Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 5- Issue 1, Paper 49 January 2022

Study and Analysis of Various Control algorithms for Coupled Tank System

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Abstract-The four-tank system is reviewed in this paper and this is a common mechatronic laboratory configuration in control theory. This research aims to identify the best controller for a four-tank system (4TS) with dual input forces. For the level control of 4TS, the optimal control technique is described, and it is one of the finestmethods in terms of presentations. Among the different controller schemes created are the H2, H∞ controller, linear quadratic regulator (LQR) and linear quadratic Gaussian regulator (LQGR) systems. The system's tank level is then controlled using a PI controller, a PID controller, and a FOPID. To explore the influence of various controller systems on the 4TS controlled state, these controllers were provided to this significant mechatronic system (4TS) independently and their outputs for disturbance rejection was compared. Various computational approaches for the control process of a connected tanks system are discussed and analyzed in this research. The determination of the appropriate water level in the tanks might be stated as an optimal control issue for a meaningful operating decision since the dynamics of the connected tanks system are nonlinear. System optimization and parameter estimates are incorporated on this foundation. For example, the numerical parameters of a connected tank system are investigated, as well as the applicability of the methodologies.

Keywords: *four tank system (4TS), coupled process, disturbance rejection, PI, PID Controller and FOPID Controller*

I. INTRODUCTION

A large-scale system is usually made up of a number of distributed subsystems that are linked together. Multi-axis equipment, electric power systems, chemical reactors, petrochemical systems, and other examples of such systems are frequently used in practise [1]. One of the most difficult systems to govern is nonlinear interconnected networks. For dynamical systems described by state–space models, state estimation and control techniques have been executed [2]. The linearization of high-order state–space models prove to be a crucial and time-consuming computational step in the development of a state estimator for highly nonlinear systems. Furthermore, centralised approaches overlook the structural properties of typical plant-wide systems. Due to the computational expense of calculating the Kalman filter, the traditional centralised technique is insufficient for on-line applications to large-scale systems. Because a typical filter tuning techniques to calculate the Kalman filter for many values of process and extent noise covariance in order to obtain an acceptable approximation for the application of interest, off-line computational efficiency is also a concern, albeit to a lesser extent. For linear quadratic control (LQR) control architecture, same principles apply when determining the feedback controller gain with the concomitant change of error penalty functions. Recent multi-sensor data fusion research employs information theoretic principles to transform the estimation and control issues into a completely distributed and decentralised framework.This method delivers the required scalability while retaining global optimal performance comparable to a centralised fusion system. DDEC has been successfully used to a range of low-order mechanical and aeronautical systems.

The majority of today's control problems are non-linear and require several control elements. Significant vulnerabilities, non-minimum phase behaviour, and a high degree of cooperation are shown by the frameworks associated with such modern processes [1]. More than one control loop exists in a multivariable outline; these loops interact with one another so that a single piece of information affects both its own output and the outputs of other processes. Fluid level frameworks are typically extremely simple, making it difficult to describe various process advancements; nevertheless, the quadruple tank system (QTS) addresses these drawbacks without introducing additional sophisticated equipment [5].For this operation, QTS is a highly nonlinear framework that has been used to assess different MIMO controllers. An internal model controller, a model predictive controller, a quantitative feedback controller, a fuzzy logic controller, neural system control, and a H controller have all been proposed for QTS control [8-14]. At various working levels, these control plans were produced utilising the QTS's linearized model. The documents that survive are given below. The recent review study of the tank system is described in section 2, and the proposed technique is offered in section 3. The conclusion portion is addressed in section 3.

1.1. Contribution of the Review

The main purpose of this research is to use an exponential stability method to build a state feedback controller with trajectory tracking skills for a specific type of nonlinear MIMO system. The exponential stability of a model-based nonlinear predictive controller is first investigated. The connected four-tank MIMO system is then explored utilizing a mix of control techniques and the continuous-discrete time observer.

II. SYSTEM MODELLING OF COUPLED FOUR TANK SYSTEM

Figure 1 depicts the paradigm of a two-degree-of-freedom (DOF) coupled four-tank MIMO process. This system consists of a liquid basin, two pumps, and four tanks with orifices and level sensors at the bottom of each tank. Pumps 1 and 2 deliver in feed to Tanks 3 and 4, respectively, and the outflows from Tanks 3 and 4 become in feed to Tanks 1 and 2, as shown in Fig. 1. The discharge from Tanks 1 and 2 is collected in the liquid basin.

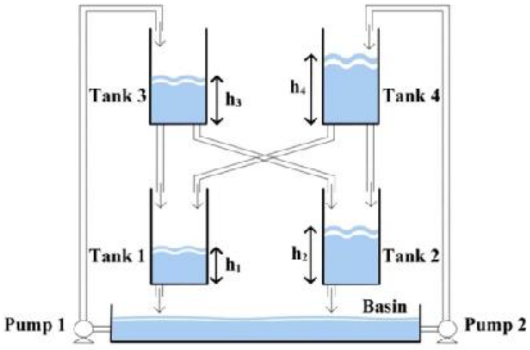


Fig. 1: Coupled 4 tank System

The control and sensor less control of a connected four tank MIMO system are investigated in this paper (Fig. 1). This factory uses a modified quadruple-tank procedure, which has been proved to be a successful method for control training and validation of sophisticated multivariable control systems. We examine and implement the nonlinear generalized predictive control (NGPC) technique, which outperforms a Backstepping approach in recent comparative research on this system, in order to obtain good tracking performance for the connected four tank MIMO system. The tank level is monitored and the water flow is controlled in the connected 4TS using a variety of controls, which are described below.

2.1. Various Controllers in the 4TS

In the event of unstable systems with multiple types of disturbances, a controller is needed to achieve desired performance for stable systems while stabilizing the unstable processes first. The techniques will achieve their purpose by identifying the system with less modelling errors, selecting the best controller, and tweaking it effectively. The first half of the recitation's purpose was to show how P, P-I, and P-I-D controllers change closed loop systems' steady state response. The methods for tweaking the controllers mentioned above were also discussed. It was designed to show how to predict the dynamics of a continuous-time plant and how to choose an appropriate sample time for a discrete-time P-I-D controller. It was also meant to show how different transformation methods can produce distinct z-plane pole locations. The PI, PID, and FOPID controllers are defined in the section below.

2.1.1. PI Controller

The P-I controller is primarily used to eliminate the steady state inaccuracy of the P controller. However, it has a negative impact on the overall stability and response time of the system. This controller is commonly used in applications where system speed is unimportant. The P-I controller is unable to minimize the rising time and remove oscillations because it is unable to predict future system faults. When any number of integral values of I are applied, set point overshoot is guaranteed.

(A) PI Controller with different Optimization Algorithms for various systems

In general, using a PI controller for nonlinear plants is not suggested because the controller may not provide the appropriate performance in a changing environment/operating point. The controller should be able to track a reference signal under various situations. The controller is suited for the majority of industrial/process applications, but not for complex applications such as military, robotics, financial models, and so on. For variables that vary slowly, we can't use a PI controller. Although PI control is clearly faster than Integral control, it may or may not be faster than Proportional control alone.

The various algorithms are applied to a standard PI Controller. If a typical PI controller produces an approximate but not exact output. As a result, the gain settings are tweaked using an optimization process to increase the performance of the PI controller. When various types of upgraded PI controllers are employed to study or monitor the tank system, the results are automatically improved; some of them are discussed here.

Table 1: Comparison Analysis of PI controllers in various forms

Various Controllers	**Parameters**	**Minimum phase**		**Non-minimum phase**	
		Level-1	**Level-2**	**Level-1**	**Level-2**
PI Controller	Settling Time	250 sec	150 sec	1380 sec	1380 sec
	Peak Overshoot	1%	2%	10%	25%
	Rise Time	15 sec	10 sec	240 sec	210 sec
PI Controller with MRAC	Settling Time	6 sec	8 sec	7 sec	10 sec
	Peak Overshoot	30%	70%	30%	40%
	Rise Time	2 sec	1 sec	3 sec	2 sec

D.AngelineVijula*et al.* [26] have provided a quantitative comparison of the performance of PI controller and adaptive decoupled PI controller in Table 1. It demonstrates that when compared to other methods, the standard PI controller produces less results. Level 1 and level 2 reference models are chosen based on their kp values (kp=5000 and 3000) and ki values (ki=1000) for both levels. The linearized model of a quadruple tank system includes a multivariable transmission zero, making non-minimum phase control significantly more complex than minimum phase control. A design of an auto adjustable decentralized PI controller for quadruple tank process employing MRAC techniques is discussed in their model. Based on the given reference model, their controller can update the controller parameters in response to changes in plant uncertainties and disturbances, preventing the system from interacting with process variables. The simulation results revealed that the MRAC technique solves the dynamic problem of the quadruple tank process and is suitable for controller design within the system's requirements. In the future, optimization approaches may be employed to pick the adaptation gains in order to ensure greater performance [26].

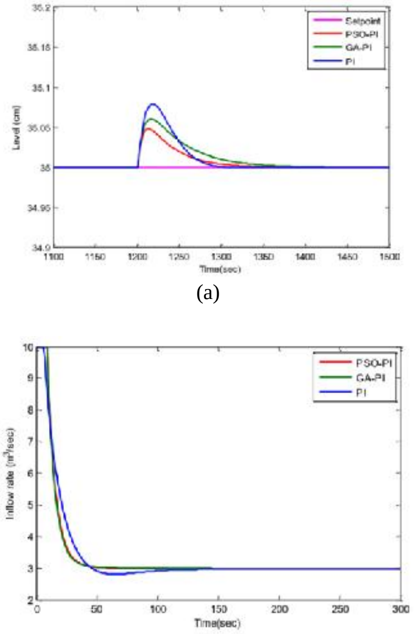
Suriyaprabh*et al.* [27] investigated the industrial conical tank system because of its non-linear construction, which allows solid mixes, slurries, and viscous liquids to be handled more efficiently. Because of its nonlinear shape, controlling a conical tank system was difficult. Level control in a conical tank process was studied in their study, and a mathematical model based on the White box approach was built and used for simulation control. For comparison analysis, various optimal PI controllers were analysed and implemented in the conical tank level process.

EAs are frequently used to tackle problems with a large number of decision variables and non-linear objective functions. The genetic algorithm (GA) was the first evolutionary-based optimization technique [15]. GA was created using Darwin's survival of the fittest concept and the natural process of evolution through reproduction. Particle Swarm Optimization (PSO) [16] is one of numerous algorithms.

Table 2: Measure of Servo Response conical tank System

Set Point	**ISE**			**IAE**		
	PI	**GA-PI**	**PSO-PI**	**PI**	**GA-PI**	**PSO-PPI**
30-35	1308	1301	1268	739.5	591.6	559.4
40-45	2462	2264	2210	1069	940	888.6
50-55	3899	3839	3677	1679	1652	1512

Table 2 compares the values of performance indices for the above-mentioned controllers in terms of Integral Square Error (ISE) and Integral Absolute Error (IAE). The values show that the PI controller has a significant Integral Square Error (ISE) and Integral Absolute Error (IAE) (IAE). The GA-PI controller enhances the control loop's performance, but it also produces more ISE and IAE. However, when compared to other controllers, the PSO-PI is more accurate for the target operating point. It indicates that PSO-PI outperforms other methods in the conical tank level process.



(a)

(b)

Fig.2: (a) Analysis of conical tank level process and (b) controller output

To test the controller's robustness, Suriyaprabh*et al.* [27] disrupted the tank by raising the inflow rate by 10% applied at 1200th second for the operational points 35 cm and 55 cm. The level of the conical tank is increased from nominal value due to a 10% increase in input rate at the operational point, as indicated in Figure 2. The appropriate action is taken by PI, GA-based PI, and PSO-based PI controllers, which return the level to its nominal operating point. It is clear from the results that PSO-based PI delivers superior responses than GA-based PI and conventional PI controllers. According to the findings, PSO-based PI gives superior results in terms of minimum ISE and IAE. For both levels, the Kp and Ki values are tweaked (kp=700 and ki =6) in the work.

The performance of the Proportional-Integral-Derivative (PID) controller for quadruple tank process was investigated by E. Govinda Kumar *et al.* [25]. Minimum and Non-minimum phase systems are used to control flow ratios in quadruple tank processes. When the system is switched from minimum to non-minimum phase configuration and vice versa, its performance can be compromised. It has a good ability to adjust to major changes in managing flow ratio in triple tank level procedure, according to their investigation. To summarise, the PI-PD controller has been shown to be a reliable way for controlling levels in both minimum and non-minimum phase systems.

2.1.2. PID Controller

Since the 1960s, PID controllers have been widely employed in industrial process control systems. The PID controller assists in quickly obtaining the desired output level with little overshoot and inaccuracy. All that is necessary is correct tuning of the controller parameters to achieve the desired results. Hana El Saady et al. [28] designed the Proportional Integral Derivative (PID) controller to control the desired water level of the Quadruple Tank System (QTS). Controlling the liquid level in a couple tank system and the flow between the tanks is a problem in process technologies because of the contact between the tanks. Nayanmani Deka *et al.* [29] investigated a successful fundamental concept for liquid level systems in two tanks using a PID controller.

Table 3: Comparison of different PID controllers

Authors	**Controllers**	**Overshoot**	**Rise time**	**Settling Time**	**Steady state error**
Nayanmani Deka *et al.* [29]	PID	12.70%	0.519min	2.52min	0.0054m
Sankata B. Prusty*et al.* [30]	PID	5.07	-	9.464sec	3.93
	Fuzzzy PID	0.12	-	8.935sec	4.84 sec

The system now responds to the PID control algorithm automatically, allowing the system to stabilize near the set point without the need for manual control valve adjustment. Sankata B. Prusty*et al.* [30] described a liquid level control system that is commonly used in process control. Before being utilized to maintain the tank level, the fuzzy controller was integrated with the PID controller. In their research, they looked at the transient responsiveness and error indices of PID, fuzzy, and fuzzy PID controllers. The responses of the fuzzy-PID controller were verified via simulation. The absolute error of the fuzzy-PID controller was 56.6 percent lower than the PID controller and 55.6 percent lower than the fuzzy controller.

Table 4: Comparison of Error Indices by using various Controllers

	Errors			
Controller	**IAE**	**ISE**	**ITAE**	**ITSE**
PID	14.26	7.58	269.26	94.22
Fuzzy PID	6.17	3.05	64.32	12.198

The Ziegler-Nichols tuning method is used to tune the PID controller, with the proportional gain Kp = 6, integral time Ti = 0.035, and derivative time Td = 0.005. Table 3 shows the response of the PID controller, which has a 5.07 percent overrun, a 9.464 second settling time, and a 3.93 second rise time. In the case of a fuzzy controller, the overshoot, settling time, and rise time are 0.58 percent, 13.324 seconds, and 4.93 seconds, respectively. Table 4 compares error indices for PID, fuzzy, and fuzzy-PID controllers, such as integral absolute error (IAE), integral squared error (ISE), integral of time and absolute error (ITAE), and integral of time and squared error (ITSE). The absolute error of the fuzzy-PID controller is 56.6 percent less than the PID controller and 55.6 percent less than the fuzzy controller, according to the table. The invention of a Proportional-Integral-Derivative (PID) controller for managing the required liquid level of the CTS was given by H.I Jaafar *et al.* [31]. In comparison to a simple multiloop PI controller, Qamar Saeed *et al.* [32] implemented the multivariable predictive PID controller for handling the difficulties of a multi-inputs multi-outputs control problem, i.e., quadruple tank system. After that,PID controller was used by Mostafa A. Fellani*et al.* [33] for managing the required liquid level of the CTS.

For a connected tank system, Ashutosh Prasad Yadav *et al.* [34] suggested a genetic algorithm (GA) based PID controller. Dynamic responses, structural complexity, nonlinearities, and large time delays, on the other hand, aren't always assured. In current enterprises, uncertainty in some actually constrained settings is generating interest in PID controller development. Due to their flexibility in handling uncertainties, robustness, sinking undesired oscillations, and fast change of control signal, fractional order controller concepts are required in many advanced control strategies such as phase lead lag compensator, sliding mode control based FOC, and internal model based FOC.

2.1.3. FOPID Controller

Fractional order calculus is a well-known mathematical topic that extends classical integer calculus to arbitrary orders and has a 300-year history. The first theory of fractional order derivative was created between L'Hospital and Leibniz in the seventeenth century [10]. In most cases, fractional order methods can describe, specify, model, and control real-time issues more precisely than integral order approaches. Because of the well-developed theoretical explanation and computing area in the last two decades, fractional calculus is used in a variety of engineering sectors and science applications. Furthermore, fractional-order differential equations have a variety of applications in control systems. As a result of its extra flexibility in meeting control applications more particularly, several research projects in fractional order control (FOC) have been undertaken in recent decades.

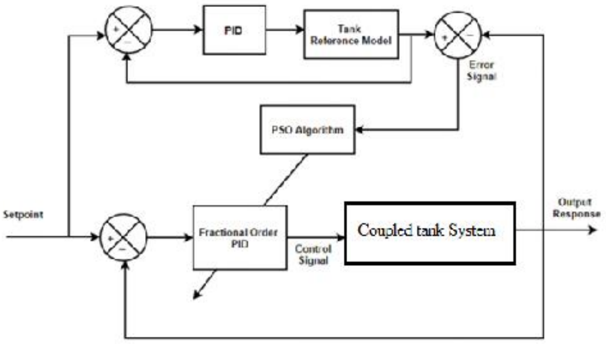


Fig. 3: FOPID Controller for tank system

Figure 3 depicts the FOPID controller in conjunction with the reference model for the tank system that was investigated. The PID and FOPID controller is developed to correctly tune the highly nonlinear single conical tank model.Differentiation, proportional, and integral order are required by the FOPID regulator. The fractional order regulator is depicted using a fractional order differential condition. Three boundaries, Kp, Ki, and Kd, need be tuned in PID regulators to plan the regulator [27]. Using fractional order controllers is one of the possible outcomes for improving PID regulators. The difference between FOPID and PID regulator is that the request for subsidiary and vital is not numbered in FOPID.

Fractional order mathematical phenomena can be used to more accurately describe and imitate a real item than typical integer methods, according to Sruthi V. J, *et al.* [35]. The unavailability of fractional differential equation solution methods was the primary motivation for using integer order models. PID controllers are the most common because of its simple design and effective and simple tweaking techniques. A FOPID controller has two extra tuning parameters than a standard PID controller, making it more adaptable and capable of higher performance. Table 5 shows a comparison of performance with a conventional integer order controller in SIMULINK.

Table 5: Comparison of Errors (Sruthi V. J, *et al.* [35])

Various Controllers	**Error Values**			
	IAE	**ISE**	**ITAE**	**ITSE**
PID	6.426	4.792	31.83	123.2
FOPID	0.367	0.7505	0.2993	0.803

In simulation, the developed FOPID controller achieves higher results than the typical IOPID controller. The FOPID controller was created using a set of enforced tuning restrictions that ensure the intended control performance as well as the designed controllers' robustness to loop gain fluctuations.P. Siva Sankar and colleagues [36] investigated the performance of coupled tank systems with fractional-order PID controllers. The FOPID controller was an addition to the integer order PID controller which includes, parameters in addition to Kp, Ki, and Kd. FOPID controllers have been shown to be more effective than integer order PID controllers in several circumstances. R. Rajesh [37] investigated the FOPID controller's performance in real-time level control of a single conical system.

The FOPID controller has several advantages over typical PID controllers, including a simplified construction, improved set point tracking, strong disturbance rejection, and a greater capacity to handle model uncertainties in nonlinear and real-time applications. Fine tuning of FOPID controller is more complex than fine tuning conventional PID control because there are two more parameters and various particular limits such as gain margin, phase margin, gain crossover frequency, and sensitivity conditions.The development of meta-heuristic methods such as the GA, PSO, ABC, BFOA, CS and Big bang big crunch algorithm has made the tuning of constraints very simple in recent years, as evidenced by the literature.The FOPID controller is clearly better to other integer order controllers, according to the literature. Many academics are now adopting the FOPID controller since the additional characteristics make the system more durable and effective for a variety of applications.

III. CONCLUSION

In order to ensure global exponential stabilization and good reference trajectory tracking for liquid level state feedback and output feedback control of a nonlinear coupled four tank MIMO system, this paper reviewed and analyzed a nonlinear various controller approach and a continuous-discrete time observer. To estimate the system's two non-measurable liquid levels, the control mechanism uses an overlapping implementation of a continuous-discrete time high gain observer, as well as an explicit nonlinear MPC solution. Here, PI controller, PID Controller, and FOPID controller with algorithm and without algorithm is reviewed. The above-mentioned controllers are used for the tank system, and most of the reviewers are suggested the FOPID controller for the analysis. The performance of the various controller has been reviewed and analyzed. The experiments perform well in the stabilization and trajectory tracking tasks when compared to previous controllers. Finally, this cost-effective and fault-tolerant technology is highly suited to dealing with critical control system issues. The controller's adaptability and ease of real-time implementation make it suited for a wide range of real-world engineering applications, such as liquid level management in a connected two-tank MIMO system. Finally, the effectiveness of the proposed strategy in obtaining the necessary water level in the connected tanks is demonstrated.

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