 meter and tracking this reference step input level to the two input flows Qa and Qb with a flow parameter gamma 1 assigned as 0.1 and gamma 2 assigned as 0.9. This flow meter values makes more flow in to the tank 1 and tank 3 more and this makes q13 to flow slowly to check the performance of tank 2 level with
the proposed controllers. The simulation result is shown in Figure 6 below.

![Fig. 6. Step response of tank 2 level h2](image)

The simulation result shows that the three coupled tank system with NARMA L-2 controller tracks the set point level h2 input with small percentage overshoot and less settling time as compared to the three coupled tank system with NN Predictive controller. The NN Predictive controller meanwhile improve the rise time.

**C) Comparison with Predictive Controllers for Tracking Level (h3) using Step Reference Signal**

The comparison of the coupled three tank system with NARMA L-2 and NN Predictive controllers is done for assigning a set point level h3 to 2.75 meter and tracking this reference step input level to the two input flows Qa and Qb with a flow parameter gamma 1 assigned as 0.1 and gamma 2 assigned as 0.1. This flow meter values makes more flow in to the tank 3 and this makes q13 and q23 to flow slowly to check the performance of tank 3 level with the proposed controllers. The simulation result is shown in Figure 7 below.

![Fig. 7. Step response of tank 3 level h3](image)

The simulation result shows that the three coupled tank system with NARMA L-2 controller tracks the set point level h2 input with small percentage overshoot and less settling time as compared to the three coupled tank system with NN Predictive controller. The NN Predictive controller meanwhile improve the rise time.

From the above simulations we conclude that the three coupled tank system with NARMA L-2 controller has better performance to regulate the three tank levels better than the proposed NN Predictive controller and the following comparisons is done for testing the performance of the NARMA L-2 controller with different flow parameter values.

**D) Comparison with Predictive Controllers for Tracking Level (h1) using Random Reference Signal for 0.8, 0.5 and 0.3 Flow Parameters**

The comparison of the coupled three tank system with different flow parameters with NARMA L-2 controller is done for assigning a set point level h1 to a random value and tracking this reference random input level to the two input flows Qa and Qb with a flow parameters gamma 1 and gamma 2 assigned as 0.8, 0.5 and 0.3. This flow meter values makes tank 1 with variable flow values to check the performance of tank 1 level with the proposed controller. The simulation result is shown in Figure 8 below.

![Fig. 8. Random response of tank 1 level h1 with 0.8, 0.5 and 0.3 flow parameters](image)

The simulation result shows that the level h1 of tank 1 of the three coupled tank system with 0.8 flow
parameters value shows a better response with more inlet flow values to tank 1 and tank 2 in improving the overshoot and steady state value.

E) Comparison with Predictive Controllers for Tracking Level (h2) using Random Reference Signal for 0.8, 0.5 and 0.3 Flow Parameters

The comparison of the coupled three tank system with different flow parameters with NARMA L-2 controller is done for assigning a set point level h2 to a random value and tracking this reference random input level to the two input flows Qa and Qb with a flow parameters gamma 1 and gamma 2 assigned as 0.8, 0.5 and 0.3. This flow meter values makes tank 2 with variable flow values to check the performance of tank 2 level with the proposed controller. The simulation result is shown in Figure 9 below.

The simulation result shows that the level h2 of tank 2 of the three coupled tank system with 0.8 flow parameters value shows a better response with more inlet flow values to tank 1 and tank 2 in improving the system with no overshoot and slow steady state value.

F) Comparison with Predictive Controllers for Tracking Level (h3) using Random Reference Signal for 0.8, 1 and 1.4 Flow Parameters

The comparison of the coupled three tank system with different flow parameters with NARMA L-2 controller is done for assigning a set point level h3 to a random value and tracking this reference random input level to the two input flows Qa and Qb with a flow parameters gamma 1 and gamma 2 assigned as 0.8, 0.5 and 0.3. This flow meter values makes tank 3 from less to high flow value to check the performance of tank 3 level with the proposed controller. The simulation result is shown in Figure 10 below.

The simulation result shows that the level h3 of tank 3 of the three coupled tank system with 0.8 flow parameters value shows a better response with less inlet flow values to tank 3 in improving the system with minimum overshoot and slow steady state value.

V. CONCLUSION

The design and control of a nonlinear coupled three tank system has been done using NARMA L-2 and NN Predictive controllers. Comparison of the system with the proposed controllers for tracking a step set point level with fixed flow parameter shows that the system with NARMA L-2 controller improves the set point tracking mechanism better than the proposed NN Predictive controller. The comparison of the system with NARMA L-2 controller for a variable flow parameter using a random set point level shows that the system with higher flow parameter shows a better performance.

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