A Survey on Design of PID Controllers using Neuro-Fuzzy Systems

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Abstract - Manual tuning of PID Controllers is a difficult and challenging task. It needs experienced professionals, yet its prone to errors. Recently, automatic tuning techniques have gained a lot of importance because of their advantages. This paper presents a comprehensive survey of automatic tuning of PID controllers using Neuro-Fuzzy systems. Fuzzy logic and membership functions have been discussed in detail and subsequently the used of nuro-fuzzy systems has been exemplified. Previous work in the related field has been highlighted along with the salient features of each technique so as to bring about a comparison of different approaches used in the different papers.

Keywords: PID controllers, Automatic Tuning, neural networks, fuzzy logic, neuro-fuzzy expert system..

I. INTRODUCTION

A Proportional plus Integral plus Derivative (P-I-D) Control finds several applications in different fields. However, tuning is always a difficult and challenging task. It finds utility in the control of slow variables such as like pH, temperature, etc. in process industries.[1] The diversity of application and simplicity of design makes PID controllers one of the most popular controllers for industries.[6] Another added advantage is that it's possible to tune the controller for a process without the complete details of the mathematical model of the process. [7]

However, the accurate tuning of the PID controllers requires extensive and detailed experimentation. In general the closed loop performances, such as fast response, zero steady state error and less overshoot can be accomplished through separate implementation of proportional, integral and derivate control separately. The structure of the proportional, derivative or integral control blocks depend on the process that is needed to be controlled through the PID action. Manual tuning is generally complex and needs thorough experimentation or experienced professionals. Still, it is often prone to errors. It needs experienced professionals, yet its prone to errors. Thus automatic tuning of PID controllers has become an active area of research. With the advent of optimization tools such as fuzzy logic and neuro-fuzzy systems, automatic tuning of PID controllers through neuro-fuzzy systems is gaining more popularity.

II. FUZZY LOGIC

Fuzzy rule based approaches are generally needed in optimization problems that do not possess a clear boundary. Any system that is follows the following aspects are needed for automatic tuning of PID controllers:

1. Parallel data processing architecture.
2. Learning from updating the parameters for PID tuning.
3. Capability for the system to detect fuzziness in the taking decisions.

The various conditions that can be put forth of a fuzzy based system are the following:

1. Highly Yes
2. Possibly Yes
3. Can not be sure if yes or no
4. Possible to be No
5. Definitely No

The fuzzy logic mechanism is the architecture that analyses the data set to make a crisp decision about the actual de-fuzzified output.

Fuzzy Logic System Architecture

It architecture for the fuzzy based system are the following modules.

Fuzzification Module – This module is responsible for mapping a set or vector of values into a fuzzified set. The sub categories of this module are:−

LP x is Large Positive
MP x is Medium Positive
S x is Small
MN x is Medium Negative
LN x is Large Negative

Knowledge Base − It is the sub module that decides the expert view or the relevant expert opinion needed for taking decisions.

Inference Engine − It is the module that tries to infer data as the human mind interprets it for making actual crisp decisions. .

Defuzzification Module – This module is responsible for converting a fuzzified set of values into crisp outputs.

The major reason for the need of Fuzzification in IDS is the fact that often it may be critically important to take decisions which do not have a clear boundary of decision making and hence a crisp output needs to be rendered.

Fuzzy logic can render crisp values as the output subsequent to Fuzzification.

Membership Functions

Membership functions allow you to quantify linguistic term and represent a fuzzy set graphically. A membership function for set A can be defined as the super-set of discourse X as:

$$\mu A: X \rightarrow [0,1] \qquad (1)$$

Here, all the elements of the superset X is mapped between values of possible yes or no termed as 0 and 1. Often the term coined for the above function is called the membership value or degree of membership. It helps in the quantification of the set value in the discourse of A into the crisp values as:

x axis denotes the entire range of the random discourse or variable.

y axis denotes the value of the probability in the interval of [0, 1].

The number of membership functions for the fuzzy set is given by the sub-categories of the values in which the data is to be divided. The concept of the membership functions can be explained graphically as:

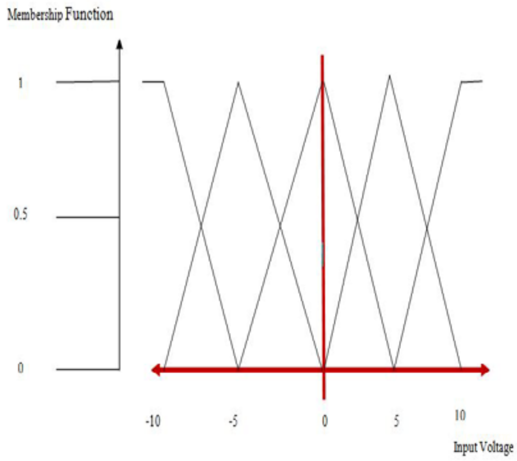

Fig. 2.1 Membership Functions

III. NEURAL NETWORKS AND NEURO FUZZY EXPERT SYSTEMS

Neural networks follow the pattern recognition capability and thought process capability of the human brain characterized by:

- Parallel processing
- Pattern recognition through adaptive learning
- Evolving through updating the weights often seen as experiences.

Mathematically, the neural network is governed by the following expression:

$$Y = \sum_{i=1}^{n} X_i . W_i \; + \; \theta_i \qquad (2)$$

Here,

X_i Represents the parallel data streams used for training

W_i Represents the weights or the learnt experiences coming from the inputs

θ Represents the logical analysis or bias

It is often difficult to train a system with all the possible outcomes that it can attain. Typically in the case of IDS, the data can be in such a juxtaposed set of a superset or discourse that it may not exhibit clear demarcations of decision logic. Hence it is mandatory to use the self-organization attribute of the fuzzy system.

Neuro Fuzzy Systems can be seen as an amalgamation of:

1. Neural Networks
2. Fuzzy Logic

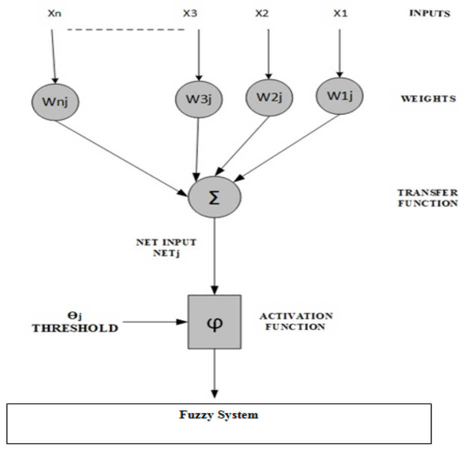

Fig. 4.1 Neuro Fuzzy Expert Ssyetm

The block diagram for the neuro fuzzy (Sugeno) architecture is shown in the figure above. In the figure, it can be seen that the parallel data stream is used to train the neural network and update its weights. Subsequently, the output of the neural network is fed to the fuzzy inference engine that is used to de-fuzzify the data and render a crisp output value in the form of a decision even if there is no clear demarcation among the data set.

IV. NFSNPID TCHNIQUE

The NFDNPID stands for neuro fuzzy single neuron PID technique. The technique can be easily visualized using the following block diagram: [1]

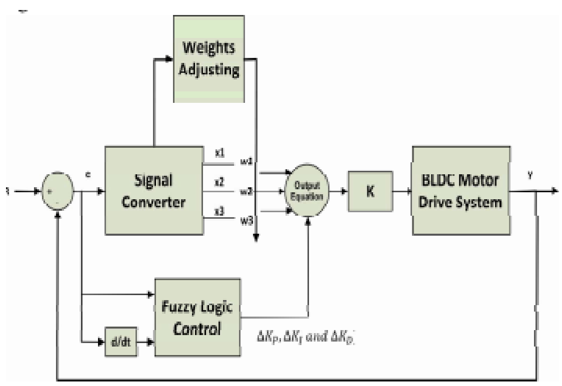

Fig. 5.1 Block Diagram of NFSNPID System

In this technique, fuzzy logic is used to update the weighted co-efficients of the PID controller dynamically according to the relation:

$$u(k) = k\left[k_p w1 e(k)\right] + \left[iw2 \int_0^k e(k)\right] + \left[k_d w3.\frac{de(k)}{dk}\right] \quad (3)$$

Here,

k_p, k_l and k_d are the co-efficients of the fuzzy controller. The weights are adapted according to the fuzzy inference machine output and adjust the weights dynamically.

V. PREVIOUS WORK

It M.A Abdel Ghany et al. in [1] proposed a Novel Fuzzy Self Tuning Technique of Single Neuron pid Controller for Brushless DC Motor. It can be visualized as a combination of a Novel Fuzzy Single Neuron PID (NFSNPID) controller to achieve a high performance brushless DC motor. The design makes use of genetic algorithm (GA) to obtain the optimum parameters of Single Neuron PID (SNPID) controller and then uses the fuzzy logic control to update the weights of SNPID control online.

Adel A. El-samahy et al. in [2] suggested a model for Brushless DC motor tracking control using self-tuning fuzzy PID control and model reference adaptive control. With separate control of motor flux and motor torque with the help of direct and quadrature component CSI's performance has been further improved making it more popular but it faced a drawback of poor dynamic response. Hence the author has felt the requirement of more efficient CSI based method for IM. For that author has utilized two PI controllers and a rotor flux observer. The utilized method is simulated over MATLAB/Simulink software and both dynamic and transient response are obtained after simulation which resulted in more stable performance has been produced. It has been shown that the performance of MRAC is much better than self-tuning fuzzy PID controller for systems encountering sudden disturbances.

Benyamin Kusumoputro et al. in [3] proposed Performance Characteristics of An Improved Single Neuron PID Controller using Additional Error of an Inversed Control Signal. Further based on this model author has developed a fuzzy logic-based model for speed controlling. The complete work is done on MATLAB platform. This work has discussed and proved that such models require less mathematical modelling and less prior knowledge of system also. On simulating IM drives the output functions are observed based on varying load and speed which concluded that the proposed method will have more accurate and easy controlling.

Tan Luong Van et al. in [4] put forward Advanced Pitch Angle Control Based on Fuzzy Logic for Variable-Speed Wind Turbine Systems. In this paper, In this paper, an advanced pitch angle control strategy based on the fuzzy logic is proposed for the variable-speed wind turbine systems, in which the generator output power and speed are used as control input variables for the fuzzy logic controller (FLC). The pitch angle reference is produced by the FLC, which can compensate for the nonlinear characteristic of the pitch angle to the wind speed.

Mohammed AbdelbarShamseldin et al. in [5] proposed Speed Control of BLDC Motor by Using PID Control and Self-tuning Fuzzy PID Controller. Author has discussed that how an old model can be replaced by a new neural network-based model which control the drives speed with the help of backpropagation training and learning. The drive thus developed is not only prove to be cheap and less bulky but also found out to be better performing. Such model is used to estimate both speed and position of IMs rotor. Results show that the proposed fuzzy PID has better performance compared to the other techniques.

Vikram Chopra et al. in [6] proposed Comparative Analysis of Tuning a PID Controller using Intelligent Methods. The paper utilizes the soft computing approaches of fuzzy logic, artificial neural network (ANN), adaptive neuro fuzzy inference system (ANFIS) and genetic algorithms (GA) for tuning a PID controller. In many cases, PID controlling is done using direct measurement. According to author in order to reduce the robustness and cost incorporated due to such techniques a new alternate way to optimize same can be achieved using VSI and space vector modulation. Along with author has also propose ANN by validating performance under motor load torque and speed ref. point variation. Simulation results show that performance than the conventional Zeigler Nichols (ZN) method in terms of various performance specifications.

Wang Sheng,YanBao in [7] put forth Fruit fly optimization algorithm based fractional order fuzzy-PID controller for electronic throttle. In this paper, the authors depicted that how non-linearity of any PID controller can be traced and its performance can be improved using different controller techniques. The models are prepared in MATLAB/SIMULINK software. The result clearly states the superiority of ANN trained model over conventional controller due to its exceptional learning capacity hence did trace the reference speed with great accuracy for better and faster than that of conventional one.

Xiao-Gang Duan et al. in [8] In this paper, a saturation-based tuning method for fuzzy proportional–integral–derivative (PID) controller is proposed. The demand requires a good controlling which is difficult to do using conventional controllers due to non-linear property of speed torque characteristics. This problem is solved by author using artificial neural network and came to the conclusion after proper training and testing and validation that this model with provide better speed controlling of a BLDC motor with the change in input voltage.

P. M. Meshram et al. in [9] proposed Tuning of PID Controller using Ziegler-Nichols Method for Speed Control of DC Motor. In this paper, a weighted tuning method of a PID speed controller for separately excited Direct current motor is presented, based on Empirical Ziegler-Nichols tuning formula and modified Ziegler-Nichol PID tuning formula. The authors showed a unique methodology for speed control of PID controller using neural network along with indirect -FOC. The author has developed these models in MATLAB/SIMULINK environment and has done the comparison with PID controller-based drive and found the previous one much better in terms of compactness, reliability and closeness with which predicted speed follows reference speed of controller.

R. Arulmozhiyal ,R. Kandiban in [10] put forth Design of Fuzzy PID controller for Brushless DC motor. In this paper, it was shown that Brushless DC (BLDC) are used widely for industrial applications because of their high efficiency, high torque and low volume. This paper proposed a improved Fuzzy PID controller to control speed of Brushless DC motor. The modeling, control and simulation of the BLDC motor have been done using the software package MATLAB/SIMULINK.

VI. PROPOSED SYSTEM

The proposed approach can work on the Polak-Rebiere (PR) algorithms along with fuzzy logic. The Ploak Rebiere approach is based on finding the steepest gradient descent fo the error with respect to weights. It generally has low time and space complexity which adds to its advantage for practical utility.

The training rule for the Polak-Rebiere algorithm is given below:

$$p_0 = -g_0 \quad (4)$$

Where,

$p_0$represents the negative gradient given by $\frac{\partial e}{\partial w}$

The search direction vector p_k for iteration k (representing adaptive learning rate gradient descent) is given by:

$$p_k = -g_k + \beta_k p_{k-1} \quad (5)$$

The constant β_k is computed by:

$$\beta_{k-1} = \frac{g_k^T + g_k}{g_{k-1}^T + g_{k-1}} \quad (6)$$

The weight adaptation is given by:

$$w_{k+1} = w_k + \beta_k p_k \quad (7)$$

Here,

$w_{k+1}$is the weight of the next iteration

$w_k$is the weight of the present iteration

The activation function used by the Polak-Rebiere algorithm is the tan-sig function mathematically defined as:

$$tansig(x) = \frac{2}{1+e^{-2x}} - 1 \quad (8)$$

The block diagram for the proposed system is shown in the figure below:

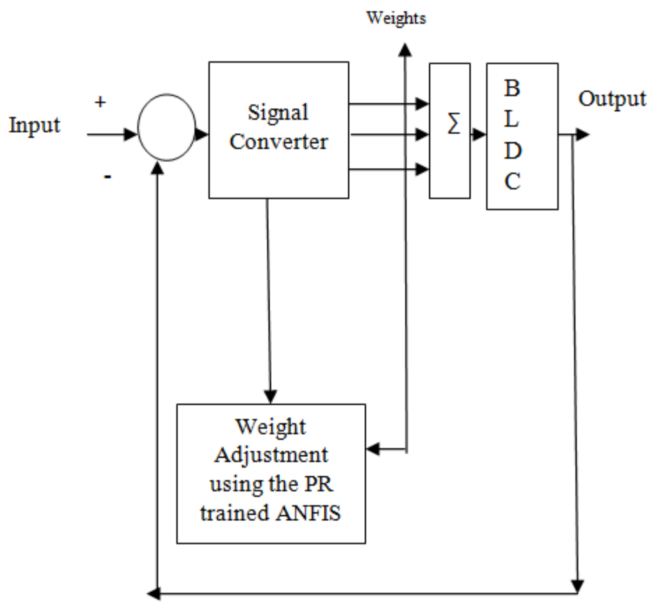

Fig. 6.1 Block Diagram of Proposed System

It is expected that the proposed system using the Polak Rebiere Restarts trained ANFIS system will perform better than conventional systems.

VII. CONCLUSION

It can be concluded from the previous discussions that automatic tuning of PID controllers is a critical task and needs self adapting mechanisms such as neural networks and fuzzy logic. The paper presents the basics of fuzzy logic and neural networks. Different approaches in the field have been highlighted along with their approach so as to render insight into the techniques used for automatic tuning. Also the paper proposes a Polak-Rebiere (PR) based ANFIS system for the automatic tuning and control of a BLDC system.

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