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Implementation and Performance Analysis of an Improved Relay Feedback Auto Tuning PID Controller

Geetha M. and Jovitha Jerome

Department of Instrumentation and Control Systems Engineering, PSG College of Technology, Coimbatore, India

Abstract: PID Controllers are widely employed in industries for the purpose of controlling the parameters of the process. This is because it is easier to deploy hardware for PID controllers comparing the other controllers. It is very important to provide proper tuning parameters for the PID Controller. Auto tuning is a method by which a controller can be tuned on demand. Since the introduction of the relay feedback test by Astrom and Hagglund , auto tuning of PID controller has received much attention, and many commercial auto tuners have also been designed accordingly. Without knowledge of the model structure, most of these relay feedback auto tuners use Ziegler-Nichols-type tuning rules to set controller parameters. This can lead to poor performance in some cases, because no single tuning rule can work well for all model structures over the entire range of parameter values. Luyben points out that additional information can be obtained from relay feedback tests, namely, the shape of the response .T. Thyagarajan and Cheng-Ching Yu have suggested that the shape of the response from the relay feedback tests, processes can be broadly classified into three major categories (model structures). They have given the procedures to find out the parameters for the corresponding model structures also. In this work, relay feedback tests are conducted on processes with large dead time for different range of set point parameter and found out the dead time to time constant ratio. Based on that ratio, different tuning rules are employed to find appropriate PID controller settings. The procedures are tested against level process in real time using conventional Auto tuning and Improved Auto tuning. Experimental results clearly indicate that, by incorporating the shape information, improved auto tuning can be gives better performance. It should be emphasized that the improvement is obtained from the conventional relay feedback test and no additional testing is required.

Key words: Classical Auto tuning, Improved Relay Feedback Auto tuning, ISE.

INTRODUCTION

The Proportional Integral Derivative (PID) controller has not attracted as much attention of control researchers over the last few decades as have newer control areas such as model predictive control or $H\infty$ control theory. Not many books have been published that concentrate on PID control

About 95% of process control loops are of PID or PI type. PID control is often combined with other technologies to build the complex automation systems that are used in many industries. Chemical and petrochemical control strategies are often organised in a hierarchy of functions, with scheduling and optimization functions running on top of the hierarchy, multivariable predictive controllers in the middle and PID controllers at the lower level, directly sending control signals to actuators.

Tuning a controller implies setting its adjustable parameters to appropriate values that provide good control performance. Auto-tuning can be seen as a combination of a procedure for characterizing process dynamics with a method for calculating controller parameters. The auto-tuning method using relay feedback was first introduced by Astrom and Hagglund. Industrial feedback has clearly indicated that auto-tuning is a highly desirable and useful feature. But without the knowledge of the model structure, most of these relay feedback auto-tuners use Ziegler-Nichols-type tuning rules to set controller parameters. This can lead to poor performance in some cases, because no single tuning rule can work well for all model structures over the entire range of parameter values.

The purpose of this work is to utilize the shape information from the relay feedback test to identify the correct model structure of the process and to determine appropriate PID controller settings. The additional shape information is also useful for devising dead-time compensation and higher-order compensation when necessary.The objective of the proposed work is given below.

- Emulation of the digital PID controller in Compact RIO using LabVIEW platform
- Comparison of Performance of existing Auto tuning method and Improved Auto tuning method for level control in real time at different range of set point parameter.

Corresponding Author: Geetha M., Department of Instrumentation and Control Systems Engineering, PSG College of Technology, Coimbatore, India
E-mail: geethamr@gmail.com

Existing Method:

The existing Auto-tuning method uses relay feedback test, which extracts the ultimate gain and ultimate period information from the response and employs Ziegler-Nichols tuning rule for all processes. The Astrom and Hagglund relay feedback test is based on the observation that, when the output lags behind the input by π radians, the closed-loop system can oscillate with a period of P_u. A relay of magnitude h is inserted in the feedback loop. Initially, the input $u(t)$ is increased by h. Once the output $y(t)$ starts increasing after a time delay (D), the relay switches to the opposite direction, $u(t) = -h$. Because there is a phase lag of $-\pi$, a limit cycle of amplitude a is generated. The period of the limit cycle is the ultimate period, P_u. The approximate ultimate gain, K_u, and the ultimate frequency, ω_u, are

$$\mathbf{K}_u = \frac{4h}{\pi a} \quad \boldsymbol{\omega}_u = \frac{2\pi}{Pu}$$

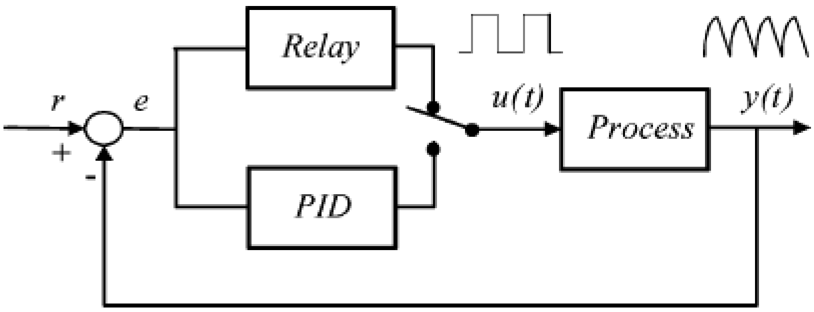

Fig. 1: Block diagram of Relay Feedback Test.

The method of relay feedback test with classic PID controller for auto tuning is shown in

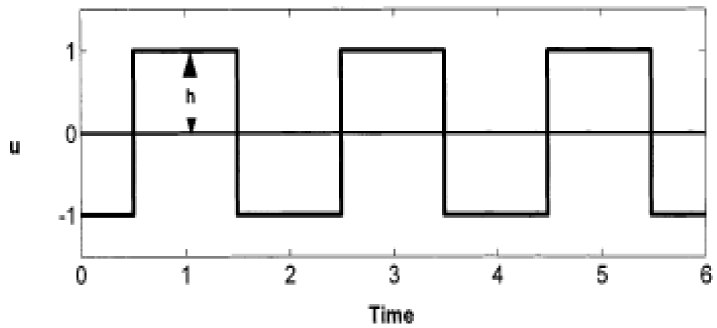

Fig. 2: Relay Input to the process.

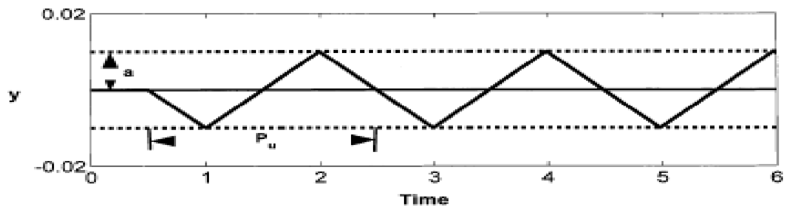

Fig. 3: Relay Response of process.

The Relay Input and its response (Continuous oscillation of process variable) are shown in Figures 2 and 3.Once the ultimate gain and period are found PID parameters can then be designed by using the closed loop Ziegler-Nichol's tuning method. The Ziegler-Nichol's tuning rule (Yun Li, KiamHeongAng and Gregory C.Y. Chong., 2006) is shown in Table 1. Ziegler-Nichol's tuning rule is widely used because when compared to other controller only a few parameters are required to tune the controller to give a better result.

Table 1: Ziegler – Nichols tuning rule.

Ziegler– Nichols	K_C	τ_i	τ_d
P	$K_u / 2$	-	-
PI	$K_u / 2.2$	$P_u / 1.2$	-
PID	$K_u / 1.7$	$P_u / 2$	$P_u / 8$

Ultimate-gain and ultimate-frequency-based auto tuning might produce poor performance in some instances, because information on model structure is lacking. Typical examples include first-order systems with large dead-time-to-time-constant ratios and second order systems with small dead-time-to-time-constant ratios. Many authors have proposed modifications to the relay feedback test, and some works recommend additional tests to extract extra information about the process dynamics.

Proposed Method:

In the proposed Improved relay feedback Auto tuning technique, Ziegler-Nichol's tuning method is not used alone like existing method. For each process, the dead time to time constant ratio (i.e ., D/τ ratio) varies and depending on the ratio different tuning rules are used. This presents a significant progress in relay feedback identification, and much reliable auto tuning has resulted.

From the shapes of the relay response curves of different process, several observations can be made.

- If the response curves have sharp edge at the peak amplitudes, the process can be considered as a First Order Plus Dead Time (FOPDT) system as shown in Figure 4.
- If the relay feedback gives a triangular wave, the process can be treated as a time-constant- dominant process. Specifically, the time required to reach the peak amplitude is equal to the dead time. If the dead-time-to-time-constant ratio becomes larger, curvature begins to appear as like the figure shown in Figure 4, and this implies gradual development toward a step response. As D/τ approaches infinity, the response resembles a symmetrical rectangular wave.

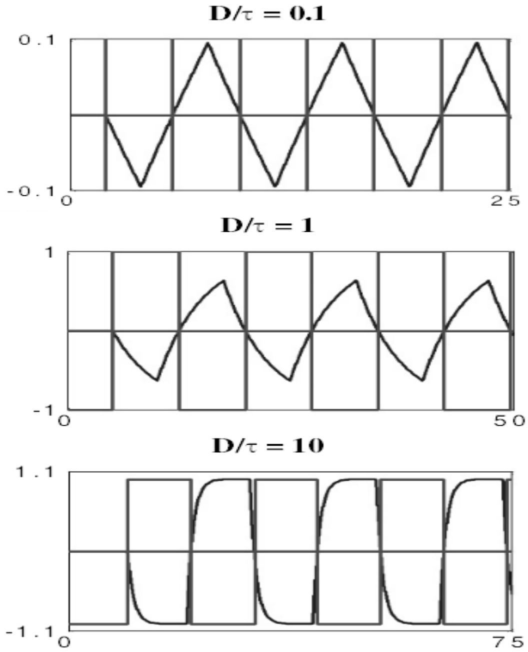

Fig. 4: Relay feedback responses of FOPDT processes.

If the order of the process increases to 2 and beyond the sharp edges disappear, and the responses resemble sinusoidal oscillations. Generally, sustained oscillations develop in all cycles except for second-order processes with small D/τ values. If the response consists of sinusoidal oscillations with exponentially increasing magnitude that reach steady state after many cycles, the process can be considered as a second order process with a small D/τ value.

From the above observations, model structure of different processes can be identified as First Order Plus Dead Time (FOPDT), Second Order Plus Small Dead Time, Higher Order system.The Table 2 gives different tuning rules for tuning of PID controller, for different D/τ ratios.

Table 2: Tuning rules for different D/τ ratios.

$D/\tau < 0.1$	$0.1 <= D/\tau <=1$	$D/\tau>1$
Tyreus-Luyben(TL)	ITAE Method	IMC Method
$Kc = K_U/2.2$	$Kc=0.965/K_P\,(\tau/D)^{0.855}$	$Kc=0.769\tau/\lambda K_P$
$\tau_I = 2.2\ P_U$	$\tau_I=\tau/(0.796-0.147)(D/\tau)$	$\tau_I = \tau$
$\tau_D= P_U\ /6.3$	$\tau_D= 0.308\ \tau\ (D/\ \tau)^{0.929}$	$\tau_D= \lambda/\ 2$

Experimental Results and Analysis:

The Conventional Auto tuning and an Improved Auto-tuning algorithm have been implemented in Compact RIO using LabVIEW, such that the user will be at the liberty to choose between improved and conventional auto-tuning method. The front-panel view is shown in Figure 5.

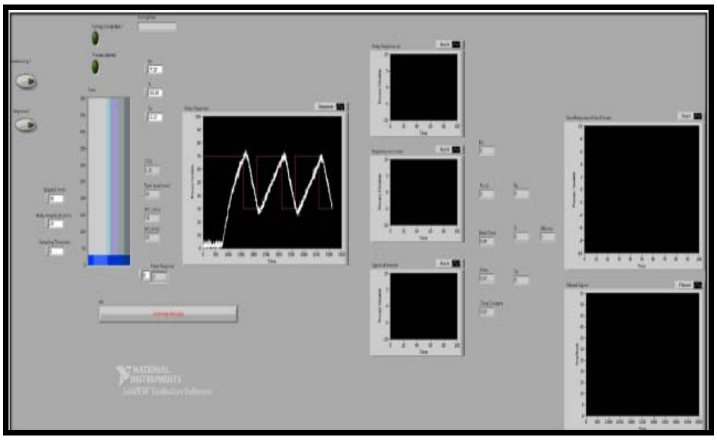

Fig. 5: Front Panel View.

From the determined ultimate gain and ultimate period, by using Ziegler-Nichol's tuning method Proportional gain (k_p), Integral Time (T_i) and Derivative Time (T_d) are found as follows. K_p = 50.4725; T_i = 205.15 s; Td = 14.8016 s. Then these parameters are substituted in the PID controller. The responses of the system under Ziegler-Nichol's tuning method are found as shown in Figures 6 and 7.

Depends on the D/τ ratio, the optimum tuning rule was selected as ITAE method. Figures 8 and 9 are the system responses obtained using Improved Auto tuning (ITAE). The tuning parameters were calculated as K_p = 28; T_i =205.15 s; T_d = 50 s.

The regulatory responses of the level process under classic Auto tuning and improved Auto tuning are shown in Figures 6 and 7(Ref Appendix 1). The set point to the system is given as 250 mm. When the process is subjected to a disturbance at the sampling instant 4000 and 7500, it is found that the performance of Improved Auto tuned process is much better than conventional Ziegler Nichol's tuned process.

The servo responses of the process under classic Auto tuning and improved Auto tuning are shown in Figures 8 and 9 (Ref Appendix 1). The set point to the system is same. When the process has settled, the set point is varied at the sampling instant 4500. The results show an Improved Auto tuned (ITAE) PID Controller has better tracking ability than conventional ZN tuned process.

From the results the following observations are made. Compared the performance of Existing Auto tuning, the proposed Improved Auto tuning provides,

- Settling time is minimized
- Rise-time is reduced
- Mean square error is reduced

The controller performance index of the existing and proposed method is discussed in Table 3. It is calculated for the responses shown in Table 4. (Ref Appendix 1)

Table 3: Controller performance index.

	Set point=250 mm			
Method	Response type	ISE	ITAE	IAE
Existing method	Regulatory	7.214236E+9	9.98517E+7	604523
Proposed Method	Servo	2.48544E+8	1.46727E+8	1.11205E+6
	Regulatory	8.421660E+7	6.86344E+7	469816
	Servo	6.97395E+7	5.07099E+7	396000

From the controller performance index it is understood that considering the shape factor of the process is very much important to find out the exact tuning rule for the process.

The Table 4 is the Comparison of Ziegler Nichol's tuned and Improved Auto tuned (ITAE) responses. The Level process has considered for implementation is shown in the Figure 10. Interfacing of the system with the control panel is shown in Figure 11.

Fig. 10: Level Process.

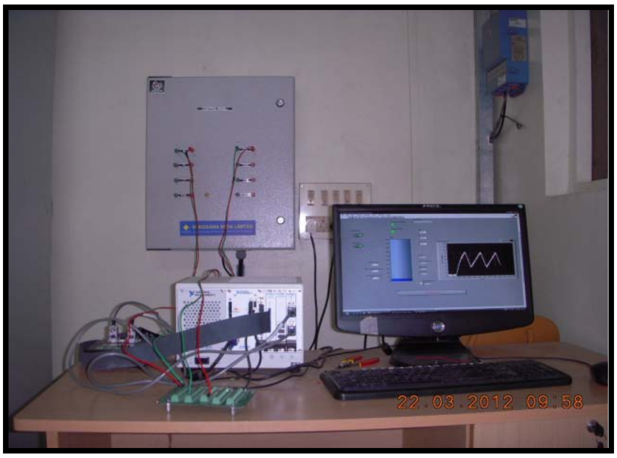

Fig. 11: Hardware Interfacing Unit.

Conclusion:

The shapes of relay feedback responses are useful in extracting additional information about process dynamics. From a methodical analysis of the shape information, different processes can be broadly classified into three major categories. Different tuning rules were employed to find appropriate PID controller settings. The results show that the proposed method results in improved auto tuning in a straight forward manner. Thus, shape information is useful in inferring the correct model structure of the process and also in selecting the appropriate control strategy to offer improved performance. The advantage of this method is that by using single relay feedback test all the parameters can be identified. The results show that the proposed method gives improved tuning parameter estimates and hence an improved closed loop response. Thus the proposed method gives the best performance.

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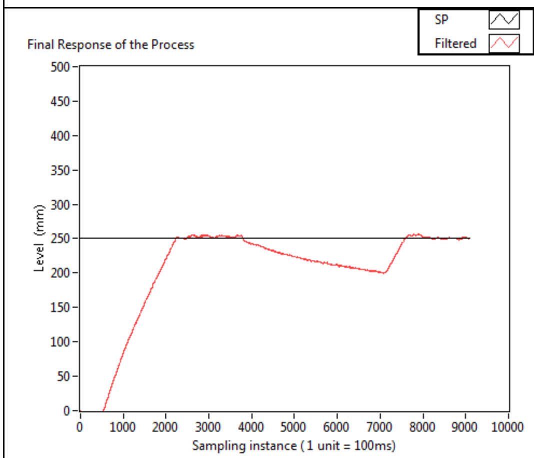
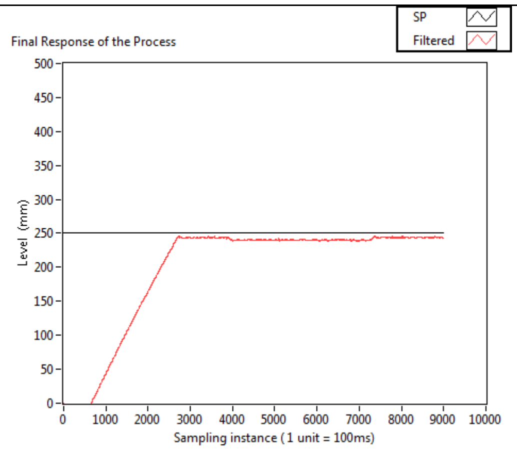
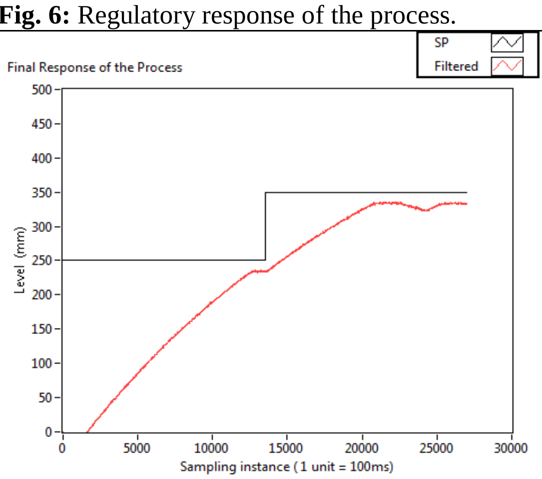
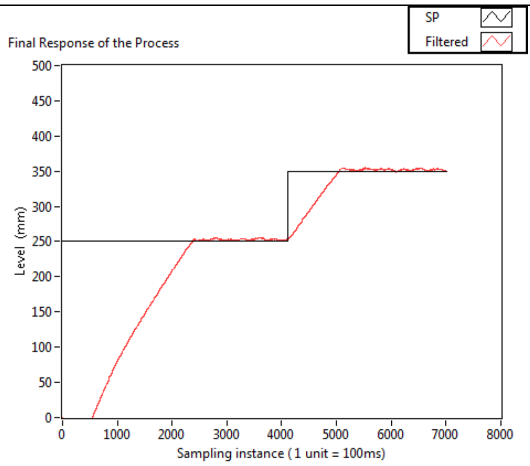
APPENDIX 1:

Table 4: Comparison of Ziegler Nichol's tuned and Improved Auto tuned Processes.
(Set point=250mm)

Ziegler Nichols Tuning Filtered-PV	Improved Autotuned (ITAE)Tuning Filtered-PV
 **Fig. 6:** Regulatory response of the process.	 **Fig. 7:** Regulatory response of the process.
 **Fig. 8:** Servo response of the process.	 **Fig. 9:** Servo response of the process.