HYBRID SOFT COMPUTING APPROACH TO CONTROL OF NONLINEAR SYSTEM

A Thesis submitted to Gujarat Technological University

for the Award of

Doctor of Philosophy

in

Instrumentation and Control

By

Prakash Mansukhlal Pithadiya

[129990917004]

under supervision of

Dr. Vipul A. Shah

GUJARAT TECHNOLOGICAL UNIVERSITY

AHMEDABAD

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Name of Supervisor: **Dr. Vipul A. Shah**

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ABSTRACT

There are many chemical and petrochemical processes plants having multiple inputs and multiple outputs for different processes. This research mainly focuses on searching the optimal controller structure by increasing the controllersô integral performance criteria. It is a very difficult to control the highly nonlinear quadruple four tank system. It is also challenging due to the cross coupling effect of highly interacting system to stabilize and control the MIMO system. It is still a very big issue to control nonlinear system. The proposed algorithm for tuning of PID constant is based on the new statistical approach combined with soft computing techniques. One of the optimization of statistical analysis is Taguchi method to combine with mutation based Particle Swarm Optimization hybrid algorithm to tune the PID parameters. These tuning parameters optimize the performance indices of the nonlinear system. The tuning parameters of controller find optimal performance indices. It is computer based nonlinear system for performance analysis and checks validation of proposed TMPSO algorithm. Laboratory experimental set up is established to communicate with MATLAB, LabVIEW and other controller platforms. Implementation is done using LabVIEW for proposed algorithm and output validates with four tank laboratory set-up for testing of performance indices. It checks the performance indices based on the PID parameter tuning with proposed TMPSO algorithm and improve the response of different performance indices for the experimental set up of quadruple tank nonlinear system.

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This thesis would have been impossible without support of many people. I would like to express my sincere gratitude to them, through their invaluable support deserve much more than this short note of appreciation. I would like to thanks almighty the God giving me strength and passion to do research.

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Finally, I give the greatest respect and love to my parents and my family. I want to express my highest appreciation for their support and cooperation. I am thankful to all those who have directly or indirectly helped me during my reserach work.

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Finally, I give the greatest respect and love to my parents, my parents in law, my wife and my son **Devarsh**. I want to express my highest appreciation for their support and cooperation. I would like to say thanks to my wife **Mrs. Kinjal** for encouraging me to do research and her moral support. Thanks to **Almighty the God** for giving me patiently to complete research.

This thesis is dedicated to all of my good wishers with my love for assisting me to achieve the most important stage in my life. I will never let them down and wish them all the successes in the future.

As it is a prolonged journey, maybe I have forgotten few names to consider, but nonetheless, they remain a core part of this mammoth task, and I seek forgiveness for the same and offer my kind respect to every one of them.

Thanking you,

Prakash Mansukhlal Pithadiya

Table of Content

List of Abbreviation

AC	Adaptive control
AISTGA	Artificial immune system taguchi genetic algorithm
ANN	Artificial neural network
ANOM	Analysis of means
ANOVA	Analysis of variance
BSP	Binary space partitioning
CSTR	Continuous stirred tank reactor
DAQ	Data acquisition
DOF	Degree of freedom
DP	Dynamic programming
DPSO	Discrete particle swarm optimization
FLC	Fuzzy logic control
FOPDT	First order plus delay time
FSP	Flow shop scheduling problems
GA	Genetic algorithm
HSLTPSO	Hybrid sliding level taguchi based particle swarm optimization
IAE	Integral absolute error
IMC	Internal model control
ISE	Integral square error
ITAE	Integral time absolute error
ITSE	Integral time square error
MAE	Mean absolute Error
MGPSO	Multiple group of gradient particle swarm optimization
MIMO	Multi input multi output
MPC	Model predictive control
MPSO	Mutation particle swarm optimization
NI	National instruments
NLP	Nonlinear programming
NN	Neural network

PC	Personal computer
PID	Proportional Integral Derivative
PSI	Pound per square inch
PSO	Particle swarm optimization
PV	Process value
PWM	Pulse width modulation
QTS	Quadruple tank system
SISO	Single input single output
SP	Set point
TCGA	Taguchi combined genetic algorithm
USB	Universal serial bus
Z-N	Ziegler Nichols

List of Symbols

Kp	Proportional Constant
Ki	Integral constant
Kd	Derivative constant
td	Derivative time
e	Error
Ɋ	Dynamic iteration
ɔi	Fraction of water flow of pump in tanks
L1,L2	Level of the water tanks
S/N	Signal to noise
L_{18}	Orthogonal array
a_i	Area of the outgoing flow pipe
A_i	Area of the tank
kc	Motor constant
h_{max},h_{min}	Height of the tank1 and tanks2
g	Gravity
tp	Settling time
l/min	Litre per minute
V1,V2	Voltage of pump
Ti	Time constant of four tanks

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CHAPTER -1

1 Introduction

1.1 General Overview

As a result of increments of the worldwide competition and major changes in marketing and advertising business during the past many years, the process industry has presented a significant serious change in the market. Therefore, it is essential to develop all the facet of process control technology such as modeling, dynamic optimization, integrated software tools, and high-performance process control.

Process characteristics tend to become too complex to be successfully handled by the existing era of control and optimization techniques. One of the advanced control technology, which has made a significant impact on industrial control engineering, is hybrid soft computing based control. The hybrid soft computing control technology is used in different soft computing algorithm, which meets all the performances to entice users. (Tyagunov, 2004). This is perhaps one of the most interesting and attractive approaches in process control practice for our century.

This research work aims at combined developing the effect of PID controller parameter tuning, based on improving the performance indices, for the nonlinear control quadruple tanks systems in way of simulation as well as a real system controlled by the most used control laws in real industrial environments.

We have in followed the way for approach by:

- Derivation of the nonlinear quadruple-tank process model, using physical principles and some experiments to extract process parameters.
- Hardware and software set up to close the loop with the NI USB 6001DAQ devices.

- To implement all control laws in commercial program LabVIEW.
- Design and test, in both simulation and real process, six control laws: simple PID control, PSO PID and GA PID and Taguchi based PID, Taguchi GA PID, and MPSO Taguchi PI control
- Design and test of several kind of input servo and regulatory applied to the real process.

Aside from each other of the standards well worthwhile addressing to choose the controllers, which are recently chosen, especially to analyze some special performance characteristics, possible use of Taguchi based MPSO, difference between performances of control laws with and without pure Integral action and this improvement of a control law makes the closed loop more robust against conventional controller techniques. All these aspects will be analyzed with several experiments and different type of controller techniques and improve the performance criteria.

1.2 Nonlinear Control System

The nonlinear control system is one of the theory which is regulating the output, but not corresponding to a change in input. Nonlinear has one problem that it is always oppose the linear system.

The nonlinear system plays an important role in the various stages in the controller or in the process. The nonlinear system always considered as a natural process and used in various engineering control fields.

For analysis purpose, the nonlinear control theory is used in the design and also to control the nonlinear system.

Characteristics of the Nonlinear System

Various techniques and approaches help to analyse and design the nonlinear control systems. A basic schematic of a nonlinear control system is shown in Figure 1.1

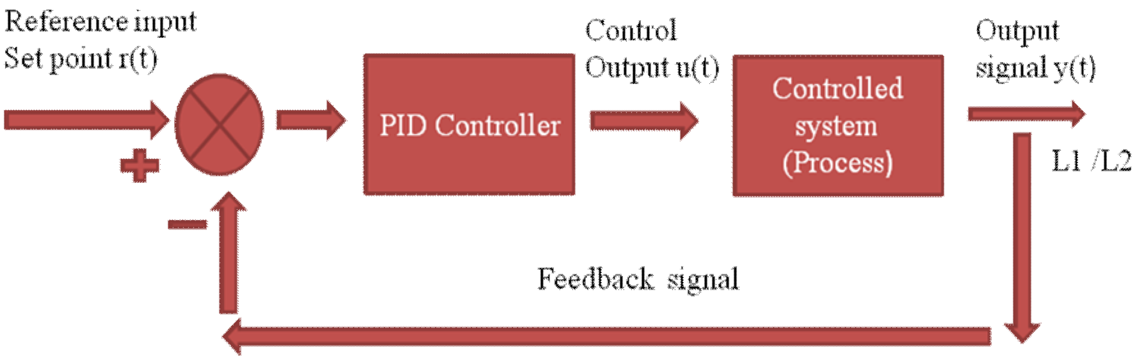

FIGURE 1.1 Basic Structure of the Process Control System

1.3 Systems Theory

The following systems theory is of specific magnificence and relevance to nonlinear control system.

- Lyapunov stability
- Lyapunov's direct method
- Passivity
- Equilibrium points
- Linearization
- Controllability
- Observability
- Input-output stability and gain

1.4 Control Design Techniques

The control design all in all plans to fulfill specific execution destinations, such as stability, noise rejection, disturbance and parameter uncertainty, input tracking, and disturbance robustness. The various types of systems required to claim for a variety of design techniques of various conditions and a portion of the wide remarkable ones, are quickly depicted beneath.

One best technique for design perspective is to see the system which is to be controlled as roughly linear. The linear system by appropriate change, to which settled a direct control, procedures might be connected.

Lyapunov Design

It begins with a stabilizing control law and Lyapunov function for the ostensible system and includes certain terms to the control that guarantee stability in the face of all admissible uncertainties. A stable system is very synthesized by initial selecting a candidate Lyapunov function V, and then choosing a state feedback control law that renders the derivative of V negative. The Lyapunov overhaul strategy furnishes the system with robustness to (bounded) uncertainty in the system dynamics. While the Lyapunov overhaul is limited systems that satisfy a matching condition, so that the uncertainty terms enter the state equations at the same point as the control input, the fundamental methodology has been reached out to more broad circumstances utilizing recursive or back steeping strategies.

Conventional PID Control

The Proportional-Integral-Derivative controller is a typical direct controller, which is regularly referred to as the nigh predominant criticism controller. Specifically, it discovers use in numerous non-linear process control applications from well known industrial process control to automated controllers. In the practical setting of tuning of the parameters of controller is frequently utilized, particularly in the chemical process industry and various auto tuning as well as manual tuning methods, exist based on the direct measurement of a few attributes of the system reaction. Scientific outline is obviously additionally utilized, it is frequently expanding on one of the linearization techniques.

Gain Scheduling

The simplest analytical way to deal with controller design for a complex system depends on fitting on the estimated linear model to the controlled system, normally through local linearization around an average working point and after that developing a linear controller for a particular model. Obviously, this strategy may fail when nonlinear impacts are huge. Gain Scheduling adopts this strategy above and beyond, the controllers are intended for a scope of conceivable working focuses and status and the proper regulate technique is put into cavort as indicated by the present system state.

Feedback Linearization

Estimation of the entire state vector is needed to actualize the exchange. The hypothesis gives conditions under which feedback linearization is conceivable and strategies to process the required changes, accompanying the strategies for new design issue specifically utilizing non-linear tools, Lyapunov functions and Lyapunov stability, which are prominent precedents of robust nonlinear control.

Sliding Mode Control

Variable Structure Control is a sort of powerful design approach, a proper manifold (often a linear surface) in the state space is first situated on which the system time and frequency domain take a basic and stable form. This complex is called the sliding surface or the switching surface. The control law is proposed to compel directions to accomplish that manifold in restricted time and stay from that point. As the essential control law is spasmodic by design around the switching surface, undesirable chattering around that may result and regularly may require some smoothing of the control law. Numerous different strategies from control engineering are connected to the design of nonlinear systems, some of which might be considered as independent fields of control engineering.

Among these, we mention:

Optimal Control

In the optimal control, improvement the cost function is the main control objective, using basic dynamic programming and variation method tools for providing a solution of optimal control.

Model Predictive Control

Online optimization for finite time horizon is a control objective for optimal control. Most of the industrial control, the model predictive control having computational feasibility used widely applicable in the various process industry.

Adaptive Control

This adaptive method helps to control time variation of and uncertainty of the system model. Basically, the control variable tuned online in term of controller operation using learning and estimation various method.

Neural Network Control

The first objective of the ANN approach was to tackle issues similarly that a human brain. In any case, after some time, consideration moved to perform particular assignments, prompting deviations from science. Neural systems have been utilized on an assortment of undertakings, including computer vision, speech recognition, machine interpretation, playing board, computer games and medicinal analysis.

Fuzzy Logic Control

A control system is an arrangement of physical components designed to alter another physical system so that this system exhibits certain desired characteristics. The fuzzy controller often applies heuristic set of logical or discrete rules for synthesizing the control signal which depends on the measurement outputs. Fuzzifier, Knowledgebase, Rule base, Inference engine, and Defuzzifier components are used to obtain a robust control and increase the efficiency of the control system.

Hybrid Soft Computing Control

Here the controller implement is based on combination Fuzzy ï Neural Network and Fuzzy ï GA, Fuzzy- Evolutionary algorithm, GA- PSO, Fuzzy ï NN and more other combination.

Proposed Algorithm Hybrid soft computing with the statistical approach Taguchi MPSO based control

Here the Controller implement is based on PSO with Taguchi method, GA with Taguchi method and Mutation PSO with Taguchi method.

1.5 Definition of the Problem

Nonlinear processes are exceptionally regular in the process industry and outlining a stabilizing controller is constantly wanted to amplify the production rate. In this Research work, tuning of PID controller for a class of time-delayed stable and unstable nonlinear system utilizing Taguchi Mutation Particle Swarm Optimization (MPSO) calculation is proposed. The effectiveness of the proposed plot has been approved through a relative report with traditional controller tuning strategies and heuristic techniques, for example, Genetic Algorithm, Artificial Bee Colony, Bacteria Forging Fuzzy control, and Particle Swarm Optimization and Taguchi with GA. At long last, an ongoing execution of the proposed technique is carried out a nonlinear Quadruple tank system. From the recreation and ongoing outcomes, it is obvious that the Taguchi MPSO algorithm performs well on the nonlinear complex process models, considered in this work. The Taguchi MPSO tuned controller offers upgraded process qualities, for example, better time domain details, smooth reference tracking, supply unsettling influence and error minimization. Impact of the Tuning parameter in view of TMPSO simulation and experimental set up has also been examined.

1.6 Objective and Scope of the Work

In this the research work, the objective is to develop and test different control strategies on a four-tank laboratory process in order to achieve good performance and stability in the system. It is required and expected that the implemented control strategies be able to handle the multivariable system effectively not minding any process limitation. The implemented strategies would be compared, that is the Taguchi MPSO based controller and the other controller and their various performances would be analyzed. And since the objectives are to analyze the implemented strategies and making it available for further studies, so that it would enrich the user's hands-on experience. It is moreover important to make the implemented approach more helpful to industries as regards to the user interfaces.

The Objective of this research work is to control the nonlinear system using a hybrid soft computing approach. The statistical method is combined with soft computing techniques to optimize performance indices and to reduce the interaction effect of the nonlinear MIMO system.

Objectives:

- To review the control method of a nonlinear system, based on the PID controller.
- To survey nonlinear system, based on PID controller exists mathematical modeling and control strategies of the controller.
- To study and investigate the optimal tuning of PID controller for the nonlinear system, based on Z-N method, other heuristics approach like PSO, GA and Taguchi combine with Genetic algorithm and Taguchi combine MPSO algorithm implementation for the nonlinear system. The proposed algorithm is implemented

on MATLAB with a mathematical model of quadruple tank system for the simulation as well as real experimental set up.

- To investigate simulations of Taguchi MPSO strategies using the SIMULINK models as process plants for QTS cases.
- To design and to develop the quadruple-tank system for implementation and validation of the proposed algorithm.
- To identify the hybrid soft computing approach for improving performance indices for quadruple tank nonlinear system.

The scope of the of work

- We have designed and tested control strategies to illustrate their performances and reliabilities
- We have investigated simulations of the PID with Ziegler Nichol, PSO, GA Taguchi, Taguchi GA and Taguchi MPSO techniques for improvement of performance indices.
- We have designed and developed the quadruple-tank system for proposed algorithm validation
- We have compared the result of proposed techniques based on performance indices with other techniques.

1.7 Original Contribution by the Thesis

The contribution of this research is to control the nonlinear system for improvement of performance indices, in terms of a combination of the statistical approach, Taguchi method with a mutation on Particle Swarm Optimization algorithm to control highly nonlinear system. This proposed hybrid algorithm improves the performance indices of a nonlinear system. This proposed calculation is exhibited to design optimal PID controller in the nonlinear framework for enhancing the performance indices. This combinational algorithm selects optimal parameter of PID controller, which are controlling the Quadruple tank nonlinear system and it is improving performance criteria ISE, IAE, ITSE and ITAE of the nonlinear control system. The contributions are as under:

- The utilization of the AI of both PSO and a GA and Taguchi with GA and Taguchi with MPSO for the non-linear MIMO System.

- Real-time practical implementation of the control strategy for a Quadruple Tank system MIMO System.
- The real-time optimization of the above using either a GA or a PSO, Taguchi GA and Taguchi MPSO approaches for Quadruple Tank system
- The Design and Development of Quadruple tanks system for implementation of a Taguchi combine with MSPO Method.

1.8 Thesis Organization

The thesis organized in seven chapters which presents detailed information of our work here.

In the first chapter we have given a brief introduction to problems and challenges engaged in nonlinear MIMO control system. We have shown literature related to the problems, challenges and research gaps. We now have added the issue assertion, objectives and our contributions to this thesis.

In the second chapter, we have briefly seen how it works and finds that it is unique from the others alternatives and how it addresses the problems towards a better way and also consists of literature review about other techniques for the nonlinear system.

In the third chapter, we have projected Taguchi MPSO manner of nonlinear Quadruple tanks MIMO system. We are going to conjointly discuss simulation results of the projected theme for varied performance indices with the present schemes.

In the fourth chapter, we have explained the planned control technique primarily based upon the Taguchi MPSO. We are going to additionally compare the conventional, as we tend to give another hybrid soft computing methodology. We are going to conjointly discuss the manoeuvre results of the offered theme with the prevailing schemes.

In the fifth chapter, we have extended our work primarily based upon Taguchi MPSO methodology. Improvement of the performance indices for the proposed algorithm is better. The ISA, IAE and ISTE and ITAE are reduced based on selecting various PID controller performances. We also present another soft computing algorithm for the improvement of system performance for better results. All of us will show the various simulation results and test results of the offered method and also give the comparative analysis.

In the sixth chapter, we have shown the experimental response of quadruple tank system with servo and regulatory. To calculate it we have discussed our proposed Taguchi MPSO techniques to optimize the PID tuning parameter based on the improved response of performance indices for the nonlinear system. We have shown the value of performance indices of the nonlinear system in comparison to other techniques. We will show the capital simulation over and above analysis results of the suggested method.

In the seventh chapter we have given conclusion of research, ultimate outcome and future scope of the research work.

CHAPTER 2

1 Literature Survey

2.1 Introduction

This section condenses the writing study that leads to a piece of the research work reported in this thesis. It covers appropriate built up ideas and procedures, identified with nonlinear complex quadruple tank control process. Re-enactment and ongoing execution results in servo and regulatory process utilizing regular and intelligent control methods utilized in different literature works, which are investigated and talked about here. The literature review was directed on different optimization strategies associated with advanced additions of various controllers with single and multiple interaction goals. A point by point study has led to factor change procedures and the international linear control structure in both simple feedback and cascade modes of operation methods of activity, which are examined. The study is exhibiting the accompanying topics.

A literature review is an incessant way to which it was executed during the study of research work. The main objective of this segment is to provide sufficient background information on control of nonlinear system based on Taguchi based MPSO techniques. Literature reviews of my research work are divided into four different levels, Table 1.1 shows component-wise explanations about this stage with their objectives. This different level study is based on hybrid soft computing approach towards control of nonlinear system such as Twin Rotor MIMO system, Distillation column, Quadruple tank system. In the second level reviews, control techniques are used for different control nonlinear system. The third level indicates the various optimization techniques used for the control system to optimize the various integral performance criteria and also optimize the time domain and frequency domain characteristics of the system.

TABLE 2.1: Various levels of Literature review based on research

Level	The topic of Literature Review	Objective	Outcomes
1	The nonlinear Quadruple tank system	To get the concept of the nonlinear mimo system	explored the knowledge of the nonlinear system
2	Control techniques	To understand the various control techniques	Made a study of various conventional and hybrid soft computing techniques and its limitation
3	Optimization method	To find an efficient and stable optimization technique for Nonlinear Quadruple tanks system	Taguchi based MPSO based optimization technique is identified which selects best PID controller parameter to the improvement of performance indices. This algorithm is most suitable for MIMO system. It is efficient and stable.
4	Performance index based on various control techniques	To analysis which method is better for improvement of performance indices	Enhanced the category of the performance indices for nonlinear control system

Following are the literature that reviewed throughout my research analysis work

- Nonlinear MIMO system based research papers
- Quadruple tank system related Conference proceeding
- Control techniques referred Peer review Journal
- Report on control laws and regulation for various country
- Video lectures delivered by long familiar universities on various hybrid soft computing techniques for nonlinear system
- Nonlinear system control based Thesis and Dissertation database
- Various books referred based on research work level

The literature reviewed throughout my research study is extremely helpful to search out the chasing information as under:

- Nonlinear control system understanding
- The concept of Quadruple tank nonlinear MIMO system

- Various control techniques to control and improve the performance of nonlinear MIMO system with advantages and disadvantages.
- Challenges to control and improve the performance of the nonlinear control system
- The concept of optimization techniques
- Find the best optimization techniques for nonlinear MIMO system
- prevail the result based on simulation
- prevail the result based in experimental
- Compare all performance indices with all other techniques by simulation as well as experimental set up

2.2 Literature Reviewed on control techniques

2.2.1 Conventional PID Controller

Ziegler Nichols (1942) proposed a time domain approach to identify the parameters of controllers in terms of the parameters obtained from the process reaction curve and a frequency domain approach which is a closed loop method in which the controller parameters are calculated from the ultimate gain and ultimate period but Cohen and Coon (1953) derived empirical formula for finding the tuning parameters of proportional, proportional integral and proportional integral derivative controllers in terms of process parameters of the FOPDT model. He concluded that open loop step responses of all the processes were sigmoid (ósô shaped) curve and also they can be approximated as FOPDT models. Then he used different criteria to obtain the tuning formula for the tuning parameters of controllers. He derived formula for the linear process. (Hang et al 1991)[4]. He has improved the performances by using Second Order Plus Dead Time (SOPDT) model under closed loop conditions. Krishnaswamy and Rangaiah have developed a simpler technique for estimating SOPDT process parameters using only three points of the process reaction curve [5]. The points chosen seek to minimize the discrepancy between the actual and the model responses in terms of IAE, thereby providing some theoretical consideration, involves the use of set of new correlations for parameter estimates. This needs a graphical technique or computer search which is eliminated. Performance of PID controller exploitation FOPDT model has been conferred by Lee et al [75]. He has discovered that the PID standardization strategies victimization the FOPDT model gave a terrible overall performance for some processes.

Restriction of Conventional PID has been brought out by Lee and Sung, even though the tuning of Z-N PID controllers are existing. Integration method offers poor control performance in PID controllers and also considers the huge delay method [103]. The controller cannot control effectively to ramp type set point change and slow disturbance. Optimization methods have been developed by the authors to raise the lower performances. The control structure of two PID controllers to attain set point trailing and disturbance rejection one by one has been introduced by the authors. Class of nonlinear controller has been introduced by well known Kravaris and Wright that combines the theoretical rigor of geometric control methods with the intuitive appeal of predictive model control methods known as predictive control of models [73]. In its original form, Model Predictive Control is a model predictive controller that uses a linear impulse response model to predict the future behavior of the system. According to the conceptual steps of the original method, it was developed through a generalized state approach for linear and nonlinear systems. Kravaris and Niemec have worked on additional extended to multivariable nonminimum phase in a nonlinear system [76]. In their work, an algorithm could be a nature of control law, within the recognized that the control action isn't operated off the error solely, therefore the set point is processed in different ways. Finally, a simulation example, using a non-isothermal CSTR wherever a series or parallel reaction demonstrates the closed-loop performance of the projected technique. ZN-PID controllerꞌs confinements have been presented by Shen and Yu [94]. Regardless of whether the tuning of Z-N PID controllers is very much liked, the controlling issues may emerge for under-damped frameworks. Shen and Yu had modified the Z-N PID controller to give a better output for under-damped systems [94].

Recent development and future direction on linear control of nonlinear process have been presented by Nikolaou and Misra [85]. All chemical process are nonlinear in nature virtually are summarized by the authors, but some of them linear control feedback system is enough. Specifically, they have presented a rigorous and general theoretical system as well as an associated, heuristically refined computational methodology that allow not only analysis but also the synthesis of a linear control system for a nonlinear process. Application to the multivariable case is bestowed. Potential future developments at intervals in this framework which are mentioned. Wright and Kravaris (2003) have concentrated on incorporating nonlinear decoupling controllers for multivariable nonlinear systems, represented a state-space model in the presence of dead times [72-76]. The dead times appear in both the sources of measurement as an input and the yields as an output but not in the states and are physically connected with sensors and actuators. Simple sufficient conditions for the feasibility of closed-loop dead times are derived, which rely only on the basic properties of the system. A control law is then inferred so that closed-loop systems are input and output linear and decouple, with dead time equal to smallest ones fulfil plausibility conditions. The proposed method is applied to a chemical process. Its performance is evaluated through simulation in the presence of set-point and load disturbance changes. The proposed method is connected to a compound operation. Its execution is assessed through reproduction within the sight of set-point and load unsettling influence changes.

Gimble and Ordys (2001) have presented a review of some well known predictive control algorithms like dynamic matrix control [62]. The preview controller has been outlined. The combination of predictive control and linear quadratic Gaussian control will provide improved robustness together with adequate speed for a response. Those features are sometimes difficult to execute in the traditional formulations of predictive control. Two algorithms have been proposed which merge the linear quadratic Gaussian predictive controller in the polynomial domain and the dynamic performance predictive controller in the state space domain. R. Anand Anatarajan and M. Chidambaram, (2005), they proposed two methods. One is based on the Smith prediction from the model in the transformed domain and the other is based on Newtonô s extrapolation method [94]. The simulation study was made on the conical tank level process and the results were compared with those obtained using a conventional PI controller and the Smith PI controller. All the above studies reveal that the GLC is applied only to SISO systems not to MIMO systems. But GLC is proved to be most suitable for nonlinear systems. This concept paves the way to apply GLC for MIMO systems. Thus the study based on the GLC applied to MIMO systems is proposed in this work. R.Suja Mani Malar (2008) designed a Decentralized fuzzy controller for a multivariable laboratory four-tank process. Simulation results confirm the effectiveness of the proposed control methodology [102]. This work clearly shows the potential advantages of using a decentralized fuzzy controller for a quadruple-tank process. The control algorithm has a good setpoint tracking, not for load changes

. Above study makes learn about some limitation of the conventional PID controller to control the various applications but it has some control limitation for the particular application. The multivariable system involves more than one control loop, these loops interact with each other and in such a manner that single input not solely affects its own output, however, conjointly affects different process outputs. QTS has four tanks and 2 pumps, this benchmark is simply a water level control problem. The aim of the multivariable tank system is to maintain the height of the bottom tank at demanded setpoint values. Related laboratory process introduced by Johansson, the process is used to show multivariable interactions which are also known as coupling and it limits the performance in multivariable control systems [20-24]. Multivariable interactions in a QTS are each output (water levels) of the system which have affected by two pumps. Due to these reasons, it can be regarded as a prototype for many MIMO control applications in industry such as paper production processes, chemical processes, metallurgy and biotechnological areas, medical industries.

The three-term proportional, integral and derivative (PID) controllers dominated over the process industry for over six-decades and still existing. The major important point of PID controllers is because of its simplified structure, strength and over a large very of pertinency and appropriate performance, yet , restricted to straightforward control issues. In 1939, the primary industrial application of PID controller was introduced and a good deal of analysis and research commenced. Since 1942, varied PID tuning techniques have been developed and an outline of preferred tuning strategies for PID controller is obtainable. In the previous few decades, advancement and competition within the process industry developed several complex control issues wherever classical PID was unable to cope and control community attempt for good solution. Miller et. al., has illustrated a number of the most challenges visaged by the control community. Considering the recognition and reliability of PID, several researchers tried to develop the best PID. Rivera et. al., introduced an Internal Model Control (IMC) based PID controller design using a 1st order process model [109,126], and this was later extended by Chien for a second-order process model [149].

2.2.2 Genetic Algorithm PID

Owing to the requirement of industrial manufacturing processes, the liquid tank level control system is applied to many processing fields. For example, the raw materials stock of chemical works, the mixture raw materials of lithification process, the mold casting process and the steam generator of nuclear power plant, involve liquid level control to a certain extent. Conventionally, the linear PID control schemes are employed to have control of the liquid level for a number of liquid tank systems. However, as regards to the high-precision control, it is insufficient to use linear PID controllers [108]. In the PID controller, to be implemented, which has three basic variable tuning parameters proportional gain, the integral gain and the derivative gain and it must be judged very cautiously. Various techniques have been designed and developed to find PID controller parameters for single input single output systems. Among the well-known approaches, are Ziegler-Nichols method, the Cohen-Coon method, Integral of Squared Time-weighted Error rule, Integral Absolute Error rule, Internal Model Control based method, Gain-phase margin method. Several new methods from an artificial intelligence approach, are such as GA, fuzzy logic, the applications of GAs have been expanded into various fields. With the abilities for global optimization and good robustness and without knowing anything about the underlying mathematics, GAs are expected to overcome the weakness of tradition, all PID tuning techniques and to be more acceptable for industrial practice[108]. In the previous work, it has been shown that GA gives a better performance in tuning the parameters of PID controllers than the Z-N method. The improvement of genetic algorithm based on simplex crossover operator is utilized for the parameter optimization for support vector regression to influence the crossover operation to get the gradient, to make a modification through linear computing in the parameters, which are the requirement scope after the reflection, expansion, and compression operation on the simplex operator and to introduce the crossover validation method into the selection of fitness function of genetic algorithm to improve the algorithm's generalization the performance has been proposed by Dongmei Zhang [113].

This marvelous technique will notice the sensible problem to the improvement with findings of issues. It concerns to a specific category of biological process programming that utilized techniques galvanized by a biological process like inheritance, mutation, selection and also a crossover. The best result is got by this algorithm giving a constant best fitness operates to attenuate. The genetic algorithm (GA) uses a direct analogy of such a natural evolution to do global optimization in order to solve highly complex problems (Goldberg, 1989). It presumes that the potential solution of a problem is an individual and can be represented by a set of parameters. Kim, Park, Choe, and Heo, 2008. Korkmaz, Aydogdu, and Dogan (2012) compared the performance of nonlinear conventional PID and GA based PID [25]. The result shows the effectiveness of the approaches for tuning the PID controller. In a comparative study of various intelligent techniques for temperature control of water bath systems, Saini and Rani (2012) found that the use of advanced techniques, such as Artificial Neural Networks (ANN) and GA with the conventional Fuzzy Logic Control offers encouraging advantages. The novel genetic algorithm is used to identify multi-variables nonlinear boiler system having 300MW power plant, detailing by Dimeo and Lee [80]. Neural Networks and genetic algorithm are adaptive optimization method depends on biological rules. All such methods like floating-point coding, elitist reservation and grouping method, rank based selection are implemented in this algorithm, the searching power, is to be enhanced and the premature convergence is also to be restrained. These problems consist of reducing the weighted connections in feed-forward neural networks utilizing into two category representation such as binary and real-valued, use of a genetic algorithm to develop new novel constructions with the design of property patterns for neural networks that makes learn by utilizing error propagation. Parameter improvement and good work for an associate acceptable tool have been inferred by genetic algorithm. Genetic algorithm can be used to design control system of the boiler-turbine plant. Minimize the integral squared error of input and states optimal control problem are solved by using a genetic algorithm. Interacting with a powerfully made Binary Space Partitioning file has been arranged by Yuen. The origination of Binary Space Partitioning file starts from the fields of computer graphics and mathematical detailing computational geometry. The Binary Space Partitioning method chronically developed as an irregular tree that its development strategy mirrors the advancement part of the various soft computing techniques and is a quick technique to address regardless of whether there is return.

2.2.3 Particle Swarm Optimization PID

PSO algorithm is the most widely used optimization technique since it has fast convergence, few parameters to adjust and hence easy to implement. The interactions of the four tank system are studied and the controller strategies such as Internal model control, Bacterial forging optimization method and Particle swarm optimization techniques are implemented and analyzed using MATLAB Simulink to maintain the heights of the bottom two tanks. The response of the aforementioned techniques is analyzed and compared. This techniques procedure utilized for setting of neural network systems used to compel both inverts and forward representing of metal inactive gas welding system an optimization method in light of Particle Swarm Optimization improvement is presented. The PSO reactions are contrasted to decentralized PI and GA reactions. In this response, it is seen that the integral error criteria such as ISE and IAE esteem are very low with PSO based controller than the decentralized PI-based as well as GA based controller. For the basic tuning of the PID parameters, there are many optimization techniques are available like Zeigler Nicholas method, Ant Colony algorithm, Particle Swarm Optimization, Genetic Algorithm. PSO procedure has been utilized to tune the controller consequently that can altogether diminish the computational exertion contrasted with manual graphical systems. It has likewise been exhibited that this strategy robotizes circle forming as well as enhances outline quality and most conveniently, enhances execution with ideally tuned PID controller in a quantitative way. Current studies on tuning PID controller focus on the new approach of PSO. For example, Tandan and Swarnkar (2015) introduced Modified Particle Swarm Optimization (MPSO) which is a simple and fast approach for optimizing PID controller. This approach is able to improve closed-loop performance over the PSO based optimized PID controller parameters. In a study by Asifa and Vaishnav (2010), PSO is proposed to improve the step response of a third order system. A comparison with other conventional approaches shows that the PSO based PID controller produces superior results, especially on the stability convergence and computational efficiency. The advantages of PSO approach have attracted our attention to apply this approach for solving a single water control system in this study. Classical optimization techniques are not applicable here because of the roughness of the multidimensional objective function surface. We, therefore, use a derivative-free optimization technique Particle Swarm Optimization (PSO) originally devised by Kennedy and Eberhart [114]. It draws inspiration from the intelligent, collective behavior of a swarm of social insects (particularly bees) foraging for food together. PSO and (subsequent modifications thereof) are highly regarded in research communities due to its combination of simplicity (in terms of its implementation), low computational cost and remarkable efficacy. Vrahatis and Pedophiles attempted to change to find efficiency in PSO by implementing two times transformations of the objective function which rejects and elevates the neighborhood of the local minima. The objective function is chosen so as to decrease the integral of time absolute error (ITAE) performance index. Comparative analysis between proposed (PSO and GA) tuning method and another method check and simulated in MATLAB. After that result it gives genetic algorithms better response compared to PSO based on the Performance Index. Particle swarm optimization is utilized for the design of frequency specific surface and other optimization based on population computation which could be utilized to take care of the minimization for this issue, display the optimal design of fast pivotal motion generator presented by Sadeghierad et al**.** advancing the effectiveness of machine to be utilized by PSO and GA. It calculates and coordinates the fundamental highlights of GA and PSO into the advancement procedure to tackle the entangled dispersing opposite issue solved by Bouzid Mhamdi et al. Tuning of neural network system has utilized for completing both forward and invert mapping of metal inactive gas welding application executed based on Particle Swarm Optimization. Multi-objective index optimization for determining the size and area of multi-distributed generation units in conveyance frameworks with various load models have been proposed by A.M. El-Zonkoly**.** The proposed work additionally considers an extensive variety of specialized issues such as the line stacking, active power losses and reactive power losses of the system, the voltage output, the Mega Volt Ampere allowed by the grid.

2.2.4 Taguchi PID techniques

E. F. Ryckebusch, I. K. Craig presents the use of Taguchi methods for tuning PID parameters in a multivariable plant [148]. Anderson (2000) explains both the basic Taguchi procedure and how to use the analysis of variance for analyzing data. In this paper, the Two Input, Two- Output controller gains are tuned with this method. Researcher has used general experiment design methods implemented by Dr. G. Taguchi since the late 1940s (Roy, 1990). This general quality method was first used for improving efficiency in industrial applications, it can be applied in many different cases where discrete changes in parameter values are made. For instance, Chen et al. (1996), used these methods for optimizing laser micro-engraving of photomasks [148]. The effects of five key parameters were analyzed and the laser linewidth was optimized using an L16 orthogonal array. Griffin (2000) also used this design method to improve the quality of the Wheatstone bridge, which is an electrical device for precise measurement of values of resistor, gai tuning of a simultaneous multi-axis PID controlled system. The parallel mechanism machine tool used in this study (the Eclipse) provided a total of 32 controller gains to tune for robustness. If there arise an occurrence of a various info parameter procedure to get the best yield result, the main routes are to direct all conceivable tests masking the whole scope of variables. In this entire arrangement of trials was directed to make desired outcomes. The quantity of investigations associated with numerous cases is widely extensive, it turns into a time consuming with costly affair to get a right picture of the impacts of different variables on the watched information legitimately. Taguchi strategy utilizes an exceptional arrangement of exhibits called symmetrical clusters. These clusters enable you to consider a chosen subset of mixes of numerous components at various levels and guarantee that all levels of all elements are thought about similarly**.** Sir R. A. Fisher was the first to propose the system of spreading out the conditions of tests including diverse various factors. The technique is famously known as the factorial outline of examinations. To beat the issue of an immense number of investigations to be directed, Taguchi proposed an exceptionally planned technique called the utilization of symmetrical exhibit to consider the whole parameter space with a lesser number of trials to be conducted.

2.2.5 TGA and TPSO Techniques

Taguchi GA is a standard GA tuned with Taguchi quality strategy. This methodology has ended up being a critical instrument in the framework plan and process quality, has been connected to take care of numerous optimization issues in electrical machines' outline, aeronautic engineering and controller configuration compared to conventional Gas. This strategy has fewer analyses to get ideal GA parameters in tackling optimization issues utilizing the orthogonal array and signal to noise proportion (SNR) strategies. In this examination, the AIS swarm knowledge is tuned with Taguchiï GA to get better execution. This artificial immune system tuned with Taguchiï genetic algorithm (TGA) is then acknowledged in FPGA to address the opposite kinematics issue of high-degree of freedom (DOF) modern automated controllers and industrial robotics. Taguchi combined GA design of the third method for determining optimal PID controller parameters of an AVR system using Taguchi Combined Genetic Algorithm (TCGA) is presented. Taguchi method is used for finding the approximate values of the PID controller, whereas the Genetic Algorithm (GA) is used to find accurate results. The dynamic response of Taguchi

Combined Genetic Algorithm, Fuzzy controller and effectiveness of the Taguchi method is validated using MATLAB Simulink. The result shows that the TCGA method gives better performance than a fuzzy controller.

The novel tuning of a PID controller in the Automatic Voltage Regulator framework is based on the Taguchi based Genetic Algorithm techniques. The population random solutions are introduced by the Particle Swarm Optimization. There is one contrast in soft computing techniques based on particle calculation which assigns randomized speed to every solution. Every arrangement is spoken to particle aviate using such an arrangement space. Contrasted with GA, it needs less calculation and fewer parameter modifications. Notwithstanding, in spite of fact that this algorithm techniques is effortlessly executed and accomplishes speedy intermingling, it has a tendency to stall out in close ideal arrangements, which are hard to enhance by additionally adjusting. A survey of the PSO writing indicates not very many investigations of the multi-objective Flow Shop Problem (FSP). Each particle speeds and refreshes model to create different population and project a self-adaptive to sort out various control procedure to maintain a strategic distance from the untimely union for the discrete techniques to improve with hindering limit to make a length as presented by Wang and Tang. The search capacity was being utilized to enhance by a most basic search technique identified stochastic variable. In an enhanced particle swarm optimization calculation in light of the "all unique" limitation, is projected to understand the Flow Shop Problem with the target of limiting range. That is by virtue of that the speed status of particle and place are both demonstrated as stages of all occupations which must satisfy the "all one of kind" constraint. This requirement of powers for each decision variable, in an offered gathering to expect esteem unique in relation to the estimation of each other variable in that gathering. PSO with genetic operator combines with this algorithm effectively. To solve multi-objective Flow Shop scheduling Problems (FSPs) for a specific system is to be presented by an HSLTPSO algorithm. This HSLTPSO efficient algorithm coordinates various other techniques such as sliding level Taguchi-based crossover, elitist protection and PSO. This new method hybrid sliding level Taguchi-based particle swarm optimization are utilized by a PSO to investigate the less executable part in full scale-space, the use of systematic reasoning techniques of the sliding level Taguchi-based crossover put to use the best solution to micro-space and the function of the elitist protection techniques to carry the good particles of multi-objective population of the following accent. The literature studies were found the application of the MGPSO using concepts of Pareto optimally to a multi-variabl quadruple-tank process. Compared to a classical multi-objective PSO algorithm which is applied to the same process, the MGPSO shows considerable robustness and efficient in PI control tuning. A multi-objective design enhancement is acquainted with the limit most extreme rate of dynamic response of the main voltage which effects the output result of the synchronous generator. Optimization related issues solved by proper selection of the constant for tuning the PID controller. In other research paper, by using discrete particle swarm optimization to solve the no-hold up Flow Shop schedule partitioning with both the criteria, creates a range and aggregate stream time. Hybridizing the discrete particle swarm optimization with the variable descent algorithm was enhanced through arrangement quality of the system.

2.2.6 Performance Indices

Awouda and Mamat (2010) found an efficient tuning method of the PID controller by using the optimization rule of ITAE performance criteria. The method implies an analytical calculation of the gain of the controller for PID controlled systems. The objective function is selected so as to minimize the ITAE performance index. The study shows that the ITAE tuning setting by the authors gives a small rise time. T.T. Erguzel found improper fitness functions were selected (some integral system performance measure such as integral time squared error ITSE, deviation from the designed trajectory, etc.) which were complex, depended on the experiment's result and did not take advantage of the GAs facilities for a multi-objective optimization by combining different requirements. Meenakshi Kishnani1, Shubham Pareek and Dr. Rajeev Gupta found PID controller is designed for the DC motor plant with its parameters optimized by the Artificial Bee Colony Algorithm [157]. The objective of this paper is to show that by using ABCA optimization was achieved and optimized system response by three fitness functions i.e. IAE, ISE, and ITAE were compared. A.B. Campo finds out the design specification presented at the references which was attended through the use of an exhaustive search algorithm to obtain the best response according to the performance index Integral Absolute Error. MATLAB code used to apply this algorithm, is effective and has generated a better response than that presented at references. From the literature, more objective functions have been proposed as an integral performance criterion. In the control system, it is to decide the objective function that will distribute in terms of time and frequency domain based on performance criteria. The most usually utilized functions are the time domain integral error performance criteria which are based on calculating the error from the controller between the process control output and the input reference signal. There are four type of integral performance functions i.e IAE, ISE, ITAE and ITSE. Tavazoei has presented the type of integral functions based on performance with the fractional order of the time weight and absolute error. General execution rule to encourage the control technique over both the time and frequency area particulars have been proposed by Zamani [111]. There are two frequency parameters consist of the eight terms objective function. The essentialness of each term is controlled by a weight factor. Confirmations have exhibited that the proposed performance criteria can look productive for the optimal controller parameters regardless, the decision of the weighting factors in the objective function which isn't a simple task.

2.3 Problem finding from the literature review

From the literature review controlling the multivariable nonlinear system, is a challenging work to perform various control techniques. We also found using various control techniques to optimize performance indices of the nonlinear system at a certain level. In this work to control the nonlinear system based on various control techniques such as Internal Model Control, Model Reference Control, Genetic algorithm , Fuzzy Control, Particle Swarm Optimization, various soft computing approach, hybrid soft computing approach, various conventional control PID, PID controller tuning of all type control techniques are very useful for the optimization of performance indices of multivariable control system in specific level such as quadruple tank system which has highly nonlinear control system for simulation as well experimental analysis of the various control system to validate the performance indices of the nonlinear system.

2.4 The Methodology of Research:

The proposed work consists of two parts i.e. Design control strategies for nonlinear system and Development of Quadruple tank system for experimental validation. The following results have been obtained for different heuristic approach with simulation and experimental process. We can use different methodology for the control and stability problem in nonlinear system to design the PID controller parameter like PID controller with Z-N Method, PSO PID Controller, GA PID Controller, Taguchi Method statistical Approach, hybrid soft computing functional Approximate GA (TGA PID) Taguch combine with Genetic Algorithm PID controller, Taguchi combine with Mutation Particle Swarm Optimization PID controller. Check and validate the result with the Taguchi method with Mutation PSO algorithm. Here there are different algorithm techniques implemented in a mathematical model to control the nonlinear quadruple tanks system in MATLAB for the different parameter of PID controller. After the result of different techniques for PID Controller, we can conclude that overall result for the different technique is to improve the result of performance indices in the simulation. Afterwards, we have designed and developed the real experiment set up for checking the stability and control the quadruple tanks system in minimum phase response. We have designed and developed the Quadruple tanks system having NI DAQ USB based card for acquiring the two analog signals from the level transmitter and generate the appropriate output signal based on control Taguchi MPSO based PID controller. We are achieving the best result out of all other techniques to control the nonlinear system and improve the performance indices.

CHAPTER 3

3 Nonlinear Control System

3.1 Introduction

Modern control industrial issues are typically consisting of highly nonlinear and have numerous parameters. The process control engaged with such higher production, industry process demonstrate noteworthy, meaningful uncertainties, minimum and non-minimum phase nature of the process based on a certain parameters of the process and multiple loop interactions.

The nonlinearity of such modern control processes comprehends that there is a requirement for a research center for hardware laboratory equipment to compete with the experimental tests. The quadruple tank system is a unique system utilized to dissect the nonlinear impacts in a multivariable control process. The nonlinear system is broadly utilized in the figures of the dynamic multiple interactions and nonlinearities showed in the reaction of petrochemical, pharmaceutical, fertilizer industries and chemical industries. The control of such collaborating multivariable process control system is of extraordinary enthusiasm for process control industries. Multivariable control systems are adopted in industrial control processes. It is exceptionally hard to control the multivariable control processes because of the multiple loop interaction between the factors. Keeping in mind the end goal to meet the high product quality and energy utilization prerequisites of the process industry, the multivariable system must be controlled successfully. Different strategies for planning PID controller and various techniques for design and development PID controllers are available in the literature. The multivariable controller is outlined based on maximum closed-loop log modulus. Since it measures the robustness of the control systems and strength of the control frameworks and consequently can show the suitability of controller outline as for the current working conditions. In recent years, heuristic techniques are used in various engineering and commercial optimization issues. The distillation column is considered as a case for simulation purpose by Ogunnaike and Ray. It is a remarkabl application of nonlinear multivariable systems. It is implemented in various multivariable distillation columns, Twin Rotor MIMO system and quadruple tank system. It is also works to check integral criteria of process system in terms of performance factors such as ISE IAE, ITAE and ITSE which are likened.

3.2 Quadruple Tank System

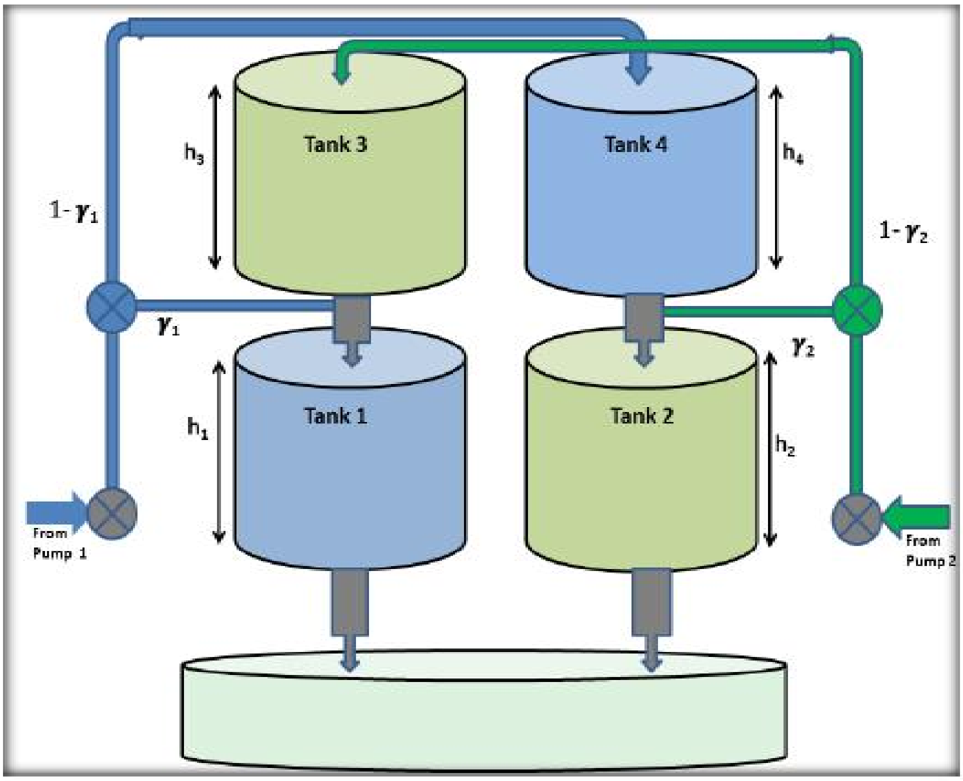

FIGURE 3.1: Schematic of Quadruple Tank System

The highly nonlinear complex system is an example of a quadruple tank system that utilized to develop various control methodologies. The experiment process set up consists of four different interacting tanks, two manually operated valves, and two water transform DC pumps. It is said as multiple interaction double tanks process. First and second tanks are set underneath and third and fourth to get water stream by effect of gravity force. The two process inputs are voltages v1 and v2 supplied thorough PWM signal to the two DC pumps. To mass the outgoing water from tank1 and tank2 a supply is available in the base of every tank and has a valve fitted to its outlet. The activity of pump 1 and 2 is to suck water from the reservoir and pass it to tanks based on the valve opening Pump 1 passes water to tank 1 and tank 4 and the pump 2 passes water to tank2 and tank3. Lower tank get water from their related upper tanks due to gravitational effect. Purpose of the system is to maintain the liquid heights of the bottom tanks. The fluid levels in the lower tanks are controlled. We can say the height of both tanks as h1 and h2. These valve positions give the proportion in which the output from the water pump is separated between the upper position and lower position tanks. The water flow to the tanks can be balanced through the position of the valve. The position of the valve is settled amid the examination and just the pump if differed by changing the input applied voltage. The task of quadruple tank system can be grasped in two stages to be a minimum phase and non- minimum phase. Consequently, the process can be kept in a minimum or non-minimum phase condition.

3.2.1 Mathematical Model of Quadruple Tank system

The process which has nonlinear characteristics has a more interaction of quadruple tank processes, which are touchstone processes used in many industrial applications. This frame-up is very simple and rugged but still, the system would elaborate concerning multiple variable techniques. Process modeling is very essential to look into how the characteristics of process responses with time under the effect of changes in the extraneous interferences, manipulated variables and consequently in designing a specifically selected controller. In this process, two different techniques have been used, one of this is experimental setup and another one is a theoretical aspect. In such a case, a representation of the process is required in order to examine its process static and dynamic characteristics. These approaches are usually contributing in terms of a set of combination, theoretical with mathematical equations whose solution gives the better dynamic characteristics of the process. The primary guideline mathematical model for this process utilizing mass balance, energy balance and Bernoulliׂs law is gotten. The process flow diagram is viewed in Figure3.1. The main object is to maintain the levels ɔ1 and ɔ2 at bottom tanks with prime movers. This mathematical model required for the present experimental lab incorporates and furthermore the exasperating impact of flows in and out of the upper side-level tank. Input voltage is applied to prime movers V1 and V2 (input voltages to the pumps). This process is represented by the differential equations according to the material balance equation.

Processes are represented by equations

$$\frac{dh1}{dt} = -\frac{a1}{A1}\sqrt{2gh1} + \frac{a3}{A1}\sqrt{2gh3} + \frac{\gamma1K1V1}{A1} \quad [1]$$

$$\frac{dh2}{dt} = -\frac{a2}{A2}\sqrt{2gh2} + \frac{a4}{A2}\sqrt{2gh4} + \frac{\gamma2K2V2}{A2} \quad [2]$$

$$\frac{dh3}{dt} = -\frac{a3}{A3}\sqrt{2gh3} + \frac{(1-\gamma2)K2\,V2}{A3} \quad [3]$$

$$\frac{dh4}{dt} = -\frac{a4}{A4}\sqrt{2gh4} + \frac{(1-\gamma2)k1\,v1}{A4} \quad [4]$$

TABLE 3.1: Physical parameters of the Quadruple-Tank

Parameter	**Limit**	**Description**
hi	Cm	Height of the tank i
Ki	Cm^3/S.V	Voltage to volumetric pump constant of pump i
Kc	V/cm	Water level to voltage proportionality constant of sensors
ɔ i	[.]	The fraction of water flow of the pump
ai	Cm^2	The cross-sectional area of water outlet hole of tank i
A	Cm^2	The cross-sectional area of the four tanks

This process presents interacting multiple variable dynamics, complex system because of each of the prime movers which involves both the outputs. This process exhibits nonlinear model and the nonlinear model converts to the linearization model of the nonlinear element available in the process which has multiparameters that becomes zero, which is to be placed on the left or the right half- S plane by setting the throttle valves position ɔ1 and ɔ2. It showed that the inverse response (Non minimum phase) will happen when the value of this valve in the range of 0 < ɔ1+ ɔ2 < 1 and minimum phase for 1 < ɔ 1+ ɔ2 Ò2. Valve position will be imparted to the general system, completely disparate conduct from various variable control perspectives. Immeasurable disturbances can be enforced through forced water out of the main upper tanks and into the main bottom man-made space small tank. It is exhibiting reject interference as well as mentioning the covering points.

TABLE 3.2: Limit of a parameter of the QTS

Parameter	Limit	Description
$h_{i\ max}$	10 cm	The maximum level of tanks
$h_{im\ in}$	0 cm	The minimum level of tanks
u_{jmax}	24 V	Maximum pump voltage
$u_{j\ min}$	0 V	Minimum pump voltage

Utilizing the multiple variable four tank process, different parts of multiple variable control systems can be delineated. For example:

- Design and analysis of mathematical model based predictive strategy. Development and analysis of ε-analysis-based HĐ control.
- Design and examination of state criticism compensator for various areas of the zeros.
- The locations of the zeros on the process output effect in different input directions
- Design and examination of decoupling compensator
- The valve positions impact on the area of the zeros.
- Design and assessment of decentralized control.
- Recognize when a procedure is simple or not to control

3.2.2 Linear Model

The hybrid model needs a discrete time, linear model of the process on the form, therefore, the nonlinear dynamic model Equation 1 to 4 will be linear around a working point x0 and u0 and then discretized. Linearization, made using First order Taylor expansion, gives

$$\frac{dx}{dt} = \begin{bmatrix} -\frac{1}{T1} & 0 & \frac{A3}{A1T3} & 0 \\ 0 & -\frac{1}{T2} & 0 & \frac{A3}{A2T4} \\ 0 & 0 & -\frac{1}{T3} & 0 \\ 0 & 0 & 0 & -\frac{1}{T4} \end{bmatrix} x + \begin{bmatrix} \frac{k1\gamma 1}{A} & 0 \\ 0 & k2\gamma 2 \\ 0 & k2(1-\gamma 2) \\ k1(1-\gamma 1) & 0 \end{bmatrix} u \qquad [5]$$

$$y = \begin{bmatrix} kc & 0 & 0 & 0 \\ 0 & kc & 0 & 0 \end{bmatrix} x \qquad [6]$$

$$Ti = \frac{ai}{A}\sqrt{\frac{g}{2xi}} \qquad Ci = \frac{Tj * kj}{Aj} \qquad j = 1, 2...$$

It is also useful for the following analysis to consider an expression of the transfer matrix of the system. The Laplace transforms of yields are the transfer matrix of the system.

3.3 Controller Design

The design method is compared with the following tuning method of PID controller design approaches

- The Conventional PID controller method
- Genetic Algorithm based PID controller
- Particle Swarm optimization based PID Controller
- Taguchi method based PID controller
- Taguchi combine Genetic algorithm PID Controller
- Taguchi combined mutation particle swarm optimization algorithm PID Controller

The tuning of the controller could be explained by maintaining the variable of the controller so that the system dynamic response is better or response based on the designer. There are numerous performance criteria for controller tuning that may accept, some of them are considered as under:

- Keep the maximum deviation as minimum as possible
- Decreases the integral of errors until the process has settled at its settling positions
- Gaining short settling times
- Performance Criteria

In the process control system, two types of performance criteria are to be satisfied, one is steady-state performance criteria and second dynamic performance criteria. Performance criteria based on the closed loop response of the system are overshoot, rise time, settling time, decay ratio and frequency of oscillation. The specified characteristics can be used by controller designers as per controller selection and parameter value adjustment. The design of controller mainly concentrates to minimize overshoot, minimum settling time and other parameters which are related to this given system. If this process is nonlinear, the main characteristics will be changed from one operating point to another operating point after that specific parameter tuning can produce the desired response at the only single operating point in the system. If there is a change in operating points in the system, it will change the controller tuning. Adaptive controller and self-tuning controllers are designed by required fine-tuning for a specific application. PSO and GA provide the best adjustment of controller parameters in the case of changing process dynamics.

3.4 PID Controller

3.4.1 Overview

Proportional-Integral-Derivative (PID) control is the most common control algorithm used in industry and has been universally accepted in industrial control. The popularity of PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity, which permits industrial engineers to run them in a very easy manner.

The whole idea of this controller solves around manipulating the error. The ERROR is the difference between the Setpoint - Process Variable. ERROR = SP ï PV. These 3 modes are used in different combinations:

Proportional ï Sometimes used
Proportional Integral - Most often used
Proportional Integral Derivative ï Sometimes used
Proportional Derivative ï Very rare, useful for controlling servo motors.

PID Controller composed of different constant such as proportional, integral and derivatives which give a better optimal response. The theory of conventional controller and its effect of tuning gives better response in basic feedback control system.

3.4.2 Control System

The fundamental thought behind a PID controller is to acquire a signal from the sensor, at that point figures the coveted actuator yield by proportional, integral and derivative reactions and summing up those three segments to process the yield before we begin to characterize the parameters of a PID controller. In a various process control system, the process parameters could be the system parameters that should be controlled, such as temperature, pressure, flow and level standard parameter. A sensor or transmitter is utilized to quantify the parameter of the process and give measurement input to the system which too is controlled. The reference point is coveted or direction esteem for the parameter of the process, such as 10cm height on account of a level control system. For example, if the deliberate level parameter is 10 cm and also coveted level reference point is 5 cm, at that point the final control output indicated by the controller program may be to drive a flow of liquid. To drive a final control element to start a pump and the system going to flow the liquid, to get the final result in increasing height (level). Subsequently, the deviation among the process variable and the set point is utilized by the control system compensator (controller), to determine the coveted a very last manipulated detail output to power the entire plant system, which is referred to as a closed loop control system, in light of the reality that the manner in the direction of reading sensors to offer in no way-finishing feedback and ascertaining the coveted actuator yield is rehashed continuously and at the constant loop rate, as represented in figure 3.2.

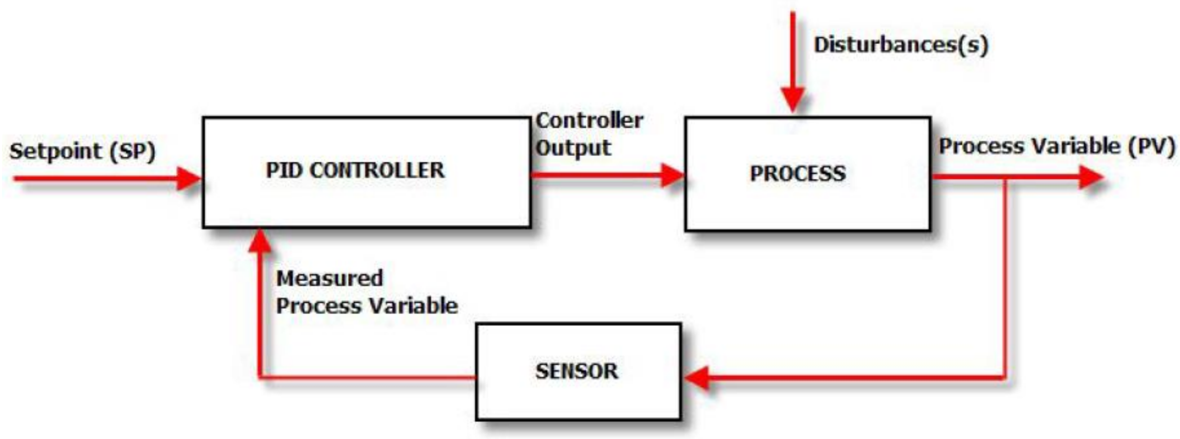

FIGURE: 3.2 Block Diagram of Control System

In many cases, the actuator output is not the only signal that has an effect on the system. For instance, in a temperature chamber, there might be a source of cool air that sometimes blows into the chamber and disturbs the temperature. Such a term is referred to a disturbance. We usually try to design the control system to minimize the effect of disturbances on the process variable.

3.4.3 Proportional Action

The deviation between the set point and the process variable just rely on the proportional element. The ERROR expression is mentioned by this deviation. The proportion of output response to the error signal is called the proportional gain (Kc). For example, if the ERROR term has an extent of 5, a proportional gain of 2 would generate a proportional response of 10. By and large, in any case, if the corresponding increase is too vast, the P, the process variable will start to sway. On the off chance that Kc is increased further, the oscillations will end up in bigger and larger and the system will end up flimsy and may even oscillate out of control.

3.4.4 Integral Action

The basic integral parts sums the ERROR term after some time. The outcome is that even a low ERROR term will make necessary part of the integral component to increase it gradually.

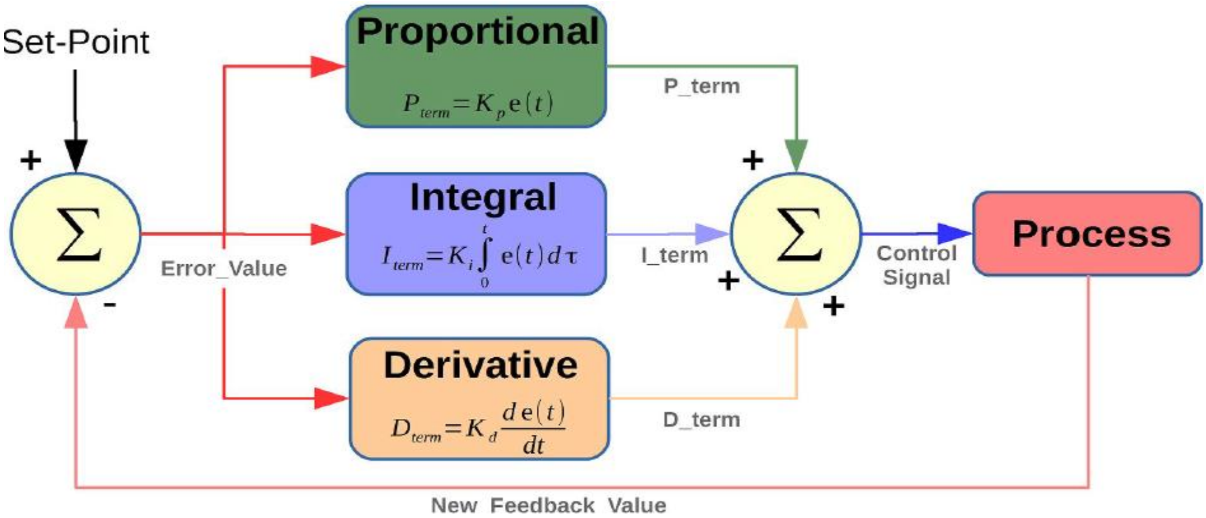

FIGURE 3.3: Block diagram of PID control.

The integral response will ceaselessly rise after some specific duration except if the process error is zero, so the high impact of the integral controller is to bring the final steady-state error to zero. The pure integral control tries to make error zero in spite of they have some value. The steady-state error is the final deviation between the process variable and setpoint. This is known as an integral windup.

3.4.5 Derivative Action

The derivative action is corresponding to the rate of change of the process variable. Expanding the derivative time (Td) parameter will make the control system respond all the more emphatically to changes in the error term. It will also develop the speed of the overall control system response. The derivative makes the yield to diminish, if the system variable is expanding fast. In the advanced systems for control to use very low derivative time (Td), in the real senses that exceedingly sensitive to the commotion in the process variable depends on the derivative response. At the off threat that the sensor feedback sign is uproarious or if the control loop rate is too sluggish, the derivative reaction can make the control system highly unstable.

3.5 Tuning based on Integral Criteria

The response of the complete closed-loop system at t=0 until steady state has been achieved can be utilized for the formulation of the dynamic performance criteria. Based on the closed response, these methods minimized the area under error vs. time curve. Significant of the tuning methods is to reduce the integral of the error so that it can address to improve the error integration. Minimize of Integral of error is not possible directly because a very large negative error will be a minimum value so that the absolute error value or square of error value is taken and will decrease.

Integral of the squared area: ISE = $\int e^2 \, dt$

Integral absolute error: IAE = $\int |e(t)| \, dt$

Integral of time multiplied by the absolute value of Error: ITAE = = $\int t|e(t)| \, dt$

Integral of time multiplied by the square the value of Error ITSE=$\int t \, e^2 \, dt$

For the computation purpose, the upper limit of the integral may be replaced by settling time. Processes with just a single output being controlled by a solitary controlled variable are delegated as Single-Input Single-Output (SISO) systems. Numerous processes, be as it may, do not fit in with such a simple control form. In the process industries, any unit task fit for manufacturing or refining a product cannot do as such with just a single control loop. Each unit operation typically requires control over not less than two control loops. The system with excess of one control loop is known as a complex nonlinear MIMO

system. MIMO processes have a multivariable zero. The control problem is simple for the minimum phase system, compared with non-minimum phase system.
The purpose of this task is to study problems related to multivariable control. The studied quadruple-tank process has two inputs and two outputs and by making minor changes to the process, it will switch from minimum phase to non-minimum phase. At the same time, the relative gain of the system will change significantly, meaning that a feedback controller controlling the process will also need a change in a sign. Preferably you use different feedback structure for the two cases. The quadruple-tank process is shown in Figure 3.4. The goal of the control system is to control the level of the two lower tanks. What makes the task more challenging is that the water from the upper tanks flows down to the tanks below. Pump 1 feeds tank 1 and 4, and pump 2 feeds tank 2 and 3. So we have interaction between the two tanks that are controlled. The way toward setting the optimal gain increases the P, I and D to get a perfect response from a control system, which is known as tuning. There are diverse techniques of tuning usage to get want output from the system the constant of a basic controller can be gotten by laboratory setup. Once an engineer encompasses the necessary gain constants, these techniques turn out to be relatively simple.

In this technique, the I and D terms are set to zero first and the proportional gain is expanded up to the point that the output of the loop oscillates. As one expands the proportional gain, the system is going to be quick respond, but attention must be given not to attain the system stable. Once gain P has been fixed to get a required fast response, the gain of the integral term is increased to remove the offset and decrease oscillations as well as steady-state error, but generates new overshoot value. The gain of the integral term is converted to reach a less steady-state error. Once the gain of P and also gain I have been fixed to get the coveted fast control system with insignificant steady-state error, the gain of the derivative term is increased until the loop is acceptably going to its desired value. In the expanding derivatives parameter diminish overshoot and show signs of improvement stability but system becomes endure to sensitive to noise. Engineering needs to trade off one behavior of the process control system for optimal to all the more better meet their fundamental requirements and desired output which is required for the process control system.

3.6 Application of Nonlinear MIMO system

Nonlinear MIMO control application area in industry such as

- Paper production processes
- Chemical processes
- Power plants
- Metallurgy
- Biotechnological areas
- Medical industries
- Distillation column in the petrochemical industry
- Batch process in the pharmaceuticals industry
- Underwater vehicle
- Spacecraft
- Robotic
- Avionic

CHAPTER 4

4 Control Techniques for Quadruple Tank System

4.1 Conventional PID controller

PID Controller is a most recent control algorithm employed in process industry & applications, more than 95% of the industrial controllers are of PID type. PID controllers are used for more precise and accurate control of various parameters. Most often these are used for the regulation of temperature, pressure, speed, flow and other process variables. Due to best performance and functional requirement of the process, it has been accepted in various industrial requirements and basic applications where numbers of accurate controls are the foremost required.

After many years, researchers have made studies to develop new advanced control strategies to give excellent dynamic nature to multiple inputs and multiple outputs system. The behavior of the multiple inputs and multiple outputs system is nonlinear. Nonlinear multivariable processes are consisting of many control inputs and outputs parameters found in various chemical and petrochemical plants. Form the many years research output indicated, in various process industrial plants, a method widely used in the decentralized method of the classical PID algorithm, is called multi-loop controller.

One strategy that has been genuine with the exception in the different research papers is the utilization of an improvement method of learning and problem solving to get the controller parameter. This is due to the strength of such methods in solving real optimization problems (mostly nonlinear), instead of with many constraints even though we got the best result in various optimized values. In such a method, the whole nonlinear multiple control systems are divided into individual parameter process loops, establishing the process easy to run. Even though there is problem distinguished in this method, this division involves the process dynamics, since there is an interaction between each process control loops.

To get effect of the tuning by r finding proper parameter of PID controller for multiple inputs and multiple outputs by using best conventional Ziegler Nichols method to get a best satisfactory response and to improve error output and reduce the coupling effect and changes for the dynamic response. It can resolve that the optimization function is very convenient for acquiring the system performance.

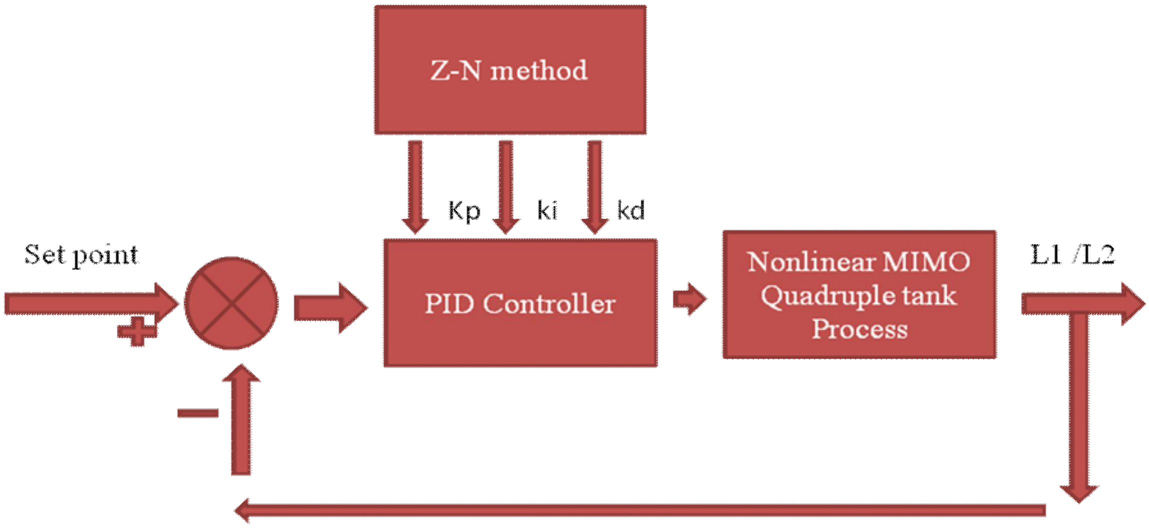

FIGURE: 4.1 Schematic of Convention PID Z-N Method for QTS

Tuning of PID controller based on Ziegler-Nichols method is a second popular method for controlling to I and D set to zero value for the process control system. P is rising until loop starts to oscillate. Once oscillation starts, a period of oscillations Pc and the critical gain Kc are calculated. For Tank 1 Kc = 12.00 Pc = 50 For Tank 2 Kc =15.70 Pc =85

TABLE: 4.1 Ziegler- Nichols Method for PID tuning

Control	**P**	**Ti**	**Td**
Proportional	0.5Kc	------	------
Proportional ï Integral	0.45Kc	Pc/1.2	------
Proportional -Integral ï Derivative	0.60Kc	0.5Pc	Pc/8

TABLE :4.2 Z-N Method PID TUNING PARAMETER

Tuning Method	Tank 1			Tank 2		
	Kp1	**Ki1**	**Kd1**	**Kp2**	**Ki2**	**Kd2**
Z-N Method	7.20	0.28	45	9.10	0.21	96.70

TABLE: 4.3 Conventional PID based on Time Domain specification -Simulation Result

Operating Point		Parameter	PID Z-N
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	50
		Overshoot (%)	7%
		Rise time(s)	9
	Level 2 5 cm	Settling time(s)	15
		Overshoot (%)	7.5%
		Rise time(s)	9.1
Non Minimum Phase ɔ1 =0.3, ɔ 2 =0.4	Level 1 5 cm	Settling time(s)	12
		Overshoot (%)	4%
		Rise time(s)	4
	Level 2 5cm	Settling time(s)	15
		Overshoot (%)	7.5%
		Rise time(s)	9.1

TABLE: 4.4 Conventional PID based on Performance Indices -Simulation result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	PID Z-N	60	11	17	10	60	41	37.5	40.3

TABLE: 4.5 Conventional PID based on Time Domain specification Exp- Result

Operating Point		Parameter	PID Z-N
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	300
		Overshoot (%)	10.8
		Rise time(s)	275
	Level 2 5 cm	Settling time(s)	320
		Overshoot (%)	12.7
		Rise time(s)	275

TABLE: 4.6 Conventional PID based on Performance Indices -Experimental Result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	PID Z-N	18.13	24.32	11.03	12.30	90.64	121.59	55.17	61.49

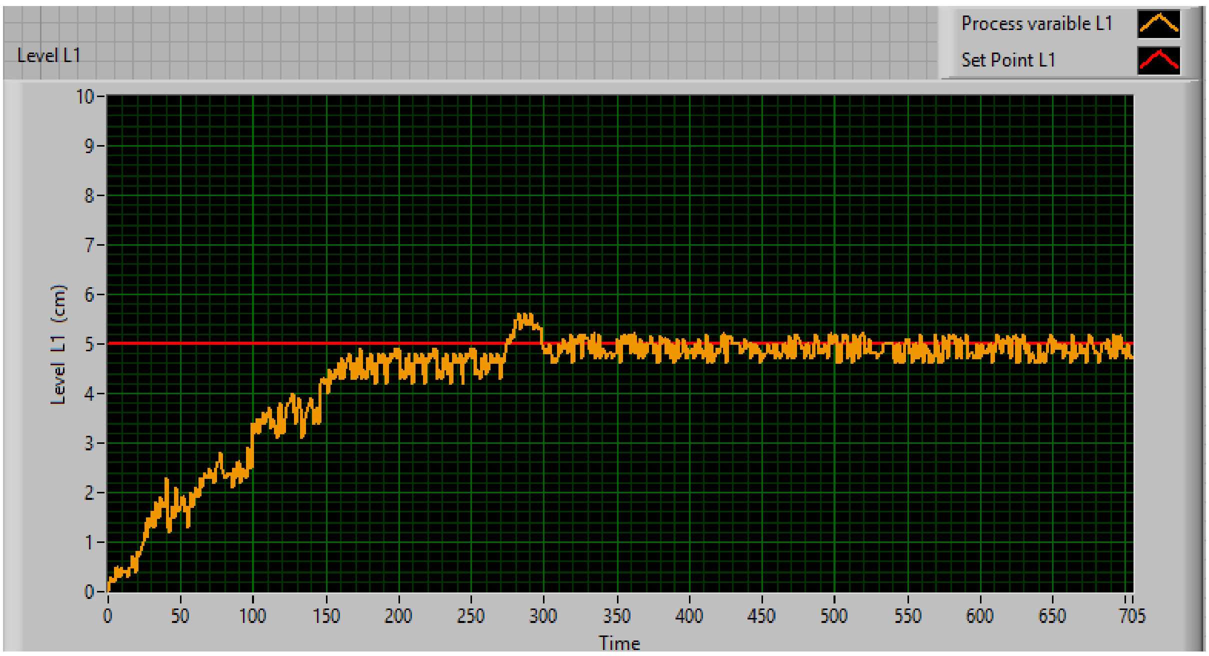

FIGURE 4.2 Tank 1 Response of Z- N method PID Controller (Level 1)

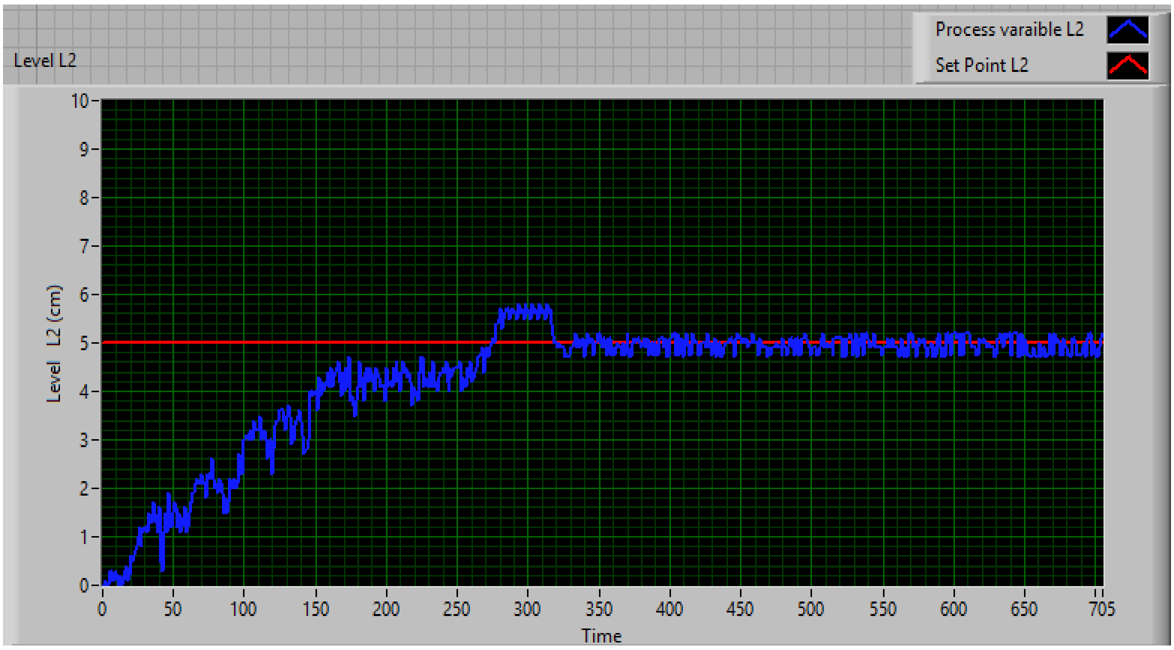

FIGURE: 4.3 Tank 2 Responce of Z- N method PID Controller (Level 2)

4.1.1Result and Discussion

The conventional PID controller used to control the nonlinear system, the design of the conventional controller tuning is based on Ziegler Nichols method. The specific application is used but it has some limitations for the control of nonlinear system. The quadruple-tank system nonlinear mathematical model is implemented in MATLAB software and got good response. Change is made in tuning parameter based on the Ziegler Nichols method. The system becomes unstable and not giving a required response but the conventional method did have some basic outputs to give a good response.

4.2 PSO PID controller

In computer science, PSO is a method that minimizes a trouble by iteratively trying to change problem results with reference to a specific measure of quality. It provides the effect of challenge have a population of problem solutions, this moves particles and traveling these particles near to the search-space based on primary mathematical rule over the particle's position and velocity. Each particle's drift is worked by its local well-cognized place but can also be run toward the well-cognized place into search-space, which is updated as best places are set up by some other particles. She was first intended for simulating social behavior, as a stylized representation of the movement of organisms in a bird flock or fish school. The algorithm was simplified and it was observed to be performing optimization. This is expected to move the swarm involve the better results. PSO is originally attributed to Kennedy, Russell C. Eberhart. An extensive survey of PSO applications is made by Poli. The book by Kennedy and Eberhart describes many philosophical views of PSO and swarm intelligence [114].

PSO is really a metaheuristic so it produces very few or no judgment about the problem being minimized and can find very large places of prospect results. Even though, metaheuristics such as PSO do not ensure minimum results, is ever base. Also, PSO does not use the gradient of the problem being minimised, which means PSO not required that the minimized problem be differentiable as is needed by classic optimization methods such as one of the gradient descent and another quasi-newton methods. Recently, a comprehensive review of theoretical and experimental works on PSO has been published by Bonyadi and Michalewicz.

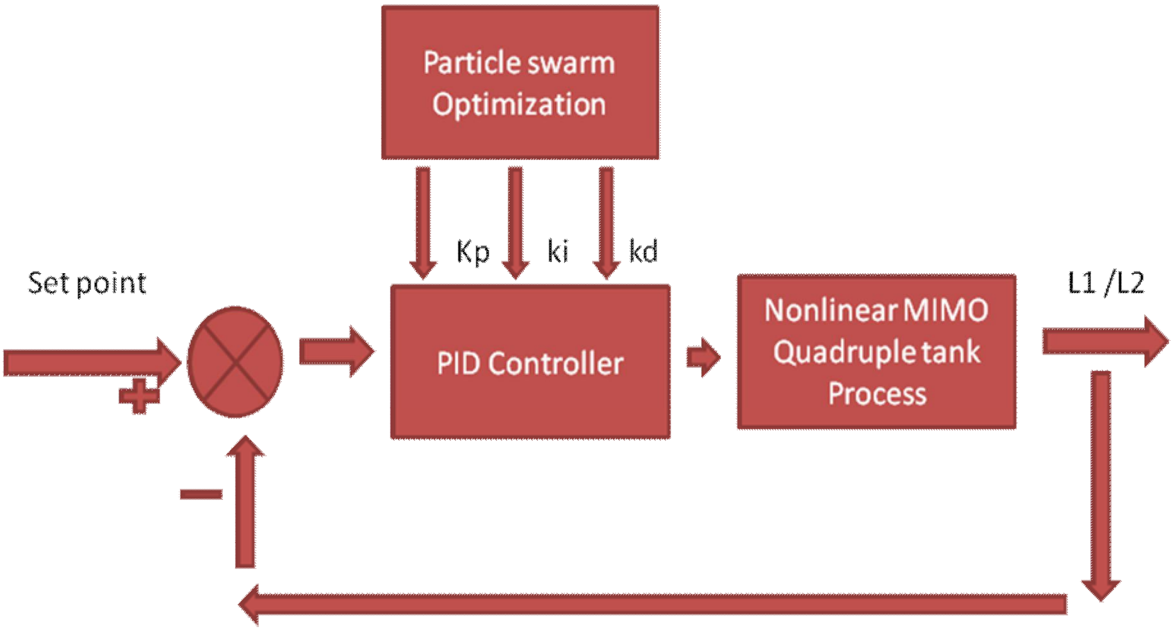

FIGURE: 4.4 Schematic of Particle Swarm Optimization PID for QTS

PSO algorithm can be implied to tune PID controller variables to grant optimal control performance at base operating conditions. PSO algorithm is applied to tuning PID variables using the two tank non-interacting liquid level model. Every particle is considered member results for PID variables where their parameters were fixing the span of 0 to 100. In this 3-dimensional problem, position and velocity are displayed by matrices with a dimension of 3 x swarm size. Parameters of the PSO algorithm are considered. A good set up of PID controller variable selections can result in a good system output and solution in minimization of the performance indices.

TABLE 4.7: PSO Specification Parameter and their values

Sr. No.	PSO Parameter	Values
1	Swarm Size	100
2	Maximum iterations	70
3	I_{max}	0.9
4	I_{min}	0.6
5	C1	2
6	C2	2

TABLE: 4.8 PSO PID TUNING PARAMETER

Tuning Method	Tank 1			Tank 2		
	Kp1	Ki1	Kd1	Kp2	Ki2	Kd2
PSO ISE	95	14.6	10.9	81	13.16	1.21
PSO IAE	35	16.62	9.22	45	2.26	1.02
PSO ITSE	80	14.3	12.2	72	12.1	0.23
PSO ITAE	24	17	11.2	20	1.36	0.12

TABLE: 4.9 PSO PID based on Time Domain Specification -Simulation Result

Operating Point		Parameter	PSO PID
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	90
		Overshoot (%)	20%
		Rise time (s)	3
	Level 2 5 cm	Settling time(s)	10
		Overshoot (%)	10%
		Rise time(s)	10
Non Minimum Phase ɔ1 =0.3, ɔ 2 =0.4	Level 1 5 cm	Settling time(s)	15
		Overshoot (%)	20%
		Rise time(s)	13
	Level 2 5cm	Settling time(s)	12.5
		Overshoot (%)	15%
		Rise time(s)	6

TABLE: 4.10: PSO PID based on performance indices -Simulation Result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	PSO PID	11.2	8.7	10	8.5	31.2	48.7	30.4	28.5

TABLE 4.11: PSO PID based on Time Domain Specification –Experimental Result

Operating Point		Parameter	PSO PID
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	255
		Overshoot (%)	19
		Rise time(s)	234
	Level 2 5 cm	Settling time(s)	266
		Overshoot (%)	9
		Rise time(s)	234

TABLE: 4.12: PSO PID based on Performance Indices -Experimental result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	PSO PID	15.63	16.37	10.09	9.30	78.13	81.88	50.45	46.47

FIGURE : 4.5 Tank 1 Responce of PSO-ISE PID Controller (Level 1)

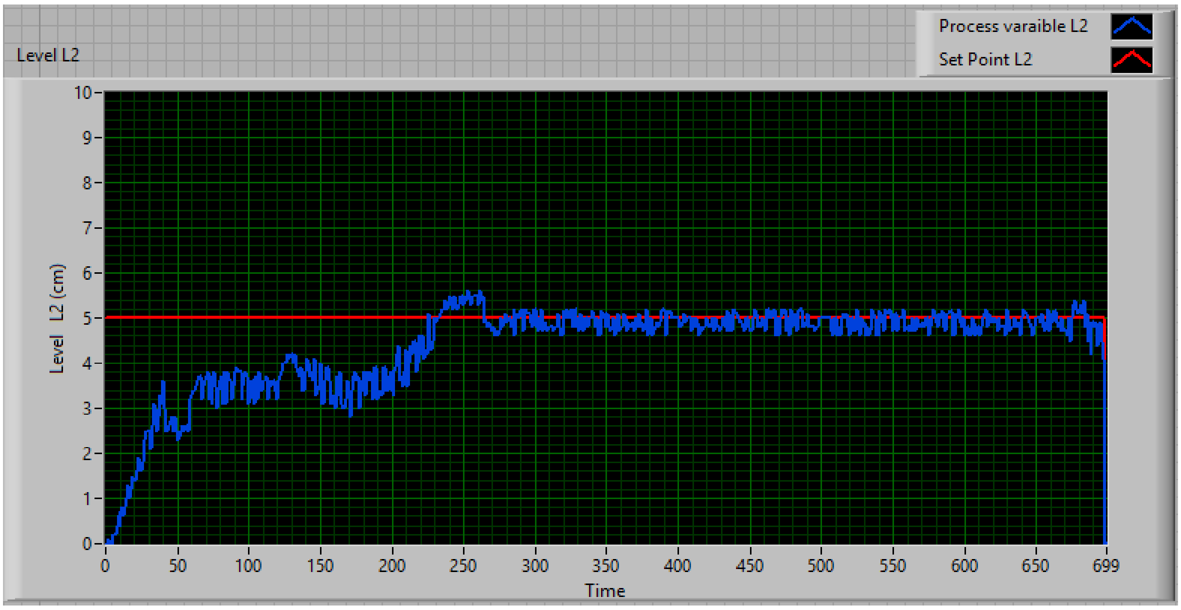

FIGURE 4.6 Tank 2 Responce of PSO -ISE PID Controller (Level 2)

4.2.1 Result and Discussion

In this work, PID controller design for nonlinear process quadruple tank system model using PSO enabled with benchmark problem and the objective function has been defined to get it optimized, considering the performance indices for the nonlinear system. The design ensures a proper trade-off between robust stability specification and robust tracking performance over the entire range of input. It has also been demonstrated that with the designed controller, the system remains within the specified performance, even in the presence of larger interaction between two loops, uncertainties and coupling effect. PSO algorithm is better controlled than conventional PID to get a better result and improve the performance indices which relates to the performance of the process.

4.3 GA PID Controller

This algorithm is stochastic global powerful search optimization method, depends on natural evolution process. Genetic algorithm executes based on the examination for a searching best place that develops analogy in nature. Genetic algorithm select probabilistic transition rules as controverter to deterministic principles and take the population of potential solutions, known as chromosomes, which are evolving iteratively. This iteratio of the program is known as a generation. The population is generally indicated by a real number or binary number string called chromosome. The objective function chooses each chromosome, a corresponding number called as its fitness. This algorithm, there are four control parameter added, such as population size, selection, crossover and mutation rate. The fitness of every chromosome is evaluated and implemented by natural selection method.

The values of the error are used to measure the fitness of every chromosome. A genetic algorithm has three main operators, these are such as reproduction, crossover, and mutation. Basic PID controller is tuned by the genetic algorithm.

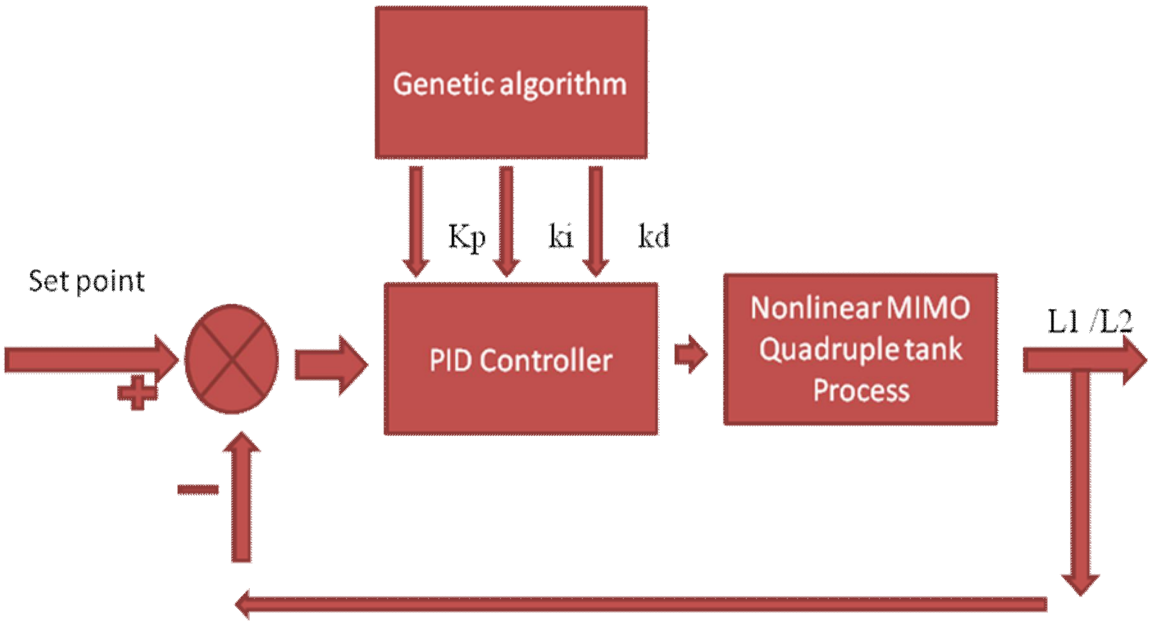

FIGURE: 4.7 Schematic of Genetic Algorithm PID for QTS

4.3.1 Implementation of the Genetic Algorithm with QTS

Development of the PID controller setting parameter is to get the stable result of the closed-loop system. The tuning of the PID controller is found using a Genetic Algorithm. All detailed set of controller variables are chromosomes whose ranges are maintained so that it can optimize the basic objective function, which in this event is the integral error criterion for the performance of the system. These parameters are assigned based on a enhanced capability of the designed controller. The tuning value of the parameter is 0-15. In the starting condition such a parameter with start up with a genetic algorithm, and certain parameter is required to define. It consists of the bit length of the chromosome, selection, crossover and mutation type and the number of iteration. GA is implemented with small population size. This requirement is important in practice in order to allow the controller to be optimized as fast as possible. In this study, the size of initial populations is set to be 300, crossover rate Pc = 0.9, mutation rate Pm = 0.01, and a number of generation G = 100. The initial population is set by encoding the PID parameter, kp, ki and kd into binary strings known as chromosome. The length of strings depends on the required precision which is about 1 significant figures. Here we want to code a three variable function assuming eight bits are used for each variable. It represent the all variables Kp,Ki and Kd (10101110 11100011 00010101). Every variable will have both lower and upper limits. For example, if Kp $\in$ [0, 15], Ki $\in$ [0, 15], and Kd $\in$ [0, 15]. The accuracy obtained with 8 bit code is 1/256 of search space. It may say that with n_i bit length coding for variable, the obtainable accuracy in that variable approximation is ($X^{U}i$ ï $X^{L}i$)/2n_i. Where $X^{U}i$ upper limit of X variable and $X^{L}i$ lower limit of X variable. hence an n bit string can represent integers from 0 to 2^{n} -1, i.e. 2n integers.

The values of the parameters for this method are as follows:

- Mutation probability : 0.01
- Chromosome Bit length : 8
- Generation No: 150
- Size of Population: 300
- Selection techniques : Maximum Geometric selection
- Crossover : Single point crossover
- Crossover probability : 0.9
- Mutation: Uniform mutation

4.3.2 Objective Function for the Genetic Algorithm

In this method, the performance of the controller is appraised in integral error criteria, such as Integral absolute error, Integral square error, Integral time absolute error and integral time square error performance. The integral error criterions are the foundation of the objective functions. A number of such specific touchstones are available. In this work, it is considered as the restraint of the mathematical analysis for range or the given time, t=0 to t= ts, where ts is the settling time of the system, to achieve steady-state response for a constant step signal. Simulation and the experimental responses were found with performance indices such as IAE, ISE, ITAE, and ITSE.

At some time, the amount of iteration becomes maximum or with the acquisition of expiration fitness value, which terminates this algorithm. From this consideration it is just inverse of the level of the main function since it is assured for a minimized value of the main function, the final result is involved to be the attainment of considerable fitness value which occurs with the most quantity of iterations which is 100. For every loop, the best among the perfect range of particles, viewed as the best result is selected. So the best values considered for 100 iterations are sketched with respect to iterations. In the simulation result for the level 1 consider 5 cm and we also considered the second level 5 cm based on operating point minimum and nonminimum phase. Dynamics response of the QTS for PID is better than GA PSO and conventional PID.

TABLE: 4.13 GA PID TUNING PARAMETER

Tuning Method	Tank 1			Tank 2		
	Kp1	Ki1	Kd1	Kp2	Ki2	Kd2
GA ISE	14.69	13.49	0.32	0.52	0.35	0.23
GA IAE	13.45	10.23	0.11	2.32	0.12	0.64
GA ITSE	14.32	12.20	0.54	0.65	0.23	0.23
GA ITAE	13.87	12.43	0.22	0.43	0.17	0.34

TABLE 4.14: GA- PID based on Time Domain Specification Simulation Result

Operating Point		Parameter	GA - PID
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	95.98
		Overshoot (%)	9%
		Rise time(s)	10
	Level 2 5 cm	Settling time(s)	12
		Overshoot (%)	12%
		Rise time (s)	4
Non Minimum Phase ɔ1 =0.3, ɔ 2 =0.4	Level 1 5 cm	Settling time(s)	13
		Overshoot (%)	8%
		Rise time (s)	10
	Level 2 5cm	Settling time(s)	8.3
		Overshoot (%)	12.6%
		Rise time (s)	4.5

TABLE 4.15: GA- PID based on Performance Indices -Simulation result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	GA PID	10.6	8.2	10.2	8	40.6	58.2	40.2	38.2

TABLE: 4.16 GA- PID based on Time Domain specification –Experimental Result

Operating Point		Parameter	GA - PID
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	247
		Overshoot (%)	12
		Rise time (s)	222
	Level 2 5 cm	Settling time(s)	254
		Overshoot (%)	25
		Rise time (s)	222

TABLE: 4.17 GA- PID based on Performance Indices Experimental Result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	GA PID	14.68	21.50	9.64	11.28	73.39	107.51	48.19	56.41

FIGURE: 4.8 Tank 1 Response of GA-ISE PID Controller (Level 1)

FIGURE : 4.9 Tank 2 Response of GA- ISE PID Controller (Level 2)

4.3.3 Result and Discussion

In this apporch the GA is utilized to find optimal value of the PID constant. This optimal constant helps to minimize the integral perfromance criteria to tune proper PID constant by using GA method for output of QTS. Genetic Algorithm is a sound optimization method that relies on the parallelism found in nature; in particular, their finding procedure depends on the mechanics of natural finding and genetics. GAs is used regularly to solve difficult search techniques, optimization approach and machine-learning problems that have previously resisted automated solutions. In this nonlinear process, we have used GA for tuning of the PID controller for better optimization than PSO and Conventional PID ZN method, which gives better performance indices of the quadruple tanks nonlinear complex system.

4.4 Taguchi PID Controller

Taguchi method reduces the number of experiments over the full-factorial approach, it is useful to use the statistical analysis of experiments, called analysis of variance (ANOVA), to provide levels of confidence in the results. A computed F value is compared to values in the Fisher criterion tables. Moreover, the analysis of variance identifies and ranks variables that affect the variance of the output signal. The percentage contribution can also be computed which gives the effect of each level of each parameter.

Given that three levels for each factor will be defined, eight factors result in an L27 orthogonal array being chosen, which actually means 27 experiments and thirteen factors. In this case, five factors would then be empty in the array. Thus, that allows you to again reduce the number of experiment and therefore, the value of the method; L18 orthogonal array was rather used. This array implies only eighteen experiments on the condition that one of the eight factors would only have two levels (i.e. 37.21). The experimental layout is shown in Figure 4.4. The eighteen rows of this matrix represent the experiments to be conducted. The level 1 as 5 cm and level 2 as 5 cm considered as a set point for level of measurement and control in simulation as well as experiment result.

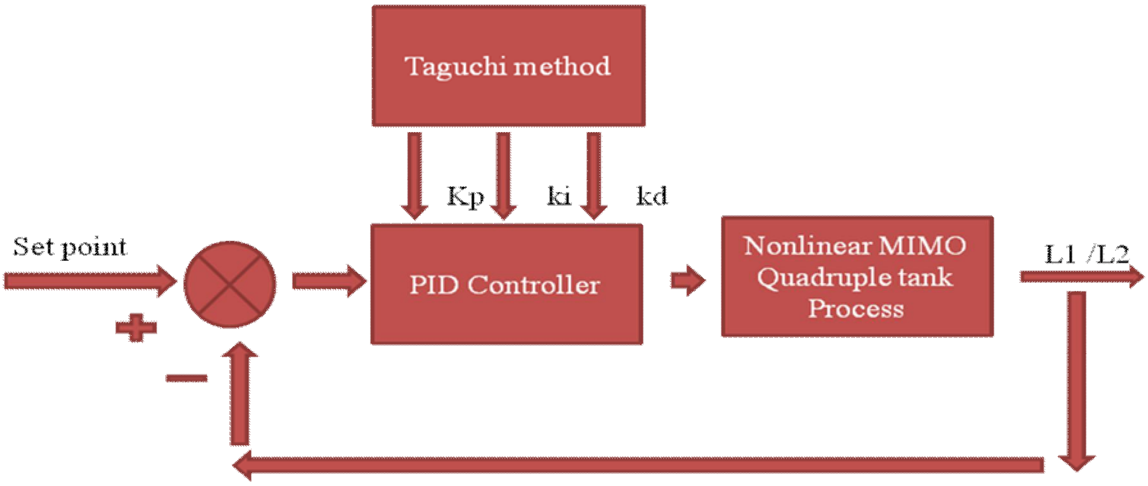

FIGURE: 4.10 Schematic of Taguchi PID for QTS

TABLE : 4.18 Taguchi PID TUNING PARAMETER

Tuning Method	Tank 1			Tank 2		
	Kp1	**Ki1**	**Kd1**	**Kp2**	**Ki2**	**Kd2**
Taguchi ISE	16	2.1	0.2	15	2.2	0.1
Taguchi IAE	21	2.3	3	19	2.8	0.3
Taguchi ITSE	16.5	2.4	0.23	15	2.9	0.1
Taguchi ITAE	24	2.9	0.1	20	2.4	0.2

TABLE: 4.19 Taguchi PID based on Time Domain Specification Simulation Result

<table>
<tr><th colspan="2">Operating Point</th><th>Parameter</th><th>Taguchi - PID</th></tr>
<tr><td rowspan="6">Minimum Phase
ɔ1 =0.7
ɔ2 =0.6</td><td rowspan="3">Level 1
5cm</td><td>Settling time(s)</td><td>89</td></tr>
<tr><td>Overshoot (%)</td><td>8.88%</td></tr>
<tr><td>Rise time(s)</td><td>12</td></tr>
<tr><td rowspan="3">Level 2
5 cm</td><td>Settling time(s)</td><td>9</td></tr>
<tr><td>Overshoot (%)</td><td>8.7%</td></tr>
<tr><td>Rise time(s)</td><td>4.5</td></tr>
<tr><td rowspan="6">Non Minimum Phase
ɔ1 =0.3,
ɔ 2 =0.4</td><td rowspan="3">Level 1
5 cm</td><td>Settling time(s)</td><td>12.8</td></tr>
<tr><td>Overshoot (%)</td><td>12%</td></tr>
<tr><td>Rise time(s)</td><td>6.7</td></tr>
<tr><td rowspan="3">Level 2
5cm</td><td>Settling time(s)</td><td>8</td></tr>
<tr><td>Overshoot (%)</td><td>12.5%</td></tr>
<tr><td>Rise time (s)</td><td>4.2</td></tr>
</table>

TABLE: 4.20 Taguchi PID based on Performance Indices Simulation Result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	Taguchi PID	11	9	11	14	22.67	34.23	34	38

TABLE: 4.21 Taguchi PID based on Time Domain Specification Experimental Result

Operating Point		Parameter	Taguchi - PID
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	225
		Overshoot (%)	11
		Rise time(s)	130
	Level 2 5 cm	Settling time(s)	265
		Overshoot (%)	21
		Rise time(s)	215

TABLE: 4.22 Taguchi PID based on Performance Indices - Experimental result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	Taguchi PID	14.79	20.18	9.83	11.01	73.97	100.94	49.13	55.06

4.4.1 Result and Discussion

This method is an optimal design method for nonlinear quadruple tank system using PID controller based on statistical Taguchi approach. This method gives a better result than other techniques. It has changed the dynamic response and improvement of the performance indices. This technique is used to optimize various integral error criteria based on fine-tuning of the PID controller. These methods also help to multiple objective optimization techniques for designing, which gives the additional design flexibility in the various control process application. Finally, we conclude that this method is better to optimize the integral criteria, which are defining the performance of the system. Using the Taguchi method with tuning of PID controller in the QTS, best result can be obtained with lesser number of experimentations for analyzing optimization problem to save time, effort and cost .Total 27 experiments were conducted based on 3 level and 6 variable with two controllers for level 1 and level 2 measurement tuning the PID parameter and getting the best Integral criteria to improve the performance of the system.

4.5 Taguchi GA Controllers

The Taguchi combine genetic algorithm techniques are a novel optimal method for tuning of the controller for the nonlinear quadruple tank system which is considered to improve the time domain specification of the level of the bottom tanks in the MIMO system. The gain ofthe proportional, gain of integral and also derivative gain decides the best optimization problem. There are designs specific variables of closed values are decided through Taguchi method using analysis of means, the survival of the fittest of the three design variables are based on analysis of variance. We can obtain the best optimum result of these three variables using a multi-objective Genetic Algorithm. This work is implemented on the MATLAB and Lab VIEW. The strength of this method is differed from that of the previous Taguchi PID approach, GA PID approach and the PSO PID approach. With this suggested Taguchi GA method, for the step response input of the nonlinear MIMO system, can be improved and change the performance indices of the quadruple-tank system optimization by GA.

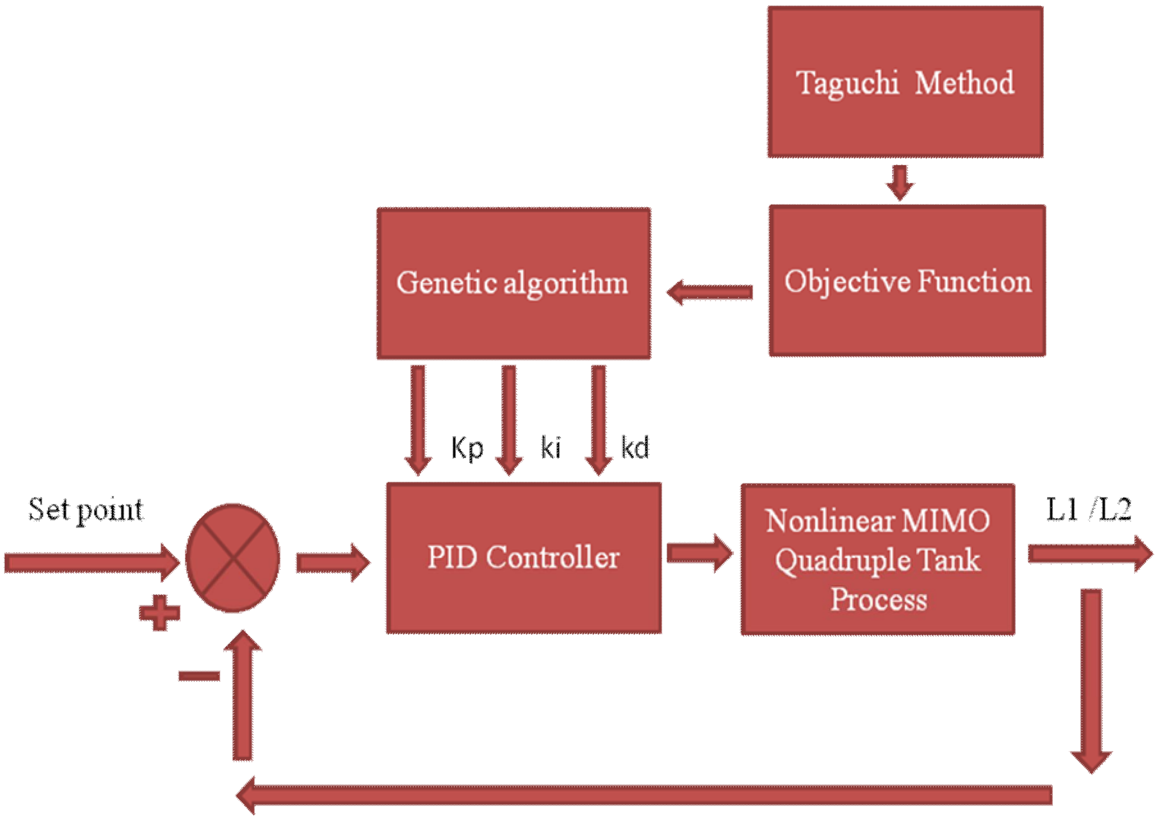

FIGURE: 4.11 Schematic of Taguchi combined GA PID used for QTS

In many engineering field and studies, a solution to the optimization problem solved based on the powerful search method genetic algorithm. The powerful search method genetic algorithm has been used in solving the various optimization problem of the complex nonlinear system. The survival of the fittest principle is used in the genetic algorithm. The Genetic algorithm initializes the optimization way with the unspecified generation of a population, which involves a number of chromosomes. When it has been achieved the unspecified population, the output indicated by each string should be assessed. The basic functional responsibility of objective function is an analysis of the result at each step.

The main purpose of given perusal is to change the integral performance indices ISE, IAE, ITSE, and ITAE. Here basically multi-objective design problem has to be optimized. Therefore, in this work multi-objective Genetic algorithm is used. The position fitness scaling is registered to keep away from untimely convergence. Furthermore, Genetic Algorithm makes use of techniques stimulated by evolutionary biology, consisting of a mutation, crossover and natural selection. There are few preference techniques within the Genetic algorithm. In this work, within the procedure, it is finished by utilizing the uni selection technique, which presents no bias and minimum explore.

The four objectives are designed as mentioned below.

- Minimize the ISE
- Minimize the IAE
- Minimize the ITSE
- Minimize the ITAE

TABLE :4.23 Taguchi GA PID TUNING PARAMETER

Tuning Method	Tank 1			Tank 2		
	Kp1	Ki1	Kd1	Kp2	Ki2	Kd2
TGA ISE	11.75	5.30	0.23	7.01	10.62	0.12
TGA IAE	10.23	2.2	0.01	3.23	2.32	3.43
TGA ITSE	12.11	3.49	2.32	7.60	9.22	0.12
TGA ITAE	9.89	2.1	0.19	3.89	2.33	4.10

TABLE: 4.24 TGA PID based on Time Domain Specification -Simulation Result

Operating Point		Parameter	Taguchi - PID
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	90
		Overshoot (%)	11%
		Rise time (s)	12
	Level 2 5 cm	Settling time(s)	10
		Overshoot (%)	9.6%
		Rise time(s)	5.3
Non Minimum Phase ɔ1 =0.3, ɔ 2 =0.4	Level 1 5 cm	Settling time(s)	60
		Overshoot (%)	23%
		Rise time(s)	6
	Level 2 5cm	Settling time(s)	7.6
		Overshoot (%)	12%
		Rise time(s)	5.4

TABLE: 4.25 TGA PID based on Performance Indices Simulation Result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	TGA -PID	9.8	8.3	12	13	39.8	48.3	30.23	23.33

TABLE: 4.26 TGA PID based on Time Domain specification Experimental Result

Operating Point		Parameter	Taguchi - PID
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	242
		Overshoot (%)	10
		Rise time (s)	198
	Level 2 5 cm	Settling time(s)	245
		Overshoot (%)	13
		Rise time(s)	198

TABLE: 4.27 TGA PID based on Performance Indices - Experimental result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	TGA -PID	13.97	20.49	9.51	11.09	69.88	102.45	47.53	55.45

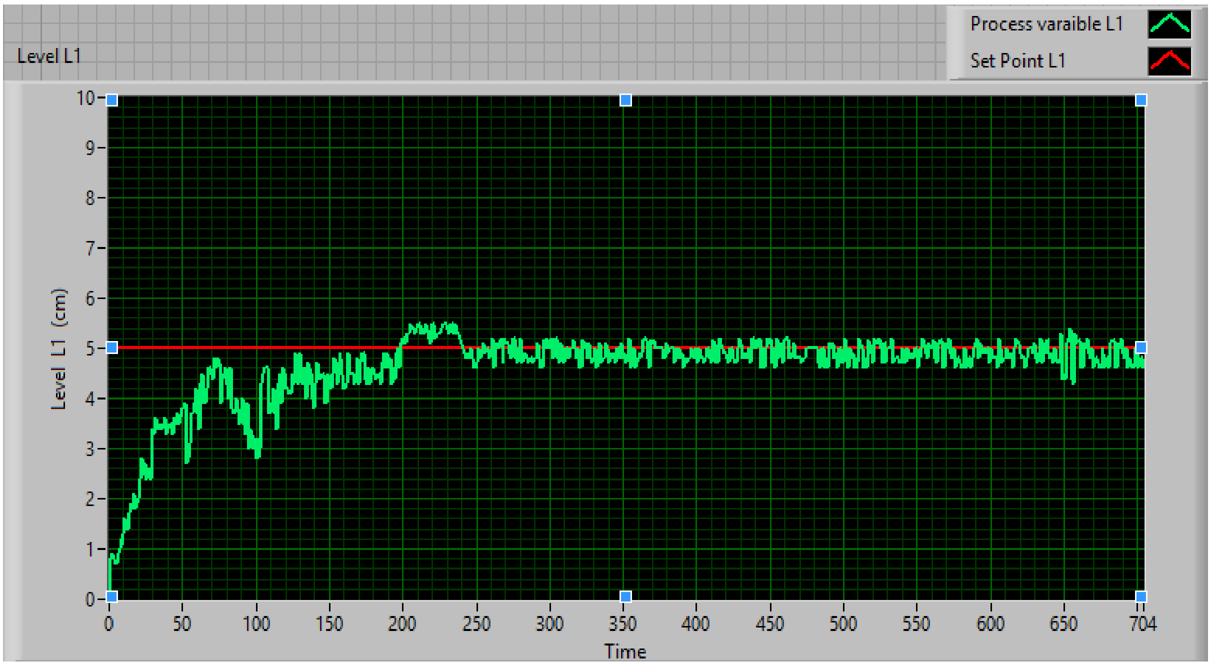

FIGURE: 4.12 Tank 1 Responce of Taguchi GA -ISE PID Controller (Level 1)

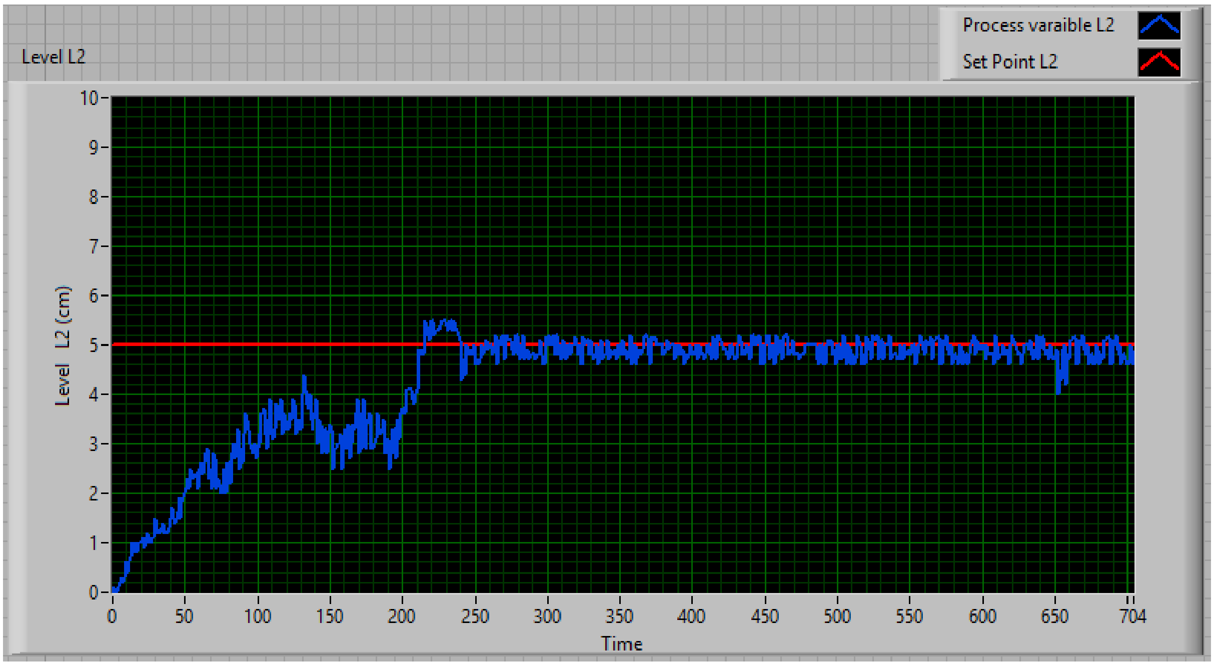

FIGURE : 4. 13 Tank 2 Responce of Taguchi GA ISE - PID Controller (Level 2)

4.5.1 Result and Discussion

This novel Taguchi GA technique represents a specific calculation for PID controller constant in the highly nonlinear QTS MIMO system. The gains of the PID controller define the search space for the specified optimization problem of the nonlinear system. The optimum values of the design variables are decided by the Taguchi method using analysis of means. Analysis of variance is used to select the three most influential design variables. TGA is used to obtain the accurate optimum values of these three variables. The potency of the proposed method is then compared with that of the previous GA method as well as PSO method with this proposed TGA method, so that the reference input response of the MIMO nonlinear system can be improved. In this method tuning of PID controller based on TGA has better result than normal Taguchi and other PSO and GA PID method. A multi-objective design optimization is found to minimize the time domain specification of the considered system as well as integral performance criteria.

CHAPTER 5

5 Design Taguchi Based MPSO Algorithms For Tuning of PID Controller

5.1 Introduction

The conventional PID and hybrid soft computing based controller is compatible for linear and nonlinear interacting process. The robustness to variation in the process parameters are improved as well as minimized the interaction effect with change, to solve the stability problem. In this section he Taguchi MPSO is designed and its performance indices are analyzed . The conventional PID as well as other soft computing techniques are approach to the controller design problem for nonlinear system

The upgrade of execution records has a precondition that it should meet the specific values of the parameters and different prerequisites formulas when the nonlinear system is running. It intends to raise the output quality. With the advancement of computer innovation and the presence of mathematical calculations, heaps of enhancements of responsive output have raised, for example, dynamic programming, conventional direct programming, nonlinear programming, and some new heuristic calculations proposed lately, for example, Genetic Algorithm, Particle Swarm Optimization and so on. These strategies have added to the investigation of execution list enhancement, in which, Particle Swarm Optimization calculation has fewer wards on the experience of the parameters, regardless of its weaknesses, so we alter this calculation for improvement. Particle swarm calculation is a sort of computing innovation in view of a shrewd strategy. These were considered by Kennedy and Eberhart in the year of 1990s [114], and these fundamental ideas make the examination on the focus conduct of winged creatures. The particles of the gathering are haphazardly introduced right off the bat, and after that every particle of the swarm tracks its own most extreme esteem and the entire swarmsô greatest esteem, to remedy its bearing and speed at whatever point. The calculation won't stop until the point when most extreme circle make a tally and achieves the esteem settled. Particle Swarm Optimization is simple and fast, with fewer terms on the encounter of the variables, however, a few hindrances likewise exist. It falls in nearby outrageous esteem effortlessly and the precision of combination isn't required more.

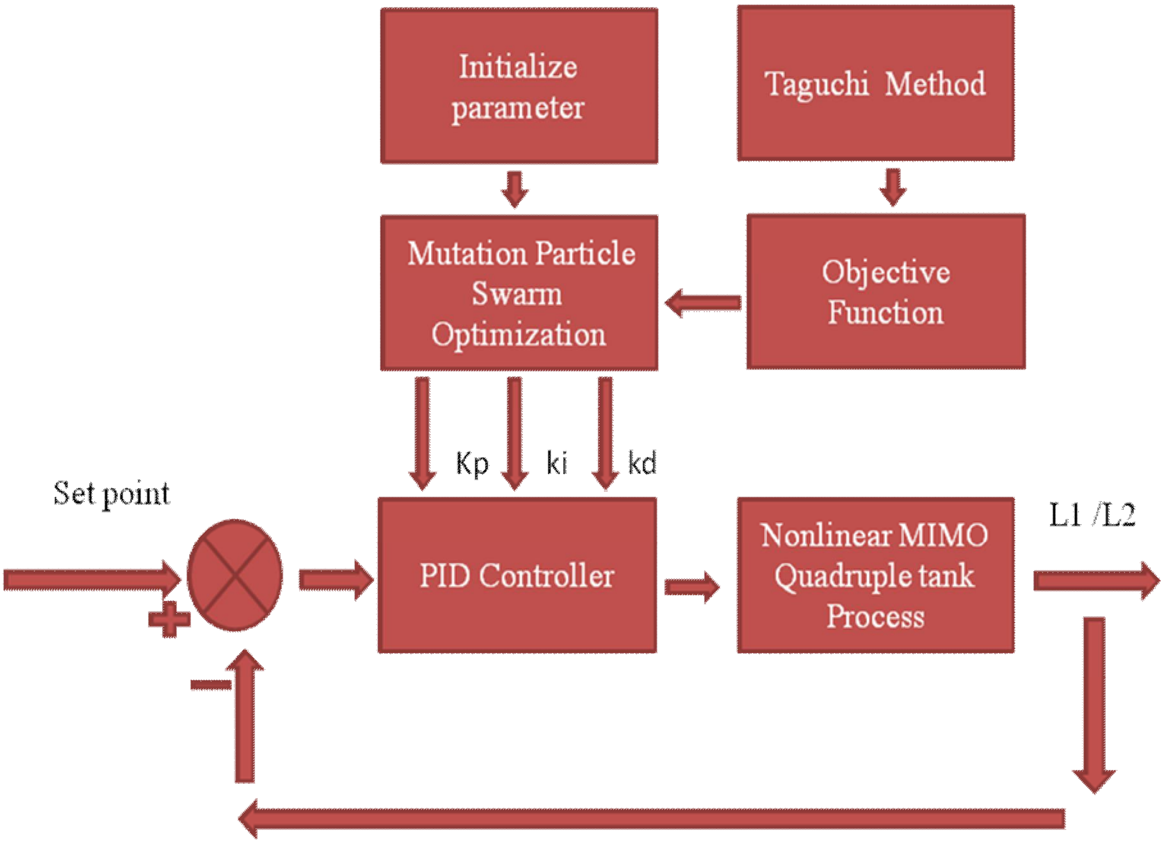

FIGURE: 5.1 Schematic of Taguchi MPSO PID used for QTS

This work can be explored by the inertial element of the Particle Swarm Optimization which will be considered, altered and a transformation administrator will be included. A gathering of ideal parameters can be gotten in light of examinations, at that point the adjusted PSO (MPSO) with Taguchi technique calculation will be utilized in the enhancement of execution records. We built up a model for four tank framework advancement in view of this calculation and a program, utilizing the programming software. The reproduction demonstrates that Mutation Particle Swarm Optimization is viable and achievable in the enhancement to execution records. Contrasted and essential Conventional PID, GA PID, PSO PID, Taguchi PID and Taguchi GA calculation, have goodexecution.

5.2 Taguchi based MPSO Algorithm

The Taguchi technique gives an extensive comprehension of the individual and joint impacts of different outline parameters in view of a base number of test preliminaries. This design variable, utilized in Taguchi technique is isolated into various factors as indicated by the reaction of every parameter to the main attributes. The response based on reactions of the procedure parameters is additionally changed into a signal to noise (S/N) proportion which effects noise in the signal. The standard S/N proportions for the most part utilized are as per the following: the Smaller-The Better, the Nominal-The Better, or the Higher-The Better. This examination utilizes the signal to noise proportion of Smaller ï The Better quality trademarks to limit the error of the quadruple-tank system and multiple inputs and multiple output complex process. The signal to noise ratio portraying the Smaller ï The Better qualities, is as per the following equation:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^{\,2}\right) \quad [9]$$

Where i indicate the number of design factors in the Taguchi OA, n is the iteration numbers under the basic design parameters, y_i indicates the measured results. The signal to noise proportion reaction chart of different parameter stages demonstrates an outline with good quality inside the preset scope of variables. Notwithstanding the Signal to noise proportion, ANOVA is utilized to get the impact of the procedure outputs. The ANOVA strategy utilized in the Taguchi technique is a factual system principally embraced to assess the essentialness levels of control process parameters and the reaction of every variable.

5.3 Optimization Method

In the investigation details, the procedure variables design issue is a compelled streamlining issue. The outline parameters speak to the design factors of the target capacities in this improvement issue. In this method, we have taken four objective functions based on the performance indices.

$\min (ISE = \int e^2 \, dt)$ [10]

$\min (IAE = \int |e(t)| \, dt)$ [11]

$\min (ITAE = = \int t|e(t)| \, dt)$ [12]

$\min (ITSE=\int t \, e^2 \, dt)$ [13]

Note that the above performance indices such as ISE, IAE, ITAE, and ITSE have energy level of any nonlinear control system which gives the performance of the system.

5.4 Mutation Particle Swarm Optimization (MPSO)

The American engineer Kennedy and Eberhart designed a particle swarm optimization which depends on the nature of individual of a swarm of birds. The pattern of particle swarm optimization is very easy in nature and its searching mechanism is very fast. The idea of PSO was propelled by the social conduct of fish tutoring or flying creature rushing. Every particle in the techniques view space speaks to a potential answer for the enhancement issue and is characterized as a gathering of factors. It is related with two vectors, which are the position and velocity vectors. In *n*-dimensional search space, the two vectors associated with each particle *i* are $A_i = (a_{i,1}, a_{i,2}, . ., a_{i,n})$ and $B_i =(b_{i,1}, b_{i,2}, . . ., b_{i,n})$, respectively. Every particle refreshes its answer in light of its own best investigation and the best swarm in general involvement to discover its wellness esteem utilizing iterative refreshing. Amid this emphasis procedure, the refreshed position and speed of every molecule are figured as appeared in Eq. (5-7). The global best position and speed term are refreshed after every cycle.

$$B(k+1) = \Psi(k) \times Bi(k) + r1 \times (pbesti(k) - Ai(k) + C2 \times r2 \times (gbesti(k) - Ai(k)$$

[14]

$Ai\,(k+1) = Ai\,(k)+Bi\,(k+1)$ [15]

$\mu(k+1) = \mu(k)\times 0.99$ [16]

Where, Ai (k) and Bi (k) are the positions and the velocity of particle i at the kth iteration, respectively where r1 and r2 are uniformly distributed random values in [0, 1] and the learning factors c1 and c2 represent the weights of the stochastic acceleration terms that lead each particle toward the local best and global best solutions. k is the current iteration number, 0Ò µ <1 is a dynamic inertia weight which determines how much the previous velocity is preserved, 0.99 is a decay factor in the inertia weight per iteration. The position of each particle is updated by using the velocity Bi (k+1). pi(k) is the best position encountered by particle i during its research, best (k) is the best particle position based on the swarming group.

5.5 MPSO Method

Looking to the procedure and region of the sanctioned PSO calculation, it enormously rely upon position best and global best. The impact of position best and global best in Particle Swarm optimization steadily diminishes as the quantity of emphases increments. Subsequently, we joined with this accepted technique with the Genetic Algorithm mutation called "MPSO" to get a more extensive scanning region for enhancing the worldwide inquiry capacity of arrangements. The MPSO method utilizes a real-coded type mutation operator to build the assorted variety of arrangements. The mutation of genetic algorithm activity just happens if a haphazardly produced number inside [0, 1] is not exactly or equivalent to the given change likelihood. At the point when a change is worked, the quantity of outline factors is increased by an irregular incentive inside [0, 1] to figure out the specific variable in every molecule which ought to be transformed in the parameter space. The genuine factor change administrators utilized in this technique are as per the following:

$$\mathrm{X}_{i,j}(k+1) = X^{L}_{i,j}(k+1) + r4 * \left[X^{U}_{i,j}(k+1) - X^{L}_{i,j}(k+1)\right] \qquad [17]$$

where, $t = ceil\ (r_3 \times n)$, n[illegible]

The ceiling function ceil (r3×n) is defined as the function that outputs the smallest integer greater than or equal to (r3 ×n). t is the variable sequence position of getting a mutation in variable space X. If some particle of each iteration mutated and randomly selected. one of the design variables are found as mutation between its upper and low limits. In Eq. (8), r3 and r4 are random numbers in [0, 1] and shows the updated design variables after mutation of each updated particle from Eq. (7). This new algorithm was designed to repeatedly update the selected parameters in Eq. (5)-(8) until reaching termination states.

5.6 Algorithm Procedures

This investigation utilizes the new algorithm based on TMPSO to examine the different variable states on the quadruple tank system nonlinear system. The iterative calculations of the MPSO calculation were first registered to utilize mathematical software and Lab VIEW. In this manner execute the LabVIEW programming for every emphasis investigations. Figure 5.2 shows the engineering of the Taguchi-based MPSO calculation to enhance the procedure execution lists process in light of tuning a PID controller. The means are portrayed as shown below:

Level 1: Choose the quality attributes. This subject applies STB quality features.

Level 2: Choose the effect main factors on the PID controller parameter, such as proportional control Kp, integral control Ki and derivative control Kd. This parameter can possibly influence the execution lists of the nonlinear quadruple tank system

Level 3: Choose an orthogonal array $L_{27}(2^1 \times 3^7)$. The layout of $L_{27}(2^1 \times 3^7)$ was randomly determined

Level 4: Compute the signal to noise proportion of every test run based on the response of the controller parameter calculated using the signal to noise expression

Level 5: Find out the most important process parameters kp, ki and kd influencing the level1 and level 2 of bottom tanks

Level 6: Start set of particles that present the start random combination of the significant process variables conditions. Identify the ranges of variable conditions between the higher and lower limits according to the final results of the Taguchi method and ANOVA.

Level 7: Calculate the new position and velocity of the particles in every loop using MATLAB.

Level 8: Apply the mutation operator used given equation to avoid previous convergence and find the global optimal solutions using Taguchi-based MPSO algorithm.

Level 9: Produce and study the performance indices models to determine the level of the quadruple tanks system for each iteration.

Level 10: Calculate the fitness function in the given equation.

Level 11: Find out whether the ISE, IAE, ITAE, and ITSE are at the minimum output by proceeding towards the fitness value. If yes, then stop iterating and proceed to the next step. If no, return to Level 7.

Level 12: Find out the best optimal controller variable of the integral criteria

Level 13: Stop calculating and counting.

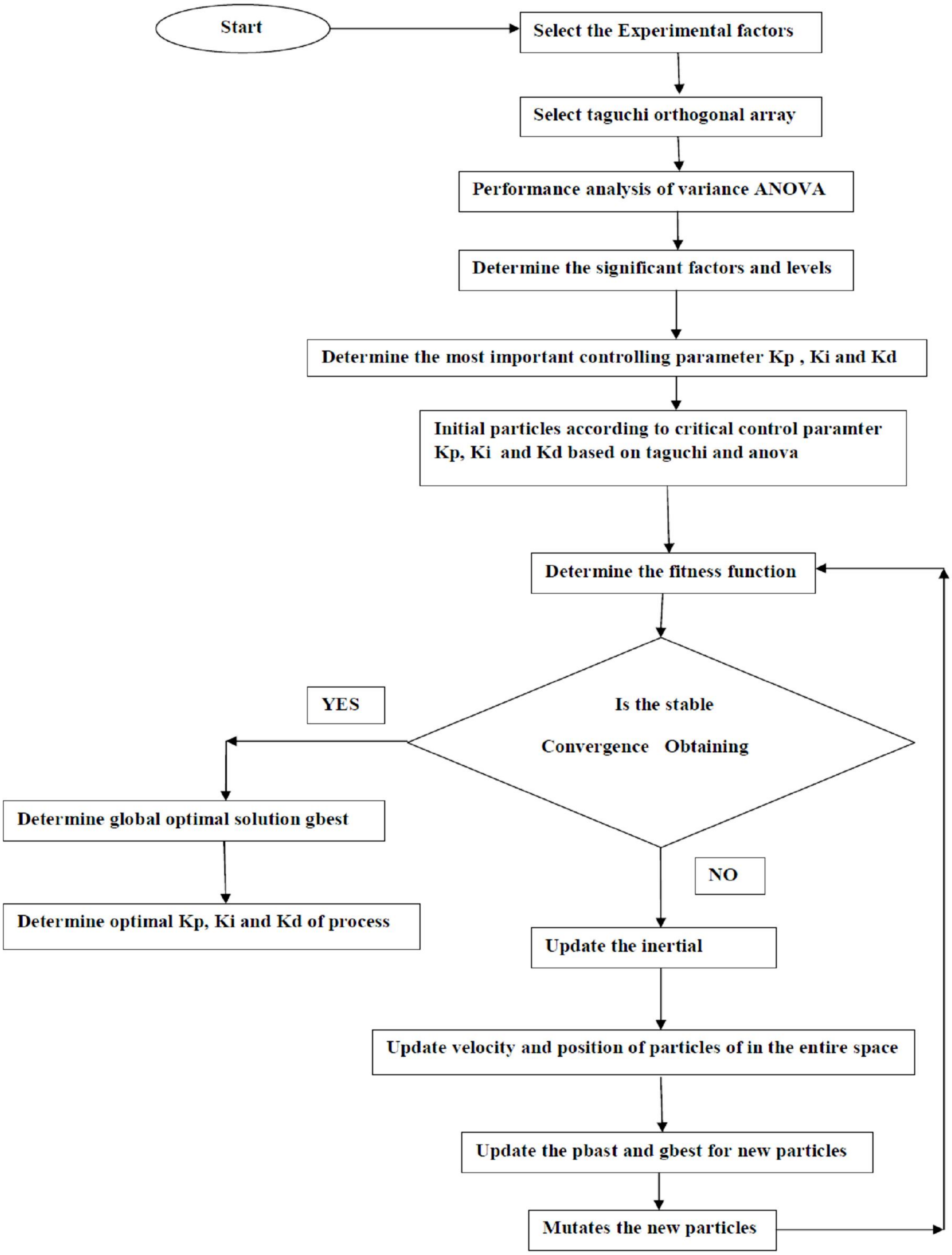

FIGURE 5.2: Flowchart of the Taguchi-based MPSO algorithm

TABLE 5.1: DESIGN VARIABLES and THEIR CODED LEVELS for ISE

Sr. No.	Factors	PID Parameter	Range	Level 1	Level 2	Level 3
1	A	KP1	15 to 25	15.00	20.00	25.00
2	B	Ki1	0.3 to 0.5	0.30	0.40	0.50
3	C	Kd1	0.1 to 0.3	0.10	0.20	0.30
4	D	Kp2	15 to 25	15.00	20.00	25.00
5	E	Ki2	0.3 to 0.5	0.30	0.40	0.50
6	F	Kd2	0.1 to 0.3	0.10	0.20	0.30

TABLE 5.2: DESIGN VARIABLES and THEIR CODED LEVELS for ISE

Expe	Kp1	Ki1	Kd1	Kp2	Ki2	Kd2	ISE	S/N Ratio
1	15	0.3	0.1	15	0.3	0.1	250	-23.98
2	15	0.4	0.1	15	0.4	0.1	123.6	-20.92
3	15	0.5	0.1	15	0.5	0.1	140.7	-21.48
4	15	0.3	0.2	15	0.3	0.2	128.8	-21.10
5	15	0.4	0.2	15	0.4	0.2	131.9	-21.20
6	15	0.5	0.2	15	0.5	0.2	137.8	-21.39
7	15	0.3	0.3	15	0.3	0.3	136.8	-21.36
8	15	0.4	0.3	15	0.4	0.3	117.8	-20.71
9	15	0.5	0.3	15	0.5	0.3	116	-20.64
10	20	0.3	0.1	20	0.3	0.1	25.3	-14.03
11	20	0.4	0.1	20	0.4	0.1	124.3	-20.94
12	20	0.5	0.1	20	0.5	0.1	116.2	-20.65
13	20	0.3	0.2	20	0.3	0.2	22.3	-13.48
14	20	0.4	0.2	20	0.4	0.2	102.2	-20.09
15	20	0.5	0.2	20	0.5	0.2	80.4	-19.05
16	20	0.3	0.3	20	0.3	0.3	79.3	-18.99
17	20	0.4	0.3	20	0.4	0.3	75.2	-18.76
18	20	0.5	0.3	20	0.5	0.3	73.8	-18.68
19	25	0.3	0.1	25	0.3	0.1	63.8	-18.05
20	25	0.4	0.1	25	0.4	0.1	65.4	-18.16
21	25	0.5	0.1	25	0.5	0.1	67.6	-18.30
22	25	0.3	0.2	25	0.3	0.2	59.5	-17.75
23	25	0.4	0.2	25	0.4	0.2	57.8	-17.62
24	25	0.5	0.2	25	0.5	0.2	49.6	-16.95
25	25	0.3	0.3	25	0.3	0.3	34.1	-15.33
26	25	0.4	0.3	25	0.4	0.3	45.9	-16.62
27	25	0.5	0.3	25	0.5	0.3	25.2	-14.01

TABLE 5.3: Level Total Of S/N Ratio

Sr. No	Factors	Level 1	Level 2	Level 3
1	A	-192.79	-164.92	-152.78
2	B	-164.07	-174.63	-171.17
3	C	-176.51	-168.64	-164.81
4	D	-192.79	-164.92	-152.78
5	E	-164.07	-174.63	-171.17
6	F	-176.51	-168.64	-164.81

TABLE 5.4: ANOVA method for QTS

Factors	SUM SQUARE	DOF	MS	F-Ratio	Effect (percent)
A	39180.73	2	19590.36	1.70	46.13
B	124.54	2	62.27	0.01	3.17
C	4499.48	2	2249.74	0.20	0.70
D	39180.73	2	19590.36	1.70	46.13
E	124.54	2	62.27	0.01	3.17
F	4499.48	2	2249.74	0.20	0.70
ERROR	23011.32	14	11505.66		
TOTAL	64598.17	26			100

TABLE : 5.5 Taguchi MPSO PID Controller

Tuning Method	Tank 1			Tank 2		
	Kp1	Ki1	Kd1	Kp2	Ki2	Kd2
TMPSO ISE	7.06	6.98	0.56	5.00	9.321	0.32
TMPSO IAE	12.00	7.00	1.23	5.23	11.21	1.65
TMPSO ITSE	8.34	5.93	0.49	4.59	7.45	0.21
TMPSO ITAE	11.00	7.00	1.23	5.10	11.39	1.65

TABLE: 5.6 TMPSO PID based on Time Domain Specification -Simulation Result

Operating Point		Parameter	TMPSO - PID
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	88.6
		Overshoot (%)	8%
		Rise time (s)	9
	Level 2 5 cm	Settling time(s)	9
		Overshoot (%)	8.7%
		Rise time (s)	3.9
Non Minimum Phase ɔ1 =0.3, ɔ 2 =0.4	Level 1 5 cm	Settling time(s)	10
		Overshoot (%)	10%
		Rise time (s)	6
	Level 2 5cm	Settling time(s)	8
		Overshoot (%)	12%
		Rise time (s)	4

TABLE: 5.7 TMPSO based on Performance Indices -Simulation Result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	TMPSO -PID	10.2	7.4	9.7	5.6	25.2	27.4	29.7	35.6

TABLE: 5.8 TMPSO based on Time Domain specification –Experimental Result

Operating Point		Parameter	TMPSO - PID
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	Level 1 5cm	Settling time(s)	233
		Overshoot (%)	9
		Rise time (s)	167
	Level 2 5 cm	Settling time(s)	233
		Overshoot (%)	8.5
		Rise time (s)	167

TABLE: 5.9 TMPSO based on Performance Indices -Experimental Result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	TMPSO -PID	13.86	19.05	9.62	10.90	69.30	95.25	48.1	54.50

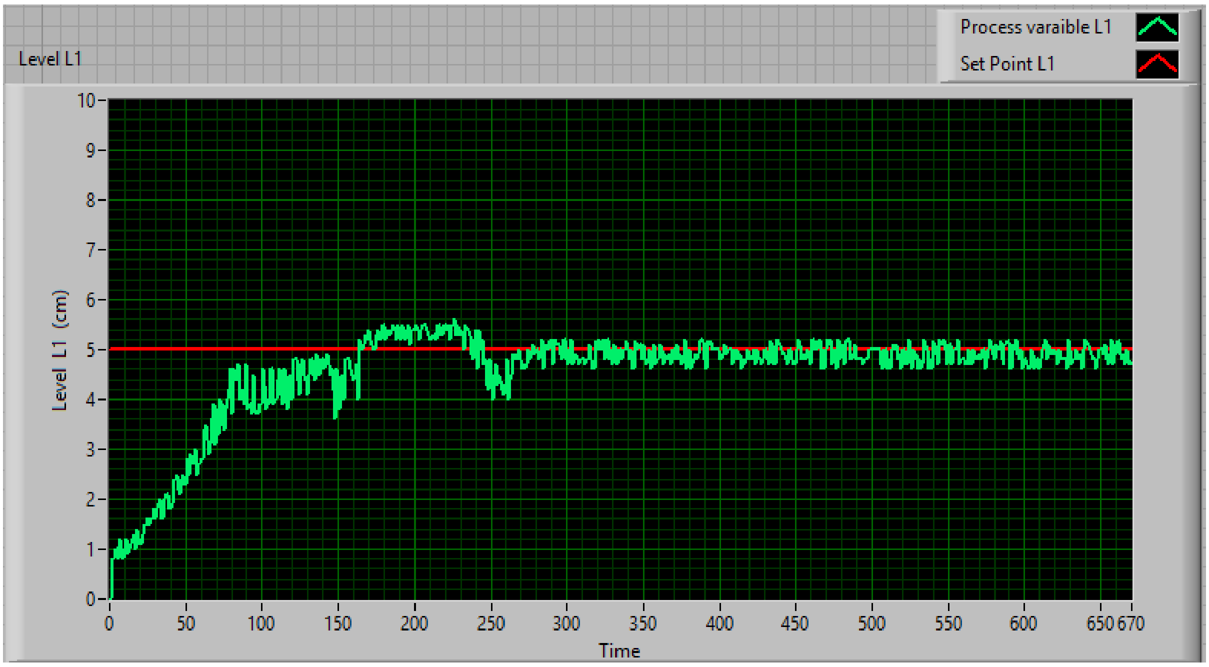

FIGURE: 5.3 Tank 1 Responce of Taguchi MPSO -ISE PID Controller (Level 1)

FIGURE : 5.4 Tank 2 Responce of Taguchi MPSO -ISE - PID Controller (Level 2)

5.7 Result and discussion

Using Mutation based PSO we can also optimize again the value from the Taguchi method so that we can get more optimized value for the parameter of PID and can get good response for nonlinear system as a result of Taguchi with MPSO.

This research work proposes Taguchi Mutation PSO calculation to improve the fitting estimations of the basic procedure controller parameters for different information and numerous yield procedures. The Taguchi technique is used to explore the ideal arrangement of process control parameters for the minimum performance indices to improve the stability of the nonlinear system so, the L_{27} $(2^1 \times 3^7)$ OA is utilized in the Taguchi strategy and used the S/N proportions to decide the levels of basic process controller parameters Kp, Ki and Kd, and ANOVA which gives the importance level of each procedure parameter. The execution record ISE, IAE, ITSE, and ITAE Taguchi based MSPO calculation execution to advanced PID controller parameter has enhanced the framework steadiness and better reaction. There is different four objective function but we mention only ISE PID parameter and response graph.

The MPSO calculation control principally enabled the pursuit to maintain a strategic distance from untimely assembly to diminish the local optimal solution into a neighborhood ideal arrangement and to look for a global best optimal solution. Taguchi-based MPSO performed superior to the Taguchi technique based GA. The minimized performance indices ISE, IAE, ITSE and ITAE for laboratory experimental set up of the Quadruple tank system. This new algorithm Taguchi MPSO calculation, demonstrating that it tends to be effectively utilized to locate the ideal controller parameter outline in the nonlinear quadruple tank system procedure to control the level of the base tank. The outcomes exhibit that the proposed strategies can go about as the best algorithm of the MIMO nonlinear process and will be stretched out to other nonlinear process control parameter for the different process control system.

CHAPTER 6

6 Design and Development of Experimental Set- up of Quadruple Tank System

6.1 Introduction

The laboratory quadruple four tank process method is employed for experimental implementation. In order to validate the simulation results, the real-time implementation is performed. The main purpose of real-time implementation is to provide the connection between the act of control theory and the real world, so that, it can give an indication of how control theory can be applied and also can give an indication of some of its limitations. Multivariable control techniques have received increased industrial interest. Most of the systems encountered are multiple input multiple output (MIMO) systems. Such systems have several inputs and several outputs which are often interacting, meaning that a disturbance at any input causes a response in some outputs or all. This interacting MIMO system makes control and stability analysis of the system very complicated compared to a single input single output (SISO) system.

6.2 Experimental MIMO Quadruple Tank System

A new laboratory process, was designed to illustrate performance limitations due to zero location in multivariable control systems. The quadruple-tank process is simple to build. The four tanks are made out of plexi glass tubes. The height of each tank is 10cm. The pumps are gear pumps with a capacity 2.5 L/min. Capacitive level transmitter is used for measuring the water levels and produce an output of 4-20mA. The entire process interfaced with a computer having configuration through an USB based NI DAQ card. The computer acts as a PID controller and collects information log to memory through LabVIEW.

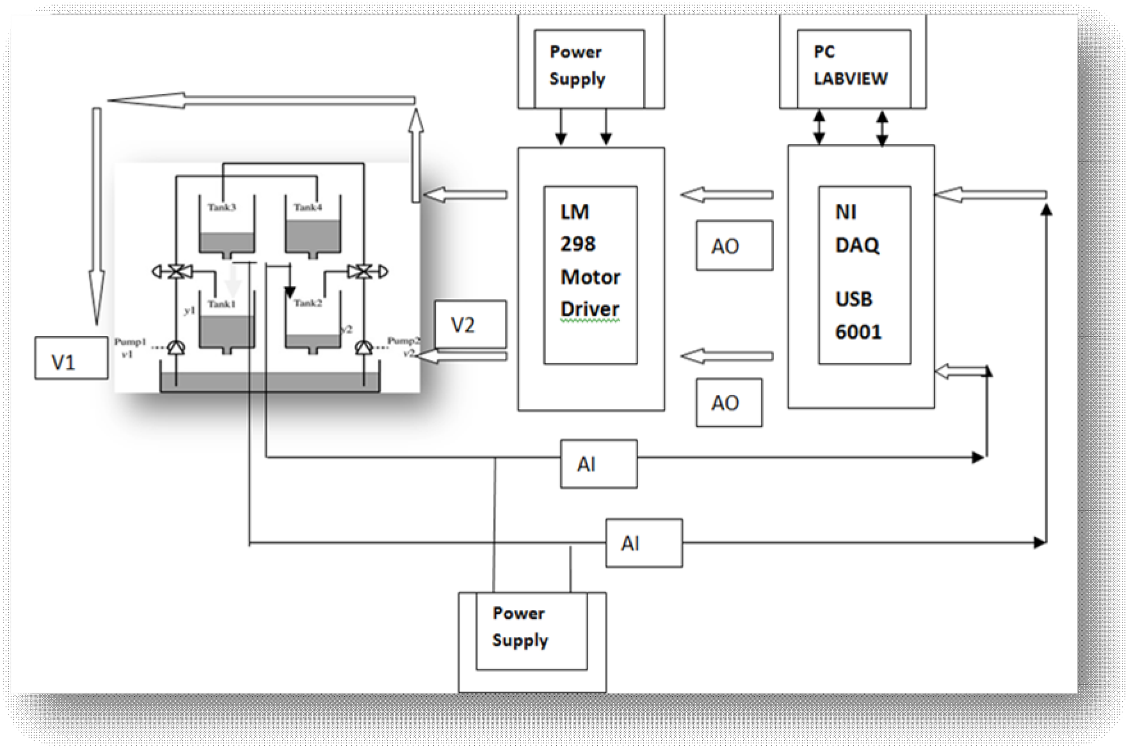

FIGURE: 6.1: Schematic Diagram of the Experimental Setup of QTS

FIGURE: 6.2: Real Experimental Setup of QTS

FIGURE: 6.3 Real Experimental Setup Structure of QTS

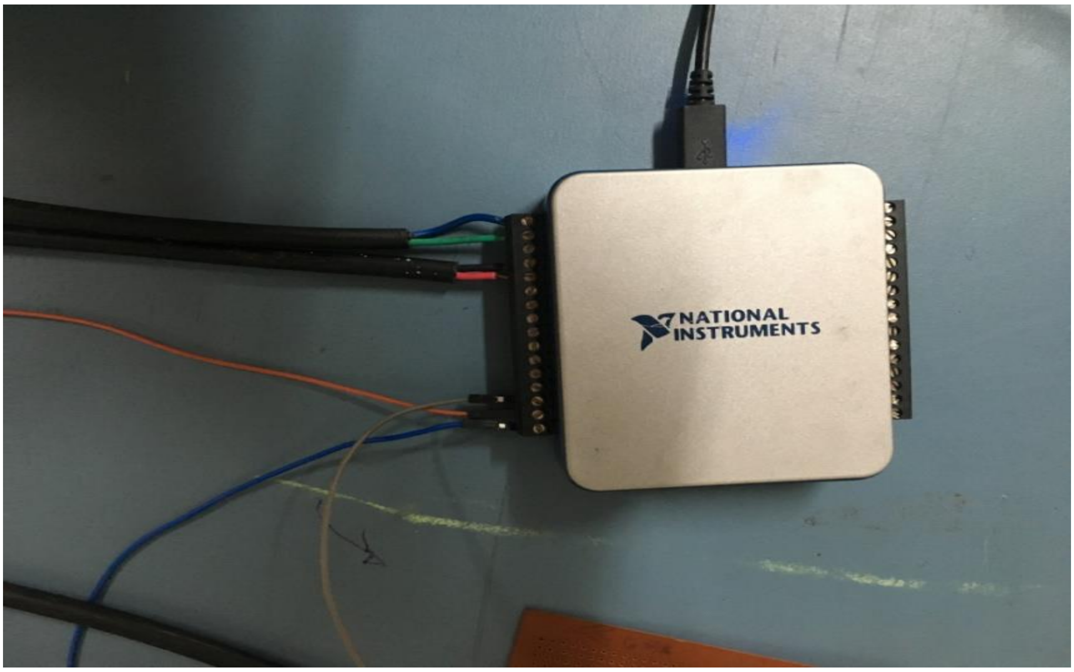

FIGURE: 6.4 National Instruments USB based Data acquisition Card 6001

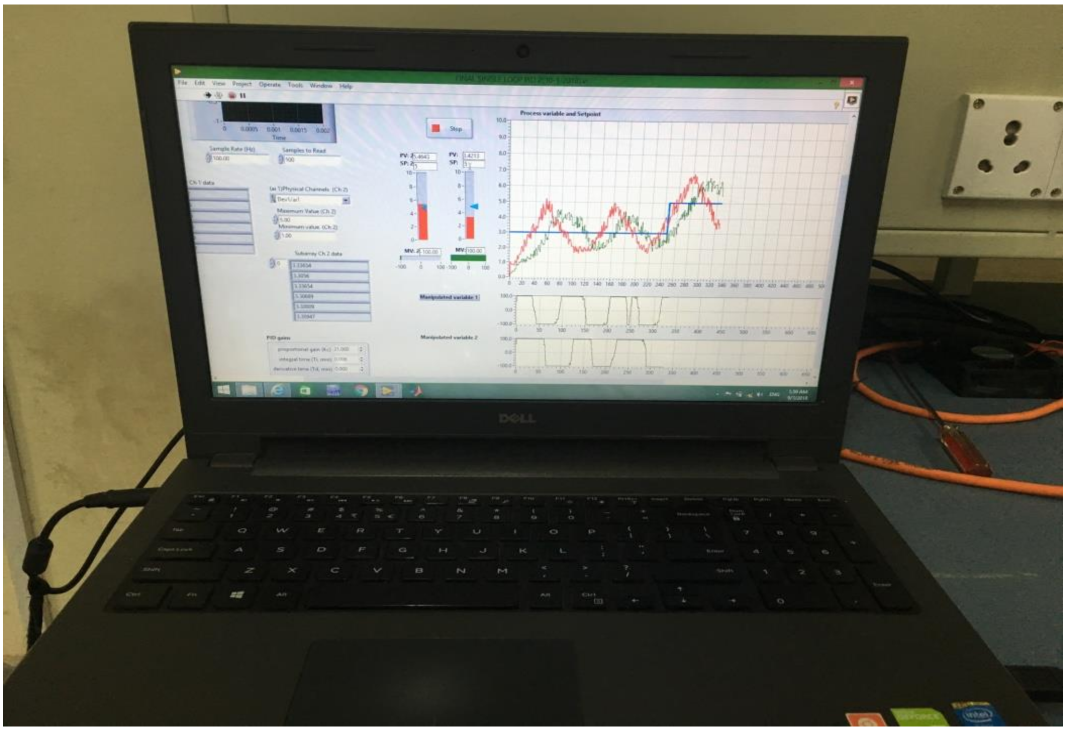

FIGURE: 6.5: GUI Real output Response of QTS

6.3 Result and discussion

The conceptualization of the 4-tank process as a multivariable control entity is originally proposed by (Johansson, 2000) and it is made up of four interconnected tanks in two pairs, two pumps, two valves and two level sensors are connected to the two lower tanks. Figure No. 6.1 is a schematic diagram of the experiment setup and Figure 6.3 is real experiment setup for quadruple tank system. Design and development hardware set up of the quadruple-tank nonlinear control system, for developing hybrid soft computing with statistical techniques based on controller LabVIEW 17 profession development system, is used.

NI DAQ 6001 USB card is used for acquiring a level signal from the bottom tanks and to maintain the level of the bottom tanks, which is maintained according to the generated analog PWM signal. By using the motor drive circuit to produce proper output voltage from DAQ and to run the motor according to control the level of both bottom tanks. We get the responses in two operating points, minimum phase and nonminimum phase. In the minimum phase response is better than the nonminimum. When the system goes in nonminimum phase system becomes almost impossible to stable. Minimum phase gives us better result based on the selection of parameter. The quadruple tank schematic diagram is shown in Figure 6.3. The goal of the control system is to control the level of the two lower tanks. What makes the task more challenging is that the water from the upper tanks flows down to the tanks below. Pump 1 feeds tank 1 and 4, and pump 2 feeds tank 2 and tank 3. So we have interaction between the two tanks that are controlled. Implementation of the proposed and other method results in term of time domain specification and also performance indices in the simulation of the mathematical model of the QTS which has two phases, minimum phase and nonminimum phase. The difficulties found in nonminimum phase are that we cannot find the result in the experiment. The system becomes unstable in the nonminimum phase so that we cannot maintain the level and control the flow of water to the tank. By providing a good transmitter and NI DAQ USB card having 14-bit resolution, good capacity pump, The computer having with configuration Intel (R) Core(TM) i7-4702MQ CPU 2.2 GHz frequency with 4 GB RAM, 64 bit operating system, help to operate LabVIEW software, the nonlinear system can operate at desired set point which ultimately improves the performance of the system. Using Taguchi MPSO method, we found the best parameter of the controller for the quadruple-tank MIMO system. Table 1 and Table 2 are for comparative analysis simulation and experiment result for time domain specification and performance indices for quadruple tank nonlinear system. From the all specified values for Taguchi MPSO and other approaches, we found the best PID value for this setup. However, we found the best result in Taguchi MPSO algorithm to improve the accuracy of the algorithm which is better than other specified algorithm used in experiment setup.

Performance of the system is to check, on the base of performance indices. Selection of the model performance is based on the process data and process reveal system. Additionally, the performance indices are used as a quantitative measure to depict the performance of the dynamic system. An optimal method may be differentiating using various techniques designed to match with the required parameter to the system. For a controlled system, we can use one of the four integral criteria to describe the system performance such as Integral Absolute Error (IAE), Integral Square Error (ISE), Integral Time Absolute Error (ITAE) and Integral time square Error (ITSE).

6.4 Outcomes with respect to objectives:

- We have designed and developed an algorithm for optimized PID parameter for the nonlinear system and determined PID Controller tuning parameter based on optimized techniques to improve performance indices
- We have designed and developed Laboratories set up of Quadruple tank system and tested figure of merits of different control techniques for experiment setup.

TABLE: 6.1 Comparative Analysis based on Time Domain specific -Simulation Result

Operating Point		**Parameter**	**PID Z-N**	**PSO-PID**	**GA-PID**	**Taguchi PID**	**TGA – PID**	**TMPSO PID**
Minimum Phase ɔ1 =0.7 ɔ2 =0.6	L1 5cm	Settling time(s)	50	90	95.98	89	90	88.6
		Overshoot (%)	7%	20%	9%	8.88%	11%	8%
		Rise time (s)	9	3	10	12	12	9
	L2 5 cm	Settling time(s)	15	10	12	9	10	9
		Overshoot (%)	7.5	10%	12%	8.7%	9.6%	8.7%
		Rise time (s)	9.1	10	4	4.5	5.3	3.9
Non Minimum Phase ɔ1 =0.3, ɔ 2 =0.4	L1 5 cm	Settling time(s)	12	15	13	12.8	60	10
		Overshoot (%)	4%	20%	8%	12%	23%	10%
		Rise time (s)	4	13	10	6.7	6	6
	L 2 5cm	Settling time(s)	15	12.5	8.3	8	7.6	8
		Overshoot (%)	7.5%	15%	12.6%	12.5%	12%	12%
		Rise time (s)	9.1	6	4.5	4.2	5.4	4

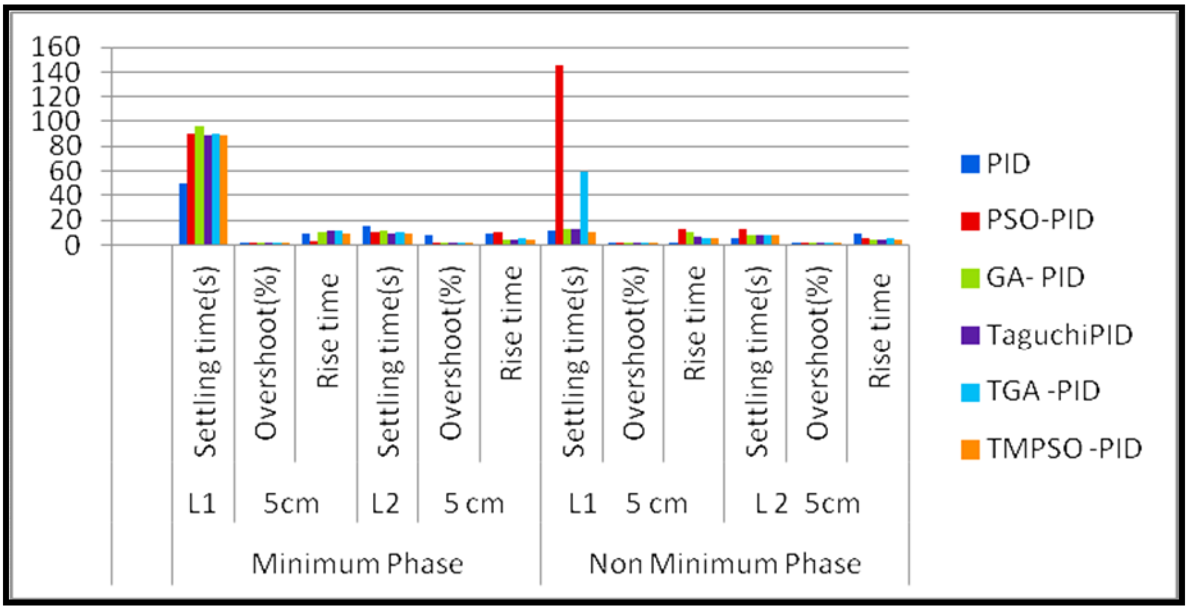

FIGURE: 6.6 Different Techniques with Time domain Specification Simulation Result

TABLE: 6.2 Comparative Analysis based on Performance Indices -Simulation result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	TMPSO -PID	10.2	7.4	9.7	5.6	25.2	27.4	29.7	35.6
2	TGA -PID	9.8	8.3	12.0	13.0	39.8	48.3	30.23	23.33
3	Taguchi -PID	11	9	11.0	14.00	22.67	34.23	34	38
4	GA PID	10.6	8.2	10.2	8	40.6	58.2	40.2	38.2
5	PSO PID	11.2	8.7	10	8.5	31.2	48.7	30.4	28.5
8	PID Z-N	60	11	17	10	60	41	37.5	40.3

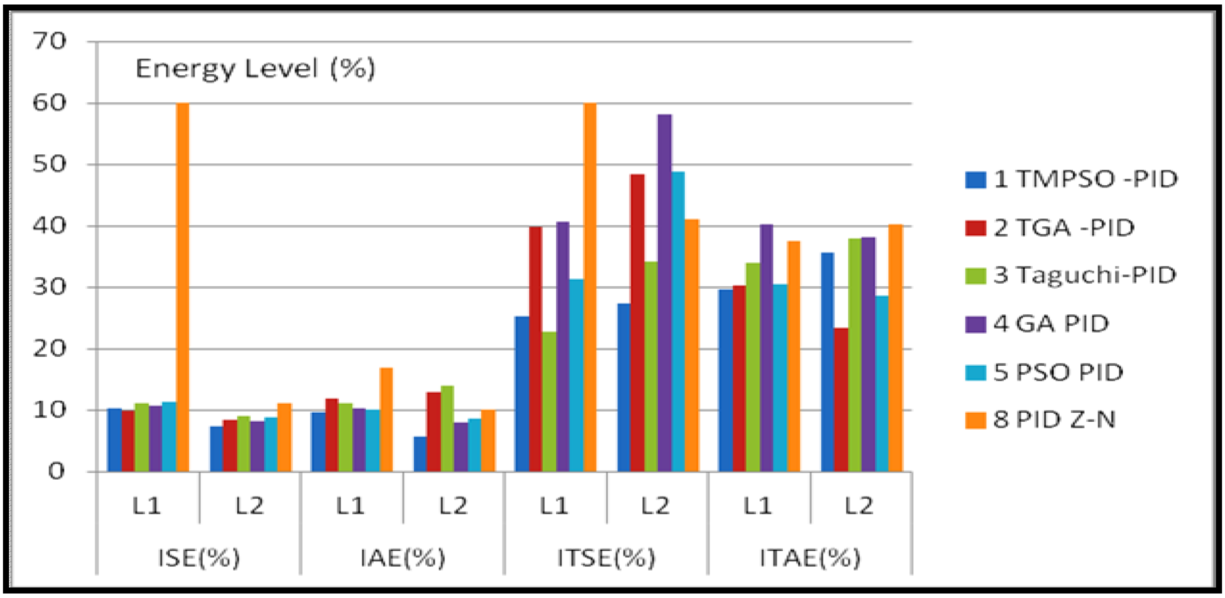

FIGURE: 6.7: Different Techniques with Performance Indices Simulation Result

TABLE: 6.3 Comparative Analysis based on Time Domain Specification –Expe Result

Operating Point		Parameter	PID Z-N	PSO-PID	GA-PID	Taguchi PID	TGA PID	TMPSO -PID
Minimum Phase ɔ 1 = 0.7 ɔ 2 = 0.6	L1 5 cm	Settling time (s)	300	255	247	225	242	233
		Overshoot (%)	10.8	19	12	11	10	9
		Rise time (s)	275	234	222	130	198	167
	L2 5 cm	Settling time(s)	320	266	254	265	245	233
		Overshoot (%)	12.7	9	25	21	13	8.5
		Rise time (s)	275	234	222	215	198	167

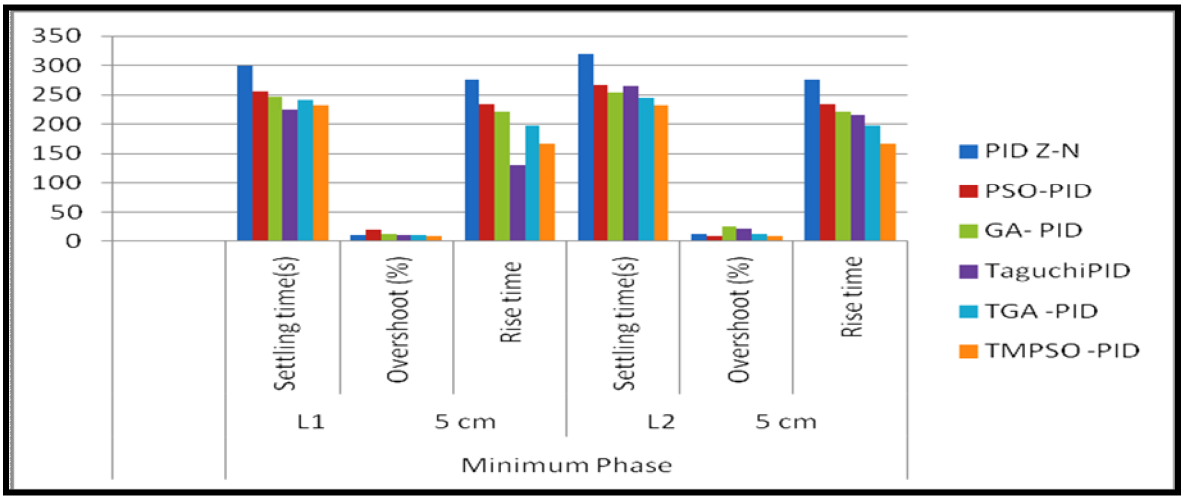

FIGURE: 6.8: Different techniques with Time domain specification Experimental result

TABLE: 6.4 Comparative Analysis based on performance indices - Experimental result

Sr. No.	Methods /Indices	ISE (%)		IAE (%)		ITSE (%)		ITAE (%)	
		L1	L2	L1	L2	L1	L2	L1	L2
1	TMPSO -PID	13.86	19.05	9.62	10.90	69.30	95.25	48.10	54.50
2	TGA -PID	13.97	20.49	9.51	11.09	69.88	102.4	47.53	55.45
3	Taguchi PID	14.79	20.18	9.83	11.01	73.97	100.9	49.13	55.06
4	GA PID	14.68	21.50	9.64	11.28	73.39	107.5	48.19	56.41
5	PSO PID	15.63	16.37	10.09	9.30	78.13	81.88	50.45	46.47
8	PID Z-N	18.13	24.32	11.03	12.30	90.64	121.5	55.17	61.49

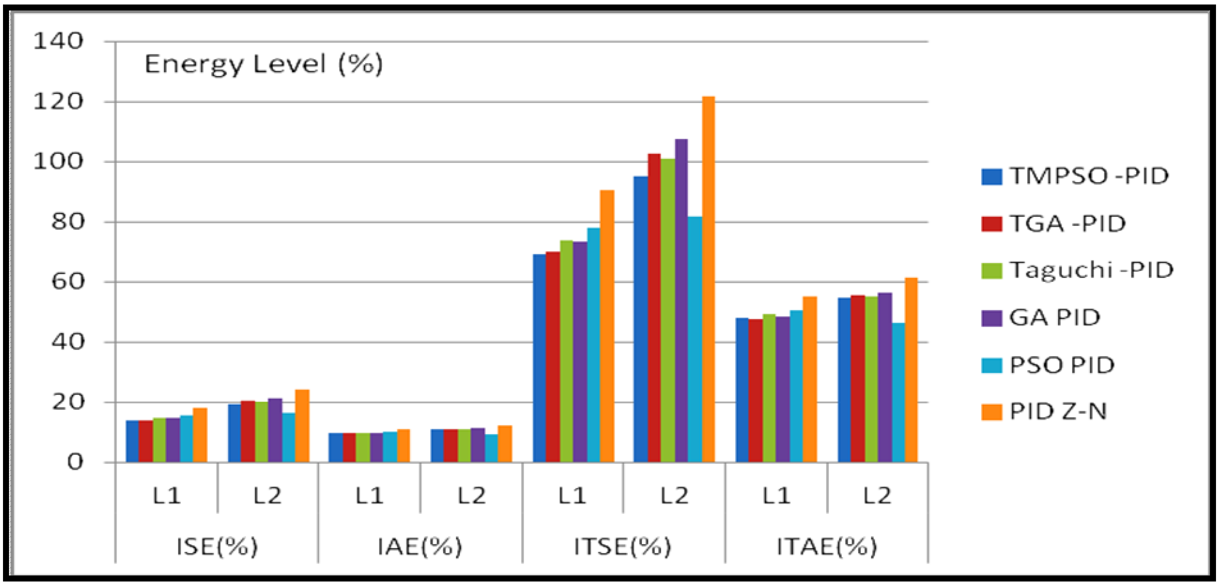

FIGURE: 6.9: Different Techniques with Performance Indices Experiment Result

The different response of the MIMO system with different magnitude of the reference signal and process load condition at the various starting point is simulated in MATLAB software. Regulatory responses exhibit oscillations for most of the control techniques. The TMPSO improves the response while the other controller gives a poorer performance. On the other ways, the proposed controller Taguchi MPSO gives better dynamics and oscillation-free response. The proposed TMPSO controller outperforms the other controller techniques when the operating point of the process was shifted over the entire range of the tank. Taguchi MPSO method improves robustness in the sense that small changes in it do not produce large steady-state errors or loss of stability. TMPSO gives better response compared to various different controllers. The objective of the design is to obtain minimum value of ISE, IAE, ITSE and ITAE. TMPSO gives minimum value ISE and IAE ITAE and ITSE compared to other controller because it produces large errors and persist for a long time. A laboratory experimental nonlinear level control process set up was used for real-time experiment implementation. A computer is used to store the measuring parameter and also work as a function of PID tuning for TMPSO controller. The servo responses of the system are obtained for all six techniques ZN-PID, PSO PID, GA PID, Taguchi PID, Taguchi combined with GA and Taguchi MPSO controllers.

The responses of TMPSO are compared with other various controllers tuned with the normal operating point. The responses given by the PID controller have more oscillations and the TMPSO improves the response in case of real-time implementation with limitations. But still, the literature studies reveal that intelligent controllers are suitable for nonlinear systems.

6.5 LabVIEW Programming Code

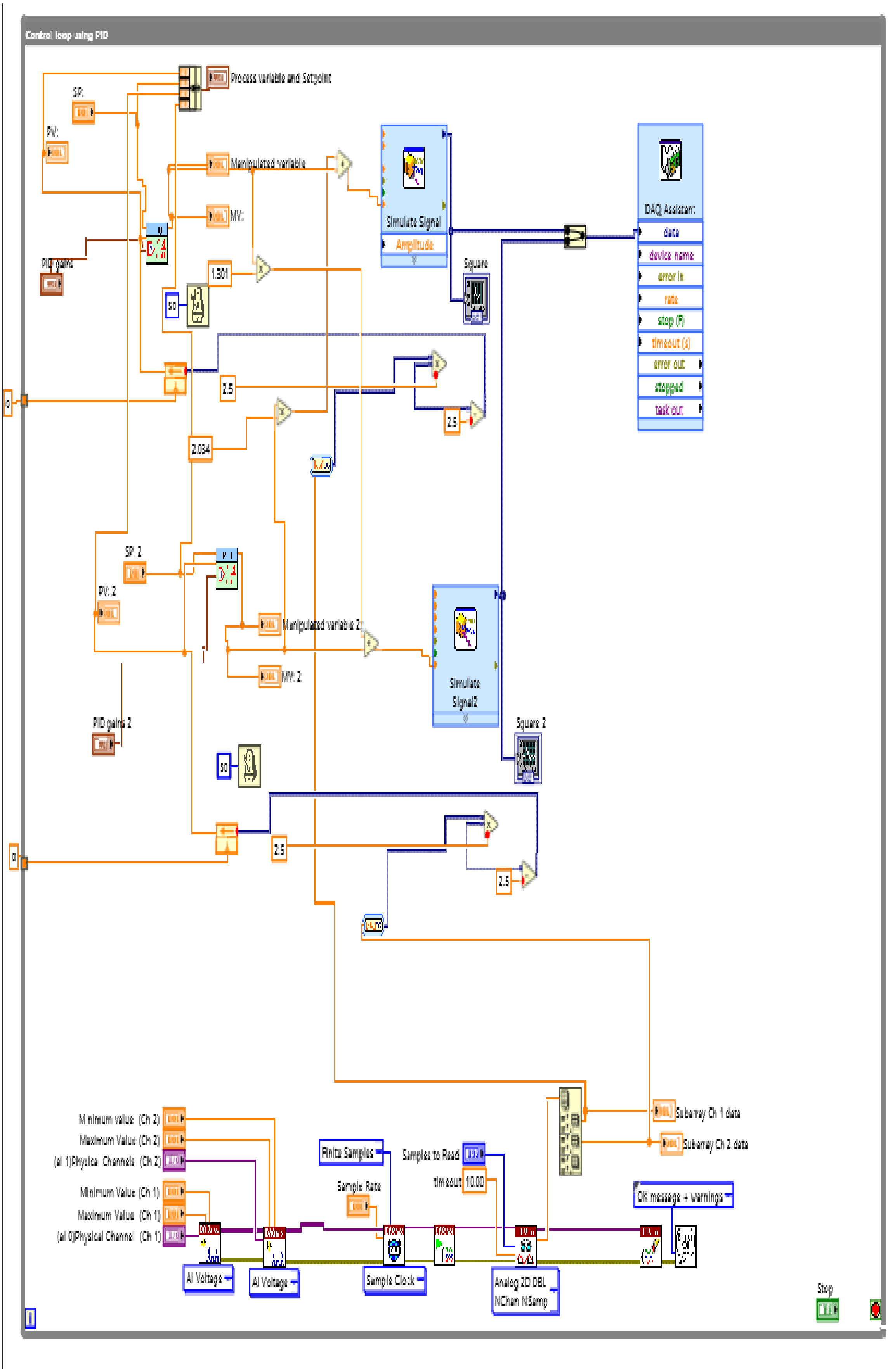

FIGURE 6.10: Programming Code LabVIEW Block Diagram

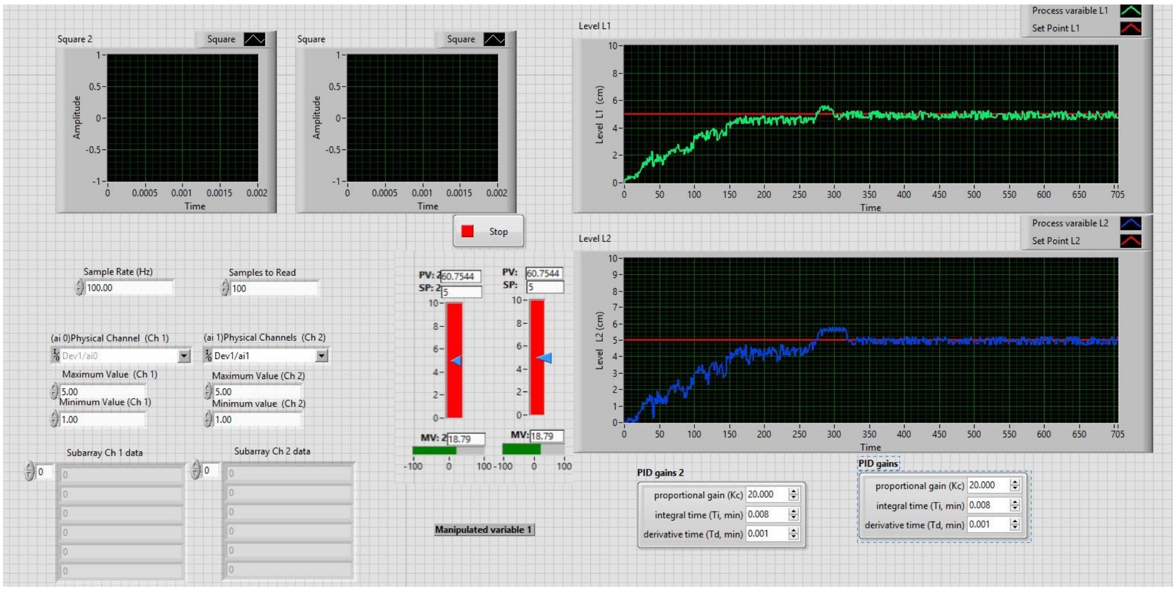

FIGURE 6.11: Programming Code LabVIEW Front panel GUI

CHAPTER 7

7 Conclusions and Future Scope

7.1 Conclusions

In this research work, a new hybrid Taguchi MPSO algorithm has been represented and implemented to improve the performance indices ISE, IAE, ITSE and ITAE of the highly nonlinear quadruple tank system. Simulation and experiment results prevailed, are equated with other optimization techniques. From the experimentation validation results, we can propose that Taguchi- MPSO algorithm is earmarked to solve the nonlinear problem and optimized performance indices. In addition to the comparative analysis and validation of the TMPSO proposed algorithm for the nonlinear system, has the potential to improve the performance indices and to solve the nonlinearity.

Optimization based on Taguchi based MPSO algorithm for tuning of PID controller is developed using LabVIEW hardware and software in the experimental setup for analysis and validation. This proposed algorithm is implemented with laboratory set up to improve performance indices compared to PID Z-N method, Genetic Algorithms, Particle Swarm Optimization and Taguchi GA techniques. The performance of the system tested gives fine tuning parameter for the said controller for different coupling effect along with multiple input outputs. The results compared with simulation and experiment set up time domain specification as well as performance indices are improved. The proposed algorithm validates with the quadruple four tank system.

This research work is carried out for finding the best optimal solution for the nonlinear dynamic system. This research found optimized parameter of the controller for multiple inputs and multiple output dynamic system, using Taguchi statistical method based on MPSO techniques. The effect indicates that Taguchi based MPSO strategies can act as quality strategy of the MIMO nonlinear process and might be extended to different nonlinear method controller parameter for the industrial process control system. The result shows that TMPSO is provided with the better result when compared to the other approaches.

7.2 Scope of Future Work

There are some good points and potential analysis directions that stretch this work as the scope of future work. The summaries for future scope of this work are following:

- To apply other optimization algorithms which may give the better improvement of the performance indices of quadruple tanks system.
- This work can be extended with the optimization of other performance indices i.e. Harris index, robustness index, sp crossing, standard deviation.
- Proposed Taguchi MPSO algorithm for nonlinear control system can be extended with SISO, MISO, and SIMO system.
- Performance of the proposed method can be evaluated with other nonlinear systems i.e. Twin rotor MIMO system, Inverted Pendulum, Magnetic Levitation system.

List of References

[1] M. Arc, T. Kara, ñAdaptive Fault Tolerant Control for Liquid Tank Processò, International Journal of Applied Mathematics, Electronics and Computers, vol. 4, Special Issue, pp. 111-117, 2016

[2] Gökçe Candan &Harun Resit Yazgan òGenetic algorithm parameter optimisation using Taguchi method for a flexible manufacturing system scheduling problem ñ in International Journal of Production Research Volume 53, 2015 - Issue 3

[3] M. Rezaie, B. Rahmani. ñFuzzy predictive control of three tank system based on a modelling framework of hybrid systemsò, in Journal of Systems and Control Engineering, 228(6), 369-384, 2014.

[4] Jatin Kumar Pradhan, Arun Ghosh, Chandrashekhar, Narayan Bhende ñTwo-degree-of-freedom multi-input multi-output proportionalï integralï derivative control design: Application to quadruple-tank systemò August 2018 doi.org/10.1177/0959651818791687

[5] E. GovindaKumar,B.Mithunchakravarthi N.Dhivyab ñ Enhancement of PID Controller Performance for a Quadruple Tank Process with Minimum and Non-Minimum Phase Behavioursò https://doi.org/10.1016/j.protcy.2014.08.061Procedia Technology Volume 14, 2014, Pages 480-489.

[6] Jaya prakash , Senthil Rajan , Harish Babu óAnalysis of Modelling Methods of Quadruple Tank Systemò in International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 3, Issue 8, August 2014 10.15662/ijareeie.2014.030807

[7] P.A. Vaghela, J.M. Prajapati ñ Hybridization of Taguchi and Genetic Algorithm to minimize iteration for optimization of solutionò in http://www.elsevier.com/locate/mex, https://doi.org/10.1016/j.mex.2019.01.002

[8] Koun-Tem Sun, Ching-Ling Lin, Hsin-Te Chan, Hong-Ming Kang, Man-Ting Ku,ò Comparisons between the Hybrid Taguchi-Genetic Algorithm and Genetic Algorithm ñ in Advance in industrial engineering and management ISSN:2222-7059 (Print);EISSN: 2222-7067 (Online) 2019 American Scientific Publishers.

[9] Ying Sun,Yuelin Gao ñA Multi-Objective Particle Swarm Optimization Algorithm Based on Gaussian Mutation and an Improved Learning Strategyò in Mathematics 2019, 7, 148; doi:10.3390/math7020148 www.mdpi.com/journal/mathematics

[10] Wen-Jong Chen, Wen-Cheng Su, Fung-Ling Nian, Jia-Ru Lin and Dyi-Cheng Chen ñApplication of ANOVA and Taguchi-based Mutation Particle Swarm Algorithm for Parameters Design of Multi-hole Extrusion Processò in Research Journal of Applied Sciences, Engineering and Technology 6(13): 2316-2325, 2013 ISSN: 2040-7459; e-ISSN: 2040-7467 © Maxwell Scientific Organization, 2013

[11] Naimul Hasan,Ibraheem Nasirudin,Shuaib Farooq ñHybrid Taguchi Genetic Algorithm-Based AGC Controller for Multisource Interconnected Power Systemñ in Technologies 2018, 6, 54; https://doi.org/10.1080/15325008.2019.1576242

[12] Nadeem Faisal and Kaushik Kumar ñ Optimization of Machine Process Parameters in EDM for EN 31 Using Evolutionary Optimization Techniques ñ in Technologies 2018, 6, 54; doi:10.3390/technologies6020054 www.mdpi.com/journal/technologies

[13] Yongli Zhang, Lijun Zhang, Zhiliang Dong ñAn MEA-Tuning Method for Design of the PID Controllerò Mathematical Problems in Engineering Volume 2019, Article ID 1378783, 11 pages https://doi.org/10.1155/2019/1378783.

[14] Nasir Ahmed Al-Awad ñOptimal Control of Quadruple Tank System Using Genetic Algorithmò in International Journal of Computing and Digital Systems ISSN (2210-142X) Int. J. Com. Dig. Sys. 9, No.1 Jan-2019

[15] Ali Thamallah, Anis Sakly, Faouzi MôSahli ñ A new constrained PSO for fuzzy predictive control of Quadruple-Tank Processò in www.elsevier.com/locate/measuremnt 136 (2019) 93ï104 https://doi.org/10.1016/j.measurement.2018.12.050, journal homepage: www.elsevier.com/locate/measurement

[16] Mohd Muqeem , Ahmad F. Sherwani , Mukhtar Ahmad , Zahid A. Khan ñApplication of the Taguchi based entropy weighted TOPSIS method for optimisation of diesel engine performance and emission parametersò in International Journal of Heavy Vehicle Systems Print ISSN: 1744-232X Online ISSN: 1741-5152. doi.org/10.1504/IJHVS.2019.097111.

[17] Z. Yu, J. Wang, B. Huang, and Z.Bi ñPerformance assessment of PID control loops subject to Set point changes,ò J. of Process Control, vol. 21, pp. 1164-1171, 2011

[18] Dale E. Seaborg, Thomas F. Edgar , Duncan A. Mellichamp, Process Dynamics and Control, John Wiley & Sons Inc., 2004.

[19] G. P. Rangaiah and P.R. Krishnaswamy ò Estimating second order dead time parameter from under damped process transients ò Chemical Engineering Science, Vol. 51, No. 7, pp. 1149-1155, 1996 Copyright 0 1996 Elsevier Science Ltd.

[20] National Instruments, NI LabVIEW PID and Fuzzy Logic Toolkit for Windows, National Instruments Available http://sine.ni.com/nips/cds/view/p/lang/en/nid/209054

[21] National Instruments, LabVIEW System Design Software, National Instruments. Available: http://www.ni.com/labview

[22]Thomas E. Merlin, Process Control Designing Processes and Control Systems for Dynamic Performance, McGraw-Hill Inc., 1995

[23] A. OôDwyer, Handbook of PI and PID Controller Tuning Rules, Imperial College Press, London, UK, 3rd edition, 2009.

[24] R. Padmasree and M. Chidambaram, Control of Unstable Systems, Narosa Publishing House, New Delhi, India, 2006.

[25]C. J. Einerson, D. E. Clark, and B. A. Detering, ñIntelligent control strategies for the plasma spray process,ò in Proc. Thermal Spray Coatings: Research, Design and Applications, 1993, pp. 205-211.

[26]R. C. Panda, ñSynthesis of PID controller for unstable and integrating processes,ò Chemical Engineering Science, vol. 64, no. 12, pp. 2807ï 2816, 2009.

[27] Kennedy, J. and R. Eberhart, 1995. Particle swarm optimization. Proceeding of IEEE International Conference Neural Networks, 4: 1942-1948.

[28]Thomas E. Merlin, Process Control Designing Processes and Control Systems for Dynamic Performance, McGraw-Hill Inc., 1995.

[29] Jignesh Patel and Hasan Vhora http://www.iaeme.com/IJARET/index.asp 104 editor@iaeme.com

[30] Alvarado, D. Limon, W. Garc'ıa-Gab'ın, T. Alamo, E.F. Camacho, "An Educational Plant Based on the Quadruple-Tank Process, in Int. Federation of Automatic Control, Madrid, Spain, 2006.

[31] Tomi Roinila, Matti Vilkko, Antti Jaatinen, Corrected Mathematical Model of Quadruple-Tank Process, in The International Federation of Automatic Control, Seoul, Korea, 2008.

[32] Xia, H. and Majeckie, P. and Ordys, A.W. and Grimble, M.J. (2004) Performance assessment of MIMO systems under partial information. In: American Control Conference 2004, 2004-06-30 - 2004-07-02, Boston.

[33] R. D. Braatz and Rusli, A Quadruple-Tank Process Control Experiment, the University of Illinois at Urbana Champaign, 2004.

[34] J. Kennedy and R. Eberhart, ñParticle swarm optimization,ò in Proc. International Conference on Neural Networks, 1995, vol. 4, pp. 1942-1948.K. H. Johansson. Relay feedback and multivariable control. Ph.D. thesis, Department of Automatic Control, Lund Institute of Technology, Sweden, November 1997.

[35]K. H. Johansson. The Quadruple-Tank Process - A multivariable laboratory process with an adjustable zero. IEEE Transactions On Control Systems Technology, Vol. 8, No. 3, May 2000.

[36]Abeykoon, C., K. Li, M. McAfee, A.L. Kelly and J. Deng, P.J. Martin, Q. Niu, , 2011. A new model-based approach for the prediction and optimisation of thermal homogeneity in single screw extrusion. Cont. Eng. Pract., 19(8): 862-874

[37]U. S. Banu and G. Uma, ñFuzzy gain scheduled continuous stirred tank reactor with particle swarm optimization based PID control minimizing integral square error,ò Instrumentation Science and Technology, vol. 36, no. 4, pp. 394ï 409, 2008

[38]M. S. Arumugam and M. V. C. Rao, ñOn the performance of the particle swarm optimization algorithm with various inertia weight variants for computing optimal control of a class of hybrid systems,ò Discrete Dynamics in Nature and Society, vol. 2006, Article ID 79295, 17 pages, 2006.

[39]Johansson, K. H.: (2000). The quadruple-tank process: A multivariable laboratory process with an adjustable zero. IEEE Trans. on Control Systems Technology, vol 8, No.3, pp. 456-465

[40] Abdullah, M. Zribi (2012), ñControl Schemes for a Quadruple Tank Processò, International Journal of Computer and Communication, Vol.7, No. 4, pp. 594- 604.

[41] ñAuto-tuning method of expanded PID control for MIMO systemsò, 9th IFAC Workshop, Adaptation and learning in control and signal processing, 2007.

[42]Richard C. Dorf, Robert H. Bishop, Modern Control Systems 10th Edition, Pearson Prentice Hall, 2005.

[43] Ian Griffin, On-line PID Controller Tuning using Genetic Algorithms, Dublin City University, 2003.

[44]T. OôMahony & CJ. Downing (Cork Institute of Technology, Ireland), Klaudiusz Fatla (Wroclaw University of Technology, Poland), Genetic Algorithms for PID Parameter Optimization, Minimizing Error Criteria.

[45] Integration of the Finite Element Method and the Taguchi Method. Available from: http://www.ecs.umass.edu/mie/ labs/mda/fea/sankar/chap3.html

[46]Jou YT, Lin WT, Lee WC, Yeh TM. Integrating the Taguchi method and response surface methodology for process parameter optimization of the injection molding. Applied Mathematics and Information Sciences. 2014; 8(3):1277ï 85. 10.12785/amis/080342

[47]Introduction to Taguchi Method. Available from: http:// www.ecs.umass.edu/mie/labs/mda.html

[48]Z. L. Gaimg, ñA particle swarm optimization approach for optimum design of PID controller in AVR system,ò IEEE Trans. Energy Convers., vol. 19, no. 2, pp. 384-391, June 2004.

[49]H. J. Jawad, ñParticle swarm optimization based optimum PID controller for governor system of synchronous generator,ò AL-Qadisiya Journal for Eng. Sci., vol. 6, no. 3, 2013.M. Rahimian and K. Raahemifar, ñOptimal PID controller design for AVR system using particle swarm optimization algorithm,ò IEEE CCECE, 2011.

[50]S.-R. Qi, D.-F. Wang, P. Han, and Y.-H. Li, ñGrey prediction based RBF neural network self-tuning PID control for turning process,ò in Proc. Int. Conf. Mach. Learning Cybern., pp. 802-805, 200

[51]D. Devaraj and B. Selvabala, ñReal-coded genetic algorithm and fuzzy logic approach for real-time tuning of proportional-integral-derivative controller in automatic voltage regulator system,ò IET Gen. Trans. Dist., vol. 3, issue 7, pp. 641-649, February 2009.

[52]L. Cai and A. B. Rad, ñAn intelligent longitudinal controller for application in semiautonomous vehicles,ò IEEE Trans. Ind. Electr., vol. 57, no. 4, pp. 1487-1497, April 2010

[53]D. B. Fogel, Evolutionary computation: Toward a new philosophy of machine intelligence, 2 ed. IEEE Press, 2006.

[54] R.-J. Wai, J.-D. Lee, and K.-L. Chuang, ñReal-time PID control strategy for maglev Transportation system via particle swarm optimization,ò IEEE Trans. Ind. Electr., vol. 58, no. 2, pp. 629-646, February 2011.

[55]H. M. Hasanien, ñDesign optimization of PID controller in automatic voltage regulator system using Taguchi combined genetic algorithm method,ò IEEE Syst. Journal, vol. 7, no. 4, pp. 825-831, December 2013

[56]C.-C. Hwang, L.-Y. Lyu, C.-T. Liu, and P.-L. Li, ñOptimal design of an SPM motor using genetic algorithm and Taguchi method,ò IEEE Trans. Magn., vol. 44, no. 11, pp. 4325-4328, November 2008.

[57]G. Chen, H. Lei, and H. Fang, ñHybrid Taguchi-particle swarm optimization based optimal reactive power flow,ò Intelligent System and Applications (ISA), May 2010

[58]Aok.S., Kawachi S. and Sugeno M. (1990), óóApplication of Fuzzy control Logic for Dead time Process in a Glass Melting Furnaceôô, *Fuzzy sets and Systems*, Vol. 38, pp. 251-265.

[59]Arjin N, Witheephanich K,Trisuannaat T and Tirasesthascc K (2004), ñIP controller design for quadruple tank systemôô, Dept. of EE, Faculty of Engg., Srinakharinwwirot Univ., Nakhonnayok, Thiland.

[60]Anandanatarajan R, Chidambaram M, Jayasingh T, ñLimitations of PI controller for a first-order nonlinear process with dead timeôô. *ISA Trans* 2006;45:185ï 99.

[61]Anandanatarajan, and Chidambaram(2005),ñExperimental evaluation of a controller using variable transformation on a hemi-spherical tank level processò, *Proc., NCPICD* , pp. 195-200.

[62]Astrom KJ and Haggluned T (1998),ñAutomatic tuning of PID controllersôô. *Instrument Soc. of America*

[63]Astrom K.J. and Wittenmark B. (1995), ñAdaptive controlôô, Second Edition, *Pearson Education,* Inc., pp. 392-398.

[64]Basker V.R., Engelstad J.D., Baab C.T. and Crisalle O.D. (1999), ñSystems with Incertain Delay ð Design for Robust Stability and Performanceôô, *Proceedings of the American*

Control Conference, pp. 414-419.Bequette, B. W. (1991), ñNonlinear Control of Chemical. Processes: A Reviewöö *Ind. Eng. Chem. Res*., 30, 1391-1413

[65]B. W. Bequetet(2003), ñProcess control, Modeling, Design and Simulationöö, *Prentice-Hall of India*.

[66]E. Bristol, ñOn a new measure of interaction for multivariable process controlöö *IEEE Trans. Automat. Contr*., vol. 11(1966), p.133

[67]Chidambaram M. (1995),ñNonlinear Process Controlöö, *New Age International Publishers Limited*, Wiley Eastern Limited.

[68]Chidambaram M. (1998), ñApplied Process Controlöö, *Allied Publishers*, India.

[69]Chidambaram M. (2000), ñComputer control of Processöö, *Narosa Publishers*, New delhi india

[70]Chidambaram M. and Nyttle V.G. (1994), ñFuzzy logic control of a fed-batch fermentor with significant measurement delayöö, Bioprocess Engineering, *Springer verlag*., Vol. 10 ,pp. 225-228.

[71]Chidambaram M., Anandanatarajan R. and Jayasingh T.(2003a), ñController design for Nonlinear process with dead time via variable transformationsöö, *Proceedings of the International Symposium on Process Systems Engineering and Control (ISPSEC'03)*, IIT, Mumbai, pp. 223-228.

[72]Chidambaram M., Anandanatarajan R. and Jayasingh T.(2003b), ñModified Double Control Scheme for Processes with large Dead timeöö, *Proceedings of the National Conference on Process Identification, Control & Diagnosis (NCPICD' 03),* Annamalai University, India, pp. 143-150.

[73]El-Farra N.H. and Christofides P.D. (1999), ñRobust Optimal Control of Nonlinear Systemsöö, *Proceedings of the American Control Conference*, pp.119-115

[74] ñFuzzy Logic Toolbox (1995)-For use with MATLAB, User's guideöö, ver.2

[75] Grimble M.J. and Ordys A.W. (2001), ñPredictive control for Industrial Applicationsöö, *Annual Reviews in Control* , Vol. 25, pp. 13-24.

[76] Guzelkaya M., Eksin I. and Ye E. (2003), ñSelf-tuning of PID-type fuzzy logic controller coefficients via relative rate observeröö", *Engineering Applications of Artificial Intelligence*, Vol. 16, No. 3, pp.227-236.

[77]Haddad W.M. and Chellabonia V. (1999), ñNonlinear Static and Dynamic Output Feedback Controllers for Passive Systems: Global Stabilization and Local Optimalityöö, *Proceedings of the American Control Conference,* pp. 263-269.

[78]Hagglund T. (1992), ñA predictive PI controller for processes with long dead timesöö, *IEEE Control Systems magazine,* pp. 57-60

[79]Hang C.C., Astrom K.J. and Ho W.K. (1991), ñRefinements of the Ziegler-Nichols tuning formulaö, *IEE Proceedings, Part D,* Vol. 138, pp. 111-118.

[80]Hatipoglul C., Bennett M.A., Amato W.P. and Moran S.P.(1999), ñOvercoming Actuator Performance Degradation Caused by Non-smooth Non-linearitiesö, *Proceedings of the American Control Conference*, pp. 167-174.

[81]Huang C.T., and Huang M.F. (1993), ñEstimation of Second-Order Parameters from the Process Transient by Simple Calculationö, *Ind. Eng. Chem.Res.,*Vol. 32, pp. 228-230.K.H. Johanson, (2000) ñThe Quadruple-tank process: A multivariable process with an adjustable zeroö, *IEEE Trans. Contr. Syst. Tech*., Vol 8.No. 3, p.no 456-465.

[82] Kim Y.H. and Kim M.H. (1995), ñExperimental Application of combined fuzzy and predictive control to a binary distillation columnö, *Journal of Chemical Engineering of Japan*, Vol. 28. No. 5. pp. 617-620.

[83]Kravaris C. and Niemiec, M. (1998), ñNonlinear Model-Algorithmic Control ï A review and new developments in Nonlinear Model Based Process Controlö R. Berber and C. Kravaris, editors, *Kluwer Academic Publishers*, pp.143-171.

[84]Kravaris C. and Soroush, M. (1992), ñDiscrete-Time Nonlinear Controller Synthesis by Input/Output Linearizationö, *AIChE J.,* Vol. 38, pp. 1923-1928.

[85]Kravaris C. and Soroush, M. (1996), ñA Continuous-time Formulation of Nonlinear Model Predictive Controlö. *Int. J. Control*, Vol. 63, pp. 121-125

[86]Kravaris C. and Wright R.A. (2001), ñPractical approach to nonlinear controlö, *AIChE conference (286), Systems and Process control*, paper ID 3020, New York

[87]Krishnaswamy R. and Rangaiah G.P. (1994), ñEstimating Second-Order plus Dead Time Model Parametersö, *I & EC Research*, Vol.40, pp.123-129.

[88]Lee I.B. and Sung S.W. (1996), ñLimitations and countermeasures of PID controllersö, *Ind. Eng. Chem*. Res., Vol. 35, pp. 2596-2610.

[89]Lee J., Cho W. and Edgar T.F.(1990), ñAn improved Technique for PID controller Tuning from Closed-Loop Testsö, *AIChE Je.*, Vol. 36, pp. 1891 -1896.

[90]Ling C. and Edgar T.F. (1994), ñExperimental verification of model-based fuzzy gain scheduling techniqueö, *Proc. American Control Conference*, pp. 2275-2480.

[91]W.L.Luyben (1986), ñSimple method for tuning SISO controllers in multivariable systemsò, *Ind. Eng. Chem. Process Des*. Dev. pp.654-660.

[92]Marshall J.E., Gorecki H., Korytowski A. and Walton K. (1992), ñTime delay systems: stability and performance criteria with applicationsö, Ellis Horwood

[93]Mahdi Alavi SM and Martin J.Hayes (2006), ñQuantitative feedback design for a benchmark quadruple tank processö, *ISSC, Dublin Institute of Technolog.*

[94]Mehra, R. K. and Rouhani R. (1980),ñTheoretical Considerations on Model Algorithmic Control for Nonminimum Phase Systemsöò, *Proc. Amer. Control. Conf*, TA8-B

[95]Meyer C., Seborg D.E. and Wood R. K. (1978), ñAn experimental application of time delay compensation technique to distillation column controlöò, *Ind. Eng. Process Des. Dev*., Vol. 17, No. 1, pp. 62-67.

[96]Meyer C., Seborg D.E. and Wood R.K.(1976), ñA Comparison of the Smith predictor and conventional feedback controlöò, *Chem. Eng. Sci*., Vol. 31., pp. 775- 780

[97]Morari M. and Zafiriou, E. (1989), ñRobust process controlöò, *Prentice-Hall Inc*.

[98]Nikolaou M. and Misra P. (2001), ñLinear control of nonlinear processes: Recent developments and future directionsöò, *proceedings of CEPAC 2001*, Guaruja, Sao Paulo, Brazil.

[99]Nurges U. and Rustern E. (1999), ñOn The Robust Control of Polytopic Plantsöò, *Proceedings of the American Control Conference*, pp. 435-441.O'Dwyer A. (1999), ñA comparison of controllers for dead-time compensationöò, *Proc. of the 2nd Wismarer Automatisierungs symposium*, Wismar, Germany.

[100]Ogunnalke B.A. (1986), ñController Design for Nonlinear process systems via variable Transformationsöò, *Ind. Eng. Chem. Pro. Des. Dev*., Vol. 25, pp. 241-248

[101]Qin S.J. and Borders G.(1993), ñ multi-region fuzzy logic controller for controlling processes with nonlinear gainsöò, Proc*. Int. Symp. Intel'. Control Chicago, IL* , pp. 445-450.

[102]Richalet, J., Rault A., Testud J. L. and Papon J. (1978), ñModel Predictive Heuristic Control: Application to Industrial Processesöò, *Automatica*, Vol. 14, pp. 413-418

[103]Richard J.P. (2003), ñTime-delay systems: an overview of some recent advances and open problemsöò, *Automatica*, Vol. 39, No. 10, pp.1667-1694

[104]Rugh W.J. (1987), ñDesign of Nonlinear PID controllersöò, *AIChE J1*., Vol. 33, pp. 738-1743

[105]R. Ananda natarajana and M.Chidambaram ñLimitations of a PI controller for a first-order nonlinear process with dead timeò ISA Transactions Volume 45, Issue 2, April 2006, Pages 185-199

[106]Schneider D.M. (1988), ñControl of process with time delaysöò, *IEEE Transactions on Industry Applications*, Vol. 24, No. 2. pp. 186-191

[107]Shen S. and Yu C. (1994), ñUse of Relay-Feedback Test of Automatic Tuning of Multivariable Systemsöò, *AIChE Jl.,* Vol. 40, pp. 627-631.

[108]Shinskey F.G. (1990), ñHow good are our controllers in absolute performance and robustnessöò, *Measurement and Control*, Vol. 23, pp. 114-121.

[109]Shinskey F.G. (1994), ñFeedback controllers for the process industriesôö, *McGraw- Hill Inc*.

[110]Smith O.J.M. (1957), ñCloser control of loops with dead timeôö, *Chemical Engineering Progress*, Vol. 53, pp. 217-219.

[111]S.J.Shiu and S.H.Huang(1998), ñSequential design method for multivariable decoupling and multiloop PID controllersò, *Industrial & Engineering Chemistry Research*, Vol. 37,pp. 107-119.

[112]Smith O.J.M. (1959), ñA controller to over come dead timeôö, *ISA Jl.,* Vol. 6(2), pp. 28-33.

[113]R.Suja Mani Malar and T.Thyagarajan(2009), ñModeling of Quadruple Tank System Using Soft Computing Techniquesò, *European Journal of Scientific Research,* Vol. 29 No. 2, pp.249-264.

[114]Tan K.K., Lee T.H. and Leu F.M. (2001), ñPredictive PI versus Smith control for dead-time compensationôö, *ISA Transactions*, Vol. 40, pp.17-29

[115]Tian Y.C. and Gao F. (1998), ñDouble-controller scheme for control of processes with dominant delayôö, *IEE Proc.-Control theory Appl.*, Vol. 145(5), pp.479-484.

[116]Vrecko D., Vrancic D., Juricic D. and Strmcnik S. (2001), ñA new modified Smith predictor: the concept, design and tuningôö, *ISA Transactions*, Vol. 40, pp. 111- 121.

[117]Watanabe K. and Ito M. (1981), ñA process-Model control for linear Systems with delayôö, *IEEE Transactions on Automatic Control*, Vol. AC-26, No. 6, pp. 1261- 1268

[118]Wright R.A. and Kravaris (2003), ñNonlinear decoupling control in the presence osensor and actuator dead timesôö, *Chemical Engineering Science*, Vol.58, No. 14, pp. 3243-3256

[119]Xu J.X., Liu C. and Hang C.C. (1996), ôöModified Tuning of a Fuzzy logic Controllerôö, *Engng. Applic. Artif. Intell.*, Vol. 9, No.1, pp 65-74

[120]Zhao F., Ou J. and Du W. (2000), ñPattern-based fuzzy predictive control for a chemical process with dead timeôö, *Engineering Applications of Artificial Intelligence,* Vol. 13, pp. 37 45.

[121]Zhao Z.Y., Tomizuka M. and Isaka S. (1993), ñFuzzy Gain Scheduling of PID Controllersôö, *IEEE Transactions on Systems , Man and Cybernetics,* Vol. 23, No.5, pp. 1392 1398.

[122]Ziegler J.G. and Nichols N.B. (1942),ñoptimum settings for automatic controllersôö, *Transactions of the ASME,* Vol. 64, pp. 759-768.

[123]D. E. Rivera, M. Morari, S. Skogestad. Internal model control for PID controller design. *Industrial Engineering Chemical Process*, 1986, 25: 252ï 265.

[124]Abeykoon, C., K. Li, M. McAfee, P.J. Martin, Q. Niu, A.L. Kelly and J. Deng, 2011. A new model based approach for the prediction and optimisation of thermal homogeneity in single screw extrusion. Cont. Eng. Pract., 19(8): 862-874.

[125]Al-Arifi, N.S., A.S. Zamani and K. Jalaluddin, 2011. Billet optimization for steering knuckle using taguchi methodology. Int. J. Comp. Theor. Eng., 3: 552-556.

[126]Chen, F.K., W.C. Chuang and S. Torng, 2008. Finite element analysis of multi-hole extrusion of aluminium alloy tubes. J. Mater. Process. Technol., 201: 150-155.

[127]Guan, Y.J., C.S. Zhang, G.Q. Zhao, X.M. Sun and P. Li, 2012. Design of a multi hole port hole die for aluminium tube extrusion. Mater. Manuf. Process., 27(2): 147-153.

[128]Kennedy, J. and R. Eberhart, 1995. Particle swarm optimization. Proceeding of IEEE International Conference Neural Networks, 4: 1942-1948.

[129]Ko, D.C., D.H. Kim, B.M. Kim and J.C. Choi, 1998. Methodology of preform design considering workability in metal forming by the artificial neural network and Taguchi method. J. Mater. Process. Technol., 80-81: 487-492.

[130]Malviya, R. and D.K. Pratihar, 2011. Tuning of neural networks using particle swarm optimization to model MIG welding process. Swarm. Evol. Comput., 1(4): 223-235.

[131] K. H. Johansson. ñRelay feedback and multivariable control. PhD thesisò, Department of Automatic Control, Lund Institute of Technology, Sweden, November 1997

[132]D. A. Vijula, K. Anu, P. M. Honey, P. S. Poorna, ñMathematical Modelling of Quadruple Tank Systemò International Journal of Emerging Technology and Advanced Engineering, vol.3, Issue 12, December 2013.

[133]K. H. Johansson, ñThe quadruple-tank process: a multivariable laboratory process with an adjustable zero,ò IEEE Trans. Control Syst.Technol., vol.8, no.3, pp.456- 465, May. 2000.

[134]G. C., Goodwin, S.F., Grabe. 2000. ñControl system designò, Pearson

[135]K., Ogata. 2009. ñModern control engineeringò, Pearson

[136]P. Nordfeldt and T. Hagglund, ñDecoupler and PID controller design of TITO systemsò, Journal of Process Control, vol.16, no.9, pp.923-936, 2006

[137]Kristiansson, B. and B. Lennartson, Robust Tuning of PI and PID Controllers - Using Derivative Action Despite Sensor Noise, IEEE Control System Magazine, 26(1), (2006), 55ï 68

[138]Cominos, P., and N. Munro, PID Controllers: recent tuning methods and design to specification, IEEE Control System Magazine, 149(1), (2002), 46ï 53.

[139]Miller. R.M., S.L. Shah, R.K. Wood and E.K. Kwok, Predictive PID, ISA Transaction, (1999), 38, 11ï 23.

[140]Rivera, D.E., S. Skogestad and M. Morari, Internal Model Control 4. PID Controller Design. Ind. Eng Chem. Proc. Design and Development, 25, (1986), 252ï 265.

[141]Chein, I.L., IMC-PID Controller Design-An Extension, IFAC Proceeding Series, 6, (1988), 147ï 152.

[142] Morari, M. and E. Zafiriou, Robust Process Control, Printice Hall, (1989).

[143] Z. L. Gaimg, ñA particle swarm optimization approach for optimum design of PID controller in AVR system,ò IEEE Trans. Energy Convers., vol. 19, no. 2, pp. 384-391, June 2004.

[144] H. J. Jawad, ñParticle swarm optimization based optimum PID controller for governor system of synchronous generator,ò AL-Qadisiya Journal for Eng. Sci., vol. 6, no. 3, 2013

[145]M. Rahimian and K. Raahemifar, ñOptimal PID controller design for AVR system using particle swarm optimization algorithm,ò IEEE CCECE, 2011

[146]S.-R. Qi, D.-F. Wang, P. Han, and Y.-H. Li, ñGrey prediction based RBF neural network self-tuning PID control for turning process,ò in Proc. Int. Conf. Mach. Learning Cybern., pp. 802-805, 2004

[147]D. Devaraj and B. Selvabala, ñReal-coded genetic algorithm and fuzzy logic approach for real-time tuning of proportional-integral-derivative controller in automatic voltage regulator system,ò IET Gen. Trans. Dist., vol. 3, issue 7, pp. 641-649,February 2009.

[148]L. Cai and A. B. Rad, ñAn intelligent longitudinal controller for application in semiautonomous vehicles,ò IEEE Trans. Ind. Electr., vol. 57, no. 4, pp. 1487-1497, April 2010.

[149]Hong-Ming Chen, Zi-Yi Chen and Juhng-Perng Su ñDesign of a Sliding Mode Controller for a Water Tank Liquid Level Control System,ò International Journal of Innovative Computing, Information and Control ICIC International °c 2008 ISSN 1349-4198 Volume 4, Number 12, December 2008

[150]Ayte Kin Bagis , "Determination of the PID Controller Parameters by Modified Genetic Algorithm for Improved Performance" , Journal of Information Science and Engineering 23, 1469-1480 (2007)

[151]T.K. Teng , J.S. Shieh and C.S. Chen , ñGenetic algorithms applied in online auto tuning PID parameters of a liquid-level control system ,ò Transactions of the Institute of Measurement and Control 25,5 (2003) pp. 433ï 450

[152]David W. Spitzer, óAdvanced Regulatory Control Applications and Techniquesô, Momentum Press, 2009.

[153]E. F. Ryckebusch, I. K. Craig, ñPID TUNING FOR A MULTIVARIABLE PLANT USING TAGUCHI-BASED METHODSò 15th Triennial World Congress, Barcelona, Spain

[154]S.N.Sivanandam, S.N.Deepa, Introduction to Genetic Algorithms, Springer Publications Co., 2010.

[155]Gotshall,S. and Rylander, B., Optimal Population Size And The Genetic Algorithm.ò, Proc On Genetic And Evolutionary Computation Conference,2000.

[156] K. Krishnakumar and D. E. Goldberg, Control System Optimization Using Genetic Algorithmsò, Journal of Guidance, Control and Dynamics, Vol. 15, No. 3, pp. 735-740, 1992.

[157]Chris Houck, Jeff Joines, and Mike Kay, "A Genetic Algorithm for Function Optimization: A Matlab Implementationò.

[158]Chipperfield, A. J., Fleming, P. J., Pohlheim, H. and Fonseca, C. M., A Genetic Algorithm Toolbox for MATLAB , Proc. International Conference on Systems Engineering, Coventry, UK, 6-8 September, 1994

[159] Anderson, D. O. (2000), Louisiana Tech University. www.latech.edu/~dalea/AY2000-2001/me566/Taguchi.pdf

[160] Bao, J., J.F. Forbes and P.J. McLellan (1999). Robust Multiloop PID Controller Design: A Successive Semidefinite Programming Approach. Ind. Eng. Chem. Res., 38 (9) pp.3407-3419

[161]*Chen*, Y. H., S.C. Tam, W.L. Chen and H.Y. Zheng (1996). Application of Taguchi method in the optimisation of laser micro-engraving of photomasks. International Journal of Materials & Product Technology, 11, Nos. 3/4, 333-344.

[162]Chien, I-L., H. P Huang, J.C. Yang (2000). Simple TITO PI tuning method suitable for industrial applications. Chemical Engineering Communications, 182, 181-196.

[163]Fienberg, S.E., Hinkley, D.V. (1980). R.A. Fisher: An appreciation. Springer-Verlag. New York. Griffin, K., K.M. Ragsdell, (2000), For credit EMGT-475: Quality Engineering www.umr.edu/~design/EM475/475Project/W00 -Projects/griffin.pdf

[164]Lee, K., Kim J. (1999). Controller gain tuning of a simultaneous multi-axis PID control system using the Taguchi method. Control Engineering Practice, 8, 949-958

[165] Roy, R. (1990). *A primer on the Taguchi method.* Competitive Manufacturing Series, Van Nostrand Reinhold, New York

[166]Effendi Rusli, Siong Ang, Richard D Braatz, 2004. ñA Quadruple Tank Process Control Experimentò, ChE Division of ASEE.

[165]Jayaprakash, J., T. Senthil Rajan, T. Harish Babu, 2014. ñAnalysis of Modelling Methods of Quadruple Tank Systemò, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 3: 8.

[167]Martin, J., Hayes, S.M. Mahdi Alavi, 2006. ñQuantitative Feedback Design for a Benchmark Quadruple Tank Processò, ISSC 2006, Dublin Institute of Technology.

[168]Karl Henrik Johansson, 2000. ñThe Quadruple-Tank Process: A Multivariable Laboratory Process with an Adjustable Zeroò, IEEE Transactions on control systems technology,

[169]Meenakshi Kishnani1 , Shubham Pareek2 and Dr. Rajeev Gupta3 Comparison of Different Performance Index Factor for ABC-PID Controller International Journal of Electronic and Electrical Engineering. ISSN 0974-2174, Volume 7, Number 2 (2014), pp.177-182.

List of Publications

1) Prakash M. Pithadiya, Dr. Vipul shah ñ*Comparative Analysis of Performance of the Highly Nonlinear Interactive Control System based on Soft Computing*ò in International Journal of Innovative Research in Computer and Communication Engineering Vol.5, Special Issue 2, April 2017 ISSN (Online) : 2320-9801 ISSN (Print) : 2320-9798.

2) Prakash M Pithadiya, Dr. Vipul Shah ñ*Performance index based Comparative Analysis using PSO and GA for Highly nonlinear Complex Control system*ò in International Journal of Engineering Sciences & Research Technology September, 2017, ISSN: 2277-9655 DOI: 10.5281/zenodo.996002 CODEN: IJESS7

3) Prakash M. Pithadiya, Dr. Vipul Shah ñ*Performance Index based comparative study and Analysis of Highly complex Nonlinear Dynamic System*ò in International Journal of Engineering Sciences & Research Technology. September, 2017, ISSN: 2277-9655 DOI: 10.5281/zenodo.996002

4) Prakash M. Pithadiya, Dr. Vipul Shah ñ*Optimization of Controller parameter based on Taguchi –MPOS Approach to Control Nonlinear System*ò in International Journal of Engineering Sciences & Research Technology. , March 2017, ISSN: 2277-9655 DOI: 10.5281/zenodo.1199376 CODEN: IJESS7

5) Prakash M. Pithadiya, Dr. Vipul A. Shah, *"Taguchi MPSO Optimization to Improve performance Index for Highly Nonlinear system with Analysis and Validation" in* International Journal of Current Engineering and Scientific Research (IJCESR) ISSN (PRINT): 2393-8374, (ONLINE): 2394-0697, VOLUME-5, ISSUE-4, 2018 DOI:10.21276/Ijcesr,

6) Prakash M. Pithadiya, Dr. Vipul Shah ñ*Optimization of PID Controller of highly nonlinear complex system using taguchi MPSO method*ò International Conference on New Frontiers of Engineering, Science, Management and Humanities (ICNFESMH-2018) at Pune, Maharashtra, India on 17th June 2018, ISBN: 978-93-87433-29-8 page no 399 to 405.

7) Prakash M. Pithadiya, Dr. Vipul Shah ñ*Optimization of PID Controller of highly nonlinear complex system using taguchi MPSO method*ò Journal of Emerging Technologies and Innovative Research (JETIR) June 2018, Volume 5, Issue 6 . Page No: 314-319, ISSN: 2349-5162.

8) Prakash M. Pithadiya, Vipul Shah ñ*Improvement performance index of highly nonlinear interacting system based Taguchi MPSO Optimization method*ò International Conference on Emerging Trends in Science, Engineering and Management (ICETSEM-2018) at Pune, Maharashtra, India on on 14th October 2018, ISBN: 978-93-87433-42-7 page no 304 to 312.

9) Prakash M. Pithadiya, Vipul Shah ñ*Improvement performance index of highly nonlinear interacting system based Taguchi MPSO Optimization method*ò International Journal of Management, Technology and Engineering (IJMTE) OCT 2018, Volume 8, Issue X . Page No: 1305, ISSN: 2249-7455. Impact factor: 6.3 .UGC approved

10) Prakash Pithadiya, Vipul Shah ñ *Improvement Performance Index of Highly Nonlinear Interacting System based Taguchi MPSO Optimization Method* ñ Conference Proceeding of International Conference on Emerging Trends in Science, Engineering and Management (ICETSEM-2018) Mahratta Chamber of Commerce Industries & Agriculture, Senapati Bapat Road, Pune, Maharashtra, India on 14th October 2018, ISBN: 978-93-87433-42-7

11) Prakash Pithadiya, Vipul Shah ñ *Improvement Performance Index of Highly Nonlinear Interacting System based Taguchi MPSO Optimization Method*ò published in International Journal of Management, Technology And Engineering Volume 8, Issue X, OCTOBER/2018 ISSN NO : 2249-7455

12) Prakash Pithadiya, Vipul shah ñ*Design and Development of Complex Nonlinear System using TMPSO for Improving Performance Integral Criteria*ò published in International Journal of Research in Advent Technology, Vol.5, No.1, November 2018 E-ISSN: 2321-9637 www.ijrat.org

13) Prakash Pithadiya, Vipul Shah ñ*Performance Integral Criteria Improve based on Taguchi MPSO for Highly Interacting MIMO System*ò published in IEEE International Conference On Electrical, Communication, Electronics, Instrumentation And Computing (ICECEIC - 2019) with catalog CFP19R88-PRJ: 978-1-7281-0173-6 31 Jan 2019

14) Prakash Pithadiya, Vipul shah ñ *Design and Development of Hybrid Soft Computing based Controller for QTS*ò in Arabian Journal for Science and Engineering (AJSE) Submission ID: AJSE-D-19-00274 Nov 2018 Springer Journals (under review)