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Tuned Proportional-Integral-Derivative (PID) Control System

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Abstract

The research work is simply based on the comparison between the PID controller and the tuned PID control system. It is highly desired that the PID controller be tuned in order to remove the oscillation experienced by the PID controller, that is, the overshoot, the delay, and the undershoot. The intelligence (Fuzzy) tuning method/technique is applied in this work, to achieve the comparison aimed at.

The developed idea was based on the process of heat control intelligently, using the IF-THEN rules of Fuzzy logic. Results obtained from simulation showed that the Untuned (Block) PID controller has a settling time of 59.38 Sec with a percentage overshoot of 40% and a percentage undershoot of 13.33%. While the Tuned PID has a settling time of 50 Sec with a percentage overshoot of 8% and percentage undershoot of 0.00%. This showed that the Tuned PID gave a better performance compared to the Untuned PID.

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Keywords: Comparison, Intelligent, Tuned, Untuned, Overshoot, Undershoot

Introduction

The Proportional-Integral-Derivative (PID) controller is one of the earliest control methods, being widely used in the industry today, due to its ease in implementation, robust performance and its ideal principle of simplicity. A PID controller is a linear control methodology with a very simple control structure. This type of controller operates directly on the error signal, which is the difference between the desired output and the actual output and generates the actuation signal that drives the plant (Costa, 2011) [4]. It is highly desired that the PID controller be tuned in order to remove the oscillation experienced, that is, the overshoot, the delay, and the undershoot, when it is being used.

In PID controller tuning, the gains of three parameters, such as proportional, integral and derivative are to be derived; this task requires best performance in the control system, but complex to achieve. Traditionally, PID controllers are tuned either manually or using intelligent-based method. The manual or human tuned method is time-consuming and can be totally ineffective when used in nonlinear and complex systems with time delays and unknown interactions, if its gains are not well tuned. In order to overcome this problem usually encountered with the PID, an intelligent tuning method is applied to the PID controller, in order to adjust the PID parameters from time to time, thus making the precision of overall control higher and hence gives an optimized performance in the system control. This research work tends to develop an intelligent based PID tuning mechanism via simulation in Matlab wares and then, compare it with the manual PID tuning method.

Review in Literature

PID Tuning

This is a process of setting the optimal gains for Proportional, Integral and Derivative to achieve ideal response from a control system. The various methods of tuning are the These and check, Ziegler-Nichols, Chien-Hrone-Reswick, Cohen-Coon and the Wang-Juang-Chan (WJC). All of these methods; the Chien-Hrones-Reswick (CHR), Cohen-Coon (CC) and the Wang-Juang-Chan (WJC) tuning methods are not too viable for the PID controllers. The CHR tuning method was proposed for both the set-point regulation and disturbance rejection in a system (Chien et al., 1952) [3].

In addition one qualitative specification on the overshoot can be accommodated. Compared with the traditional Ziegler–Nichols tuning formula, the CHR method uses the time constant T, delay time L and gain k. The CC is a tuning method based on the Ziegler–Nichols type tuning algorithm (Cohen and Coon, 1953). Referring to the first order plus dead time model, which can approximately be obtained from experiments, denote by $a = kL/T$ and $\tau = L(L+T)$. The WJC is a tuning method based on the optimum integral of time and absolute error (ITAE) criterion (Wang, Juang, and Chan, 1995) [8]. The PID tuning algorithm proposed by Wang, Juang, and Chan is a simple and efficient method for selecting the PID controller parameters. If the k, L and T parameters of the plant model are known, then the PID controller parameters can be derived.

Tuning a PID controller appears easy, requiring you to find just three values: proportional, integral, and derivative gains. In fact, safely and systematically finding the set of gains that ensures the best performance of your control system is a complex task. Traditionally, PID controllers are tuned either manually or using rule-based methods. Manual methods are time-consuming, and if used on the hardware, can cause damage. Rule-based methods do not support unstable plants, high-order plants, or plants with little or no time delay. PID control also involves design and implementation challenges, such as discrete-time implementation and fixed-point scaling. A PID controller may be considered as an extreme form of a phase lead-lag compensator with one pole at the origin and the other at infinity. Similarly, its cousins, the Proportional and Integral and the Proportional and Derivative controllers, can also be regarded as extreme forms of phase-lag and phase-lead compensators, respectively. A standard PID controller is also known as the “three-term” controller, whose transfer function is generally written in the “parallel form” given by (^{1}ABB. 2001) [1] or the “ideal form” given by (^{2}ABB, 2001) [1].

Controller tuning involves the selection of the best values of kc, Ti and TD (if a PID algorithm is being used). This is often a subjective procedure and is certainly process dependent. The most well-known tuning methods are those developed by Ziegler and Nichols. They have had a major influence on the practice of PID control for more than half a century. The methods are based on characterization of process dynamics by a few parameters and simple equations for the controller parameters.

Fuzzy Logic Controller The concept of Fuzzy Logic (FL) was conceived by Lofti Zadeh, a professor at the University of California at Berkley, and presented not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. This approach to set theory was not applied to control systems until the 70's due to insufficient small-computer capability prior to that time (Gupta, Khurana & Nishu, 2015).

Joseph, Okeke & Taiwo (2021) [7] developed a fuzzy tuned Neural network intelligent controller. In their work, they used the neural network learning techniques to tune the membership functions while keeping the semantics of the fuzzy logic controller intact. Both the architecture and the learning algorithm are presented for a general neuro-fuzzy controller. In conclusion, a resulting effective system temperature control with energy conservation up to 100 eggs was achieved.

Joseph (2017) [7] devoped a work, tagged developed Fuzzy-PID temperature control for cement kiln. The Fuzzy-PID model performance gave zero percentage overshoot compared with the high percentage overshoot in the CHR-PID, CC-PID and the WJC-PID controllers, thereby solving the problem of perennial instability in the operation of rotary kiln in cement production plant.

Method Applied

This section shows the research technique applied to achieve the aim and objectives of this work.

PID Controller Design

The PID control signal is given by equation (1), which is used in closed loop system to form system control.

$$u(t) = K_p \left(e(t) + \frac{1}{T_i} \int_0^t e(\tau)\, d\tau + T_d \frac{de(t)}{dt} \right) \qquad (1)$$

Where $u(t)$ is the input signal to the plant model, the error signal $e(t)$ is defined as $e(t) = \theta_d(t) - \theta_m(t)$, and $\theta_d(t)$ is the desired input temperature.

The PID controller transfer function is given in equation (2)

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_p \left(1 + \frac{1}{T_i\, s} + T_d\, s \right) \qquad (2)$$

$$T_i = K_p / K_i\,, \quad T_d = K_d / K_p$$

where K_p, T_i and T_d are the proportional gain, integral and the derivative time constant respectively.

Intelligent control Design

The intelligent controller applied in this case is the Fuzzy controller, to act as the tuner to the PID controller. The design includes the fuzzification, Inference system (knowledge base, data base and inference engine) and de-fuzzification.

The fuzzification unit converts the crisp data into linguistic format (fuzzy sets), by mapping the input characteristics to membership functions, and then to fuzzy rules.

The Membership function (MF) defines the user-defined charts. The MF used by fuzzy logic controller in this work is the triangular membership function, it was used in order to provide a better precision of the model output. This includes; Negative Big, Negative middle, Negative small, Zero, Positive small, Positive middle and Positive Big respectively.

The knowledge base contains the experienced knowledge of the flow process station. Data base contains the membership function and control rules of every linguistic variable, while the inference engine evaluates (process) the fuzzy sets to trigger a rule according to the IF…..THEN rules created in the graphical user interface of the fuzzy logic toolbox in Matlab. Finally, the defuzzification unit converts the fuzzy output back to crisp (real output) data (e.g., analog counts) and sends this data to the process via an output module interface.

In order to determine the tuning effect of the method under consideration, the manual PID and tuned PID were used to control the heating effect of a kiln system. The values of PID compensator configuration used for the kiln control are:

P = 0.54; I = 0.09; D = -0.23; N (filter coefficient) = 0.32.
The resulting response is as displayed in the result section below.

Result and Discussion

Result

The results for both untuned (Block) type PID and the tuned type PID was merged, to show clearly, the difference between these two methods considered. A graphical user interface (GUI) of MATLAB R2007a edition environment was used for the system simulation as shown in Figure 1.

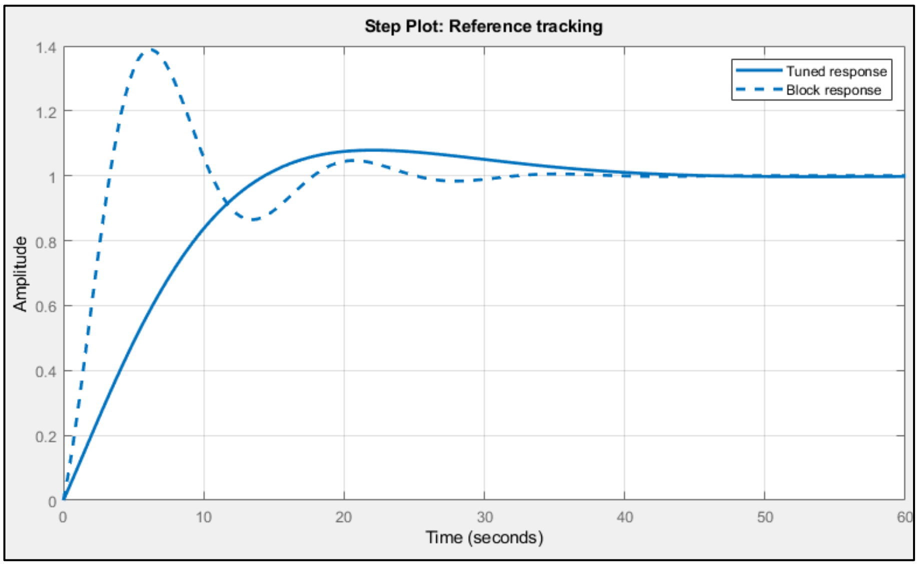

Fig 1: Result Chart for both the Untuned (Block) and the Tuned PID Controllers

Untuned (Block) PID: Represented with break lines in the chart of Figure 1.
Tuned PID: Represented in continuous line in the chart of Figure 1.

Table 1: Chart Representation

Controller Type	Settling Time(Sec)	% Overshoot Amplitude	% Undershoot Amplitu
Untuned PID	59.38	40.00	13.33
Tuned PID	50.00	8.00	0.00

Settling time = 59.38sec
Overshoot Amplitude = 0.4 (Untuned)
Undershoot Amplitude = 0.13
Overshoot Amplitude = 0.08 (Tuned)
Undershoot Amplitude (Tuned) = 0.00
Note: The Amplitude in the chart (Y- axis) represents the system heat being controlled.

Discussion

In the discussion, it shows from the chart of Figure 1, which was also interpreted in Table 1 that the Un-tuned (Block) PID controller has a settling time of 59.38 Sec with a percentage overshoot of 40% and a percentage undershoot of 13.33%. While the Tuned PID has a settling time of 50 Sec with a percentage overshoot of 8% and percentage undershoot of 0.00%.

From this analysis of both controller systems, it shows that large amount of energy will be consumed by the Untuned PID controller as compared to that of the tuned PID controller, which consumes low energy. Also, the Untuned PID is time consuming, as compared to that of the tuned PID, with low time consumption.

To this effect, the Tuned PID is economically viable compared to the Untuned PID, so, production cost, market cost and other variable will be reduced, leading to the system viability.

Conclusion

Conclusively, if a system is controlled by a PID system, whose gain is effectively tuned intelligently, the system will gain a lot of viability than when an untuned PID system is used. To this end, it is advisable to use intelligent tuned PID system in control purposes.

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