Hybrid Soft Computing Approach to Control of Nonlinear System

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by
Prakash M Pithadiya (129990917004)

Under the guidance of
Dr. Vipul A. Shah

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AHMEDABAD
MAY 2018
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</tr>
</tbody>
</table>
Title: Hybrid Soft Computing Approach to Control of Nonlinear System

Abstract:

In many chemical and petrochemical processes plant having multiple input para and multiple output para for different processes. This research mainly focuses on searching the optimal controller structure by increasing the controllers’ performance criteria. It is very difficult to control the highly nonlinear quadruple four tank system. It is always challenging due to the cross coupling effect of highly interacting system to stabilize and control of the mimo system. It is still a very big issue for control of nonlinear system. The Proposed algorithm for tuning of PID constant based on the new statically approach combined with soft computing techniques. One of the optimization of Statical Taguchi method is to combine with mutation based particle swarm optimization hybrid algorithm tune the PID parameter. This tuning parameter optimized performance index of the nonlinear system. The tuning parameters of controller find optimal performance indices. It is computer based nonlinear system for performance analysis and check validation of proposed TMPSO algorithm. Laboratory is set up to communicate with MATLAB, LABVIEW and other controller platform. With the help of LABVIEW, implementation of proposed algorithm and output of the proposed algorithm validate with quadruple four tank laboratory set-up for testing. Check the performance indices based on the PID parameter tuning with proposed TMPSO algorithm and improve the response of different performance index for the experiment setup quadruple tank nonlinear system.
State of the art:

The global energy challenges of the world are increasingly becoming more demanding and complex. World’s oil reserves need to be effectively optimised. The petroleum industry includes the global processes of exploration, extraction, refining, transportation (often by oil vessels on oceans, oil tankers on land and pipelines) and marketing petroleum products. Within the past 30 years, the world crude oil consumption had increased from to million barrels per day. This is alarming and therefore measures must be taken to meet up with these demands. There is a greater need to innovate, improve, design, optimise chemical processes, and improve the operations of equipment and facilities while making health, safety, and environment as a priority.

The application of controllers in the process industry has dated far back as before the 1940s when John G. Zeigler and Nathaniel Nichols started their pioneer research about the behaviours of controllers as well as trying to develop good methods to be used in the tuning of the controller parameters. Afterwards, more recent advances in the application of control theory emerged as a result of various problems that needed to be resolved. A good example of recent control advancement is the use of optimal control methods that are formulated using the state-space models 1, and other varying formulations that are based on the process model (step and impulse responses), disturbance type (altered white noise, decaying and constant) as well as adaptation to time varying models. There is usually an optimal balance between the control error and the amount of control power used, and certain optimal criterion are being minimized in this case of optimal solution.

Developing efficient control strategies that would be well suited for the control of multivariable systems has been quite challenging in many areas of engineering due to the cost and large amount of time spent on model identification. It is very important to have a prototype of the real process, so that the controller will inherently have knowledge about the process it will control. It is assumed that Taguchi MPSO controller would be preferred for most of the difficult control problems in the process and petrochemical industries, since it has so much impact on most industrial controls. The increased industries interest to use advanced control strategies which are robust and capable of achieving improved performance of complex industrial processes that are multivariable in nature, has made it an area of concern in the academia. And the engineering undergraduates and researchers, while in the quest for more understanding of the rigorous mathematics and modelling principles studied with pen and paper, they seem to get more knowledge and understanding of the behaviours of the
complex industrial processes by performing experiments and at the same time making judgments with their own prior ideas.

Stable control of nonlinear system should have good performance indices. Therefore, every nonlinear system which having a highly interacting, uncertain system must help together to acquired input and maintain output magnitude at specified level. QTS works by controlling level of liquid and output voltage which is fed into motor of tanks. It is very difficult for QTS system to control this closed-loop system for maintaining stable terminal output voltage. Appropriate controller to help QTS is PID controller because it has common structure, robust operation and wide range of application [34]. However, it is difficult to tune appropriate PID controller parameters because many industrial plants have problems with high order, delay time and nonlinearities [35]. From the past to present, there are numerous techniques are offered for tuning parameters of PID controller. The evolution of PID controller starts from traditional tuning is Ziegler-Nichols method. It depends on the experience of the designer, so it is quite hard to determine optimal results [36].

Artificial intelligence (AI) techniques such as neural network technique, fuzzy logic, and neuro-fuzzy system were preferred by researchers. Neural network technique faces up to some problems about long convergence time and training process [37]. Fuzzy logic does not have self-learning process. It depends on the expertise of the designer in tuning membership functions [5]. Neuro-fuzzy logic is complicated method that takes a long time in learning process especially in non-linear dynamic behaviours system [38]. Recently, evolutionary computation techniques by random search methods, such as genetic algorithm (GA) and particle swarm optimization (PSO) have received much interest for searching high efficiency solution in optimization problem. The GA’s natural genetic operations will take a heavy burden to computer in calculation. Moreover, the premature convergence of GA will reduce its performance in searching for the result [39].

The PSO is robust in finding the optimal solution in nonlinear problem. Strong points of PSO are stable convergence characteristic and take time consume shorter than other methods. All of these make PSO can produce a high quality result but it still suffers from memory capability and computational burden [40]. Nowadays, combination of two methods is proposed and got Quadruple tanks nonlinear system with PID controller much attention for improving the performance of tuning PID controller parameters. In 2012, Hany M. Hasanien suggested Taguchi combined genetic algorithm (TCGA) method for design optimization of PID controller in QTS system [42]. The result of TCGA is better than GA and PSO except for
rising time. Long rising time means long convergence time and slow system. Therefore, QTS system would like the response that short rising time.

This Research presented the method for designing the best PID controller parameters for QTS system in synchronous generator by using Taguchi combined Mutation particle swarm optimization (TPSO) method. Taguchi method is used to design the lowest cases of experiments that represent the most efficiency comprehensive all cases without elimination of significant cases [11]. In Taguchi process, ANOM is used for obtaining approximate values of PID controller parameters. ANOVA is used to select the two most influential PID controller parameters. After that, PSO is used to optimize the two most importance parameters for PID controller to produce minimize the maximum percent overshoot, the rise time, the settling time and the steady-state error of terminal voltage response of synchronous generator. The computer program is used to simulate QTS system and write PSO’s codes. Step response of this controller is compared with PSO and TCGA method. It shows the effective way to solve this problem with better response performance and robustness.
Definition of Problem:

Nonlinear processes are very common in process industries, and designing a stabilizing controller is always preferred to maximize the production rate. In this Research work, tuning of PID controller for a class of time delayed stable and unstable nonlinear system using Taguchi mutation Particle Swarm Optimization (PSO) algorithm is proposed. The efficiency of the proposed scheme has been validated through a comparative study with classical controller tuning methods and heuristic methods such as Fuzzy control, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) and Taguchi with GA (hybrid). Finally, a real-time implementation of the proposed method is carried on a nonlinear Quadruple tank system. From the simulation and real-time results, it is evident that the Taguchi MPSO algorithm performs well on the nonlinear unstable process models considered in this work. The Taguchi MPSO tuned controller offers enhanced process characteristics such as better time domain specifications, smooth reference tracking, supply disturbance rejection, and error minimization. Effect of the Tuning parameter based on TMPSO simulation as well as experiment setup has been studied.
Objectives and scope of the Research Work

In this 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 analysed. And since the interests are to analyse the implemented strategies and making it available for further studies so that it would enrich the users hands on experience. It is moreover important to make the implemented approach more helpful to industries as regards with the user interfaces.

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

Objectives:

- To review control method of nonlinear system based on PID controller.
- To survey nonlinear system based on PID controller’s existing mathematical modelling and its control strategies of controller.
- To study and investigate the optimal tuning of PID controller for nonlinear system, based on Z-N method, other heuristics approach like PSO, GA and Taguchi combine with Genetic algorithm and Taguchi combine Mutation MPSO algorithm implementation for the nonlinear system. The proposed algorithm is implemented on MATLAB with 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 QTP 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.
**Scope of the 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 in performance indices with other techniques.
Original Research Contribution by the work

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 mutation particle swarm optimization algorithm to control highly nonlinear system. This proposed hybrid algorithm improves the performance indices of nonlinear system. This proposed algorithm is presented to optimally design a PID controller in the Nonlinear system for improving the Performance indices. This combinational algorithm select optimal parameter of PID controller, which are controlling the Quadruple tank nonlinear system and improve of performance criteria ISE, IAE, ITSE and ITAE of the nonlinear control system.

1. The utilisation of the AI of both PSO and a GA and Taguchi with GA and Taguchi with MPSO for the non-linear MIMO System.
2. Real time practical implementation of the control strategy for a Quadruple Tank system MIMO System.
3. The real time optimisation of the above using either a GA or a PSO, Taguchi GA and Taguchi MPSO approaches at for Quadruple Tank system
4. The design and Development of Quadruple tanks system for implementation of a Taguchi combine with MSPO Method.
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) Taguchi 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 Different Algorithm techniques implement in mathematical model to control the nonlinear quadruple tanks system in MATLAB for different parameter of PID controller. After the result of different techniques for PID controller we can conclude that all over result for different technique is to improve the result of performance indices in simulation. Afterword we have designed and developed the real experiment set up for checking the stability and control the quadruple tanks system in minimal 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 transmitter and generate the appropriate output signal based on control Taguchi MPSO based PID controller. We are achieving best result out off all other techniques to control the nonlinear system and improve the performance indices.
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 each, two pumps, two valves and two level sensors connected to the two lower tanks. Figures 1 is schematic diagram of the experiment setup and Figure 3 is real experiment setup for quadruple tank system. Design and development hardware set up of quadruple tank nonlinear control system, for developing hybrid soft computing with statistical techniques based controller (Lab view 17).

![Schematic Diagram of Experimental set up](image1)

**FIGURE: 1 Schematic Diagram of Experimental set up**

![Real Experiment set up of Typical Quadruple Four tank system](image2)

**FIGURE: 2 Real Experiment set up of Typical Quadruple Four tank system**
NI DAQ 6001 is used for acquiring level signal from the bottom tanks and to maintain the level of the bottom tanks which is maintained according to the generate analog PWM signal. to motor drive circuit to produce from proper output voltage from DAQ and motor running accord to level maintain control the level of the both bottom tanks. We get the responses in two operating point; one is minimum phase and second is non minimum phase. In the minimum phase response is better than non minimum. When the system goes in non minimum phase system becomes almost impossible to stable. Minimum phase gives us better result based on selection of parameter.

The quadruple tank schematic diagram is shown in Figure 1. 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 result in term of time domain specification and also performance indices in simulation of the mathematical model of the quadruple tank system in two phases minimum and non minimum phase. The difficulties found in non minimum phase are we cannot find result in experiment result. System becomes unstable in the non minimum phase so that we cannot maintain the level and control the flow of water to the tank. By providing good transmitter and NI DAQ card having 14 bit resolution, good capacity pump, a nonlinear system can operate at desire set point which ultimate improve the performance of the system. Using Taguchi MPSO method, we found 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 index value for quadruple tank nonlinear system. From the all specified valued for Taguchi MPSO and other approaches we found the best PID value for this set up. But we found the best result in Taguchi MPSO method to improve the accuracy of the Taguchi MPSO algorithm which is best than other specified algorithm used in experiment setup.

Outcomes with respect to objectives:

- We have design and developed algorithm for optimized PID parameter for 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: 1 Comparative analysis based on Time Domain specification -Simulation Result
(Set point Level1 = 5cm, set point Level2=5cm)

<table>
<thead>
<tr>
<th>Operating Point</th>
<th>Parameter</th>
<th>PID Z-N</th>
<th>PSO-PID</th>
<th>GA-PID</th>
<th>Taguchi PID</th>
<th>TGA-PID</th>
<th>TMPSO-PID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Phase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>γ1 =0.7</td>
<td>Settling time(s)</td>
<td>50</td>
<td>90</td>
<td>95.98</td>
<td>89</td>
<td>90</td>
<td>88.6</td>
</tr>
<tr>
<td></td>
<td>Overshoot (%)</td>
<td>7%</td>
<td>20%</td>
<td>9%</td>
<td>8.88%</td>
<td>11%</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Rise time</td>
<td>9</td>
<td>3</td>
<td>10</td>
<td>12</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>γ2 =0.6</td>
<td>Settling time(s)</td>
<td>15</td>
<td>10</td>
<td>12</td>
<td>9</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Overshoot (%)</td>
<td>7.5</td>
<td>10%</td>
<td>12%</td>
<td>8.7%</td>
<td>9.6%</td>
<td>8.7%</td>
</tr>
<tr>
<td></td>
<td>Rise time</td>
<td>9.1</td>
<td>10</td>
<td>4</td>
<td>4.5</td>
<td>5.3</td>
<td>3.9</td>
</tr>
<tr>
<td>Non Minimum Phase</td>
<td>Settling time(s)</td>
<td>12</td>
<td>15</td>
<td>13</td>
<td>12.8</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>γ1 =0.3, γ2 =0.4</td>
<td>Overshoot (%)</td>
<td>4%</td>
<td>20%</td>
<td>8%</td>
<td>12%</td>
<td>23%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Rise time</td>
<td>0.04</td>
<td>13</td>
<td>10</td>
<td>6.7</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>L2 5 cm</td>
<td>Settling time(s)</td>
<td>5</td>
<td>12.5</td>
<td>8.3</td>
<td>8</td>
<td>7.6</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Overshoot (%)</td>
<td>7.5%</td>
<td>15%</td>
<td>12.6%</td>
<td>12.5%</td>
<td>12%</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>Rise time</td>
<td>9.1</td>
<td>6</td>
<td>4.5</td>
<td>4.2</td>
<td>5.4</td>
<td>4</td>
</tr>
</tbody>
</table>

FIGURE: 3 Different techniques with different time domain specification level
TABLE: 2 Comparative analysis based on performance indices -Simulation result
(Level 1 = 5cm, Level 2 = 5cm)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Methods /Indices</th>
<th>ISE (%)</th>
<th>IAE (%)</th>
<th>ITSE (%)</th>
<th>ITAE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L1</td>
<td>L2</td>
<td>L1</td>
<td>L2</td>
</tr>
<tr>
<td>1</td>
<td>TMPSO -PID</td>
<td>10.2</td>
<td>7.4</td>
<td>9.7</td>
<td>5.6</td>
</tr>
<tr>
<td>2</td>
<td>TGA -PID</td>
<td>9.8</td>
<td>8.3</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Taguchi -PID</td>
<td>11</td>
<td>9</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>GA PID</td>
<td>10.6</td>
<td>8.2</td>
<td>10.2</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>PSO PID</td>
<td>11.2</td>
<td>8.7</td>
<td>10</td>
<td>8.5</td>
</tr>
<tr>
<td>8</td>
<td>PID Z-N</td>
<td>60</td>
<td>11</td>
<td>17</td>
<td>10</td>
</tr>
</tbody>
</table>

FIGURE: 4 Different techniques with performance indices level

TABLE: 3 Comparative analysis based on Time Domain specification –Experimental Result
(Level 1 = 5cm Level 2 = 5cm)

<table>
<thead>
<tr>
<th>Operating Point</th>
<th>Parameter</th>
<th>PID</th>
<th>PSO- PID</th>
<th>GA- PID</th>
<th>Taguchi PID</th>
<th>TGA - PID</th>
<th>TMPSO -PID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Phase</td>
<td></td>
<td>PID</td>
<td>PSO- PID</td>
<td>GA- PID</td>
<td>Taguchi PID</td>
<td>TGA - PID</td>
<td>TMPSO -PID</td>
</tr>
<tr>
<td>γ 1 = 0.7</td>
<td>Settling time(s)</td>
<td>300</td>
<td>255</td>
<td>247</td>
<td>225</td>
<td>242</td>
<td>233</td>
</tr>
<tr>
<td></td>
<td>Overshoot (%)</td>
<td>10.8</td>
<td>19</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Rise time</td>
<td>275</td>
<td>234</td>
<td>222</td>
<td>130</td>
<td>198</td>
<td>167</td>
</tr>
<tr>
<td>γ 2 = 0.6</td>
<td>Settling time(s)</td>
<td>320</td>
<td>266</td>
<td>254</td>
<td>265</td>
<td>245</td>
<td>233</td>
</tr>
<tr>
<td></td>
<td>Overshoot (%)</td>
<td>12.7</td>
<td>9</td>
<td>25</td>
<td>21</td>
<td>13</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>Rise time</td>
<td>275</td>
<td>234</td>
<td>222</td>
<td>215</td>
<td>198</td>
<td>167</td>
</tr>
</tbody>
</table>
FIGURE: 5 Different techniques with different time domain specification

TABLE: 4 Comparative analysis based on performance indices - Experimental result

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Methods /Indices</th>
<th>ISE (%)</th>
<th>IAE (%)</th>
<th>ITSE (%)</th>
<th>ITAE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1</td>
<td>L2</td>
<td>L1</td>
<td>L2</td>
<td>L1</td>
</tr>
<tr>
<td>1</td>
<td>TMPSO-PID</td>
<td>13.86</td>
<td>19.05</td>
<td>9.62</td>
<td>10.90</td>
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<tr>
<td>2</td>
<td>TGA-PID</td>
<td>13.97</td>
<td>20.49</td>
<td>9.51</td>
<td>11.09</td>
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<tr>
<td>3</td>
<td>Taguchi PID</td>
<td>14.79</td>
<td>20.18</td>
<td>9.83</td>
<td>11.01</td>
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<tr>
<td>4</td>
<td>GA-PID</td>
<td>14.68</td>
<td>21.50</td>
<td>9.64</td>
<td>11.28</td>
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<tr>
<td>5</td>
<td>PSO-PID</td>
<td>15.63</td>
<td>16.37</td>
<td>10.09</td>
<td>9.30</td>
</tr>
<tr>
<td>8</td>
<td>PID Z-N</td>
<td>18.13</td>
<td>24.32</td>
<td>11.03</td>
<td>12.30</td>
</tr>
</tbody>
</table>

FIGURE: 6 Different techniques with performance indices level Experiment Result
Conclusion:

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

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

This research work is carried for finding the best optimal solution for the nonlinear dynamic system. This research found optimized the 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 strategies 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.
Paper Published:

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