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Intelligent Controller for Optimum PID Tuning

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ABSTRACT
The increasing compxity of the modern control systems has emphasized the idea of applying new approaches in order to solve design problems in control engineering. PID controller is employed in every facet of industrial automation. The application of PID controller spans from small industry to high technology industry. In this paper, it is proposed that the controller can be tuned using the Genetic Algorithm technique. The genetic algorithms (GA) used in the paper are a promising heuristic approach to locating near-optimal tuning solutions. They are easy to implement and robust. It is shown that GA offers a general tuning technique which is applicable to a wide variety of processes and may be based on either performance/robustness criterion of the model. The paper also compares the results obtained with those obtained using conventional tuning techniques. Simulation results indicate that the GA overcomes many of the difficulties associated with existing tuning rules, and produces satisfactory results for systems that are normally considered difficult to tune.

Keywords- controller tuning, genetic algorithms, reference model

I. INTRODUCTION

Despite the abundance of PI and PID tuning techniques available in the literature, interest in, and development of new methodologies continues unabated. This is doubtless due to the widespread application of this versatile controller in industry and also due to the recognition that the majority are poorly tuned [4]. However, most current tuning methods will only yield PI or PID parameters for a restricted class of process models. There is no general methodology for arbitrary process models other than approximating them with a first-order or second-order time-delayed model and applying an appropriate rule. Furthermore as process complexity increases e.g. first-order unstable time-delayed system, the number of applicable tuning rules decreases and in many cases vanishes altogether.

The parameter optimization has however been largely overlooked, particularly as an alternative tuning technique for processes which are otherwise difficult to tune.The contribution of this paper is to explore the potential of the GA methodology to overcome the deficiencies which are there in the present PID controller tuning methods. This paper concentrates on the minimization of a variety of error criteria for a wide variety of processes. Where possible, suitable tuning rules are identified and applied with the results then compared with a similarly optimized controller whose parameters were obtained by applying a genetic algorithm. The results indicate that the modern control engineer would do well to include the GA in his repertoire of design methodologies.

II. CONTROL ALGORITHM DESIGN

Due to the variety of PID control law permutations it is necessary to specify a minimum set of attributes which in this paper are as follows:

1) Only single-degree of freedom controllers will be treated

2) The PID controller is assumed to be of non-interacting form as defined below:

$$G_c(s) = K_P + K_I \frac{1}{s} + K_D s \tag{1}$$

By suitable transformation of the parameters this form can always be converted to interacting form, whereas the converse is not always true.

3) Minimizing one of the following error criteria generates the controller parameters (1):

$$ISE = \int_0^T [r(t) - y(t)]^2\, dt, \quad IAE = \int_0^T \left[\left|r(t) - y(t)\right|\right] dt, \qquad ITAE = \int_0^T t.\left|r(t) - y(t)\right| dt \tag{2}$$

Where: $r(t) = \text{referenceinput},$

$y(t) = \text{Measured variable}$

In this paper these error criteria will be minimized by applying an existing tuning algorithm as illustrated in the next section or through the application of a genetic algorithm, as will presently be elucidated. The GA works on a coding of the parameters (K_P, K_I, K_D) to be optimized rather than the parameters themselves. In this study Gray coding was used where each parameter was represented by 16 bits and a single individual or chromosome was generated by concatenating the coded parameter strings. In contrast to traditional stochastic search techniques the GA requires a population of initial approximations to the solution. Here 40 randomly selected individuals were used to initialize the algorithm. The GA then proceeds as follows:

***2.1 Determine fitness*:** The first step of the GA procedure is to evaluate each of the chromosomes and subsequently grade them. Each individual was evaluated by decoding the string to obtain the PID parameters which were then applied in a Simulink representation of the closed-loop system. The Simulink environment is chosen as it allows for the simple extension of the process model. On completion of the simulation the manipulated variable was automatically returned to the GA and the chosen error criterion used to evaluate the performance and assign a fitness value to that individual.

2.2 Selection: The five fittest individuals were automatically selected while the remainders were selected probabilistically, according to their fitness. This is an elitist strategy that ensures that the next generation's best will never degenerate and hence guarantees the asymptotic convergence of the GA.

2.3 Generation: Using the individuals selected above the next population is generated through a process of single-point cross-over and mutation. Mutation was applied with a very low probability – 0.001 per bit. Reproduction through the use of crossover and mutation ensures against total loss of any genes in the population by its ability to introduce any gene which may not have existed initially, or, may subsequently have been lost.

2.4 Repeat: This sequence was repeated until the algorithm was deemed to have converged (50 iterations). As was indicated previously the simulation and evaluation of the GA tuned PID controller was achieved using the MATLAB/Simulink environment. In addition the GA Toolbox [2] was utilized to aid the implementation of the GA.

III. TUNING THE PID ALGORITHM

One of the objectives of this paper is to highlight the usefulness of GA for PID controller design, by comparison with a conventionally tuned, but similarly optimized controller. Since tuning rules minimizing the error criteria of equation 2 abound for processes modeled on the premise of first-order lag plus dead-time, this structure was used to begin the evaluation. More specifically, the following process model was assumed

$$G_{P2}\left(s\right)=\frac{e^{-\tau s}}{s+1} \tag{3}$$

Where, $\tau = 0.2\,\text{sec}$. The design objective was to achieve the minimum ISE, IAE or ITAE servo response using (a) the GA approach and (b) existing tuning rules. These rules are derived by Zhuang and Atherton [15] for the ISE criterion and by Rovira at al.[11] for the IAE and ITAE criteria. For both cases the controller coefficients are listed in table 1 below, along with the total error and peak overshoot. The latter metric is defined as

$$P_{OS}\left(\phi\right)=\max\left|y\left(t\right)-y_{ss}\right| \tag{4}$$

Where y_{ss} is the steady state value of the output and ϕ is a vector of PID parameters, while the former is defined according to

$$E_{Total}\left(\phi\right)=\int_0^t J_{DO}\,dt \tag{5}$$

In (5), the design objective, J_{DO}, is either ISE, IAE or ITAE as defined by (2).

Table 1:– Servo optimized FOLPD

	Error Criterion	K_P	K_I	K_D	E_{Total}	$P_{OS}\left(\phi\right)$
Tuning Rule	IAE ISE ITAE	4.44 4.45 3.40	3.34 4.99 2.95	0.38 0.55 0.29	0.35 0.30 0.07	0.05 0.11 3.8e-3
GA	IAE ISE ITAE	4.39 5.59 3.70	3.04 3.62 2.87	0.34 0.50 0.27	0.35 0.28 0.07	0.03 0.18 3.7e-4

The regulator response,assuming a step disturbance applied at the process input, is also optimised. In this application the controller tuning algorithms proposed by Zhuang and Atherthon [15] for the ISE criterion, Shinskey [13] for the IAE criterion and Murril [9] for the ITAE criterion are compared with the GA based technique. The figures of merit defined by (4) and (5) are again utilized as the basis for comparison with the results listed in table 2.

Table 2:– Regulator optimized FOLPD

	Error Criterion	K_P	K_I	K_D	E_{Total}	$P_{OS}\,(\phi)$
Tuning Rule	IAE	6.32	18.5	0.49	0.07	0.19
	ISE	7.02	26.3	0.84	0.01	0.18
	ITAE	6.23	17.2	0.48	0.04	0.19
GA	IAE	6.07	16.7	0.50	0.07	0.19
	ISE	6.45	28.4	0.83	0.01	0.18
	ITAE	5.68	14.8	0.46	0.04	0.19

Following on from these examples, extensive computer based simulation has suggested that few real benefits accrue by applying GA to the task of optimizing PID controllers for FOLPD processes. Simple and highly accurate tuning rules for error criteria are in abundance, with results such as displayed in tables 1 and 2 being the norm rather than the exception.While the presumption of a first-order lag plus dead-time model is sufficient for many industrial processes there are many examples of where this supposition is too limiting. In such cases a higher order model, typically second-order system plus delay (SOSPD), is required with the model subsequently being utilized in the controller-tuning algorithm. Such systems are considerably more difficult to tune, not merely because of the more complex dynamics but also because the number of suitable tuning rules diminishes. Simple rules to minimize the IAE regulator response are proposed by Sinskey [13] for the PI control of a SOSPD based on the ultimate gain and ultimate cycle or the time-delay and process time constants. Similar rules for the ISE and ITAE regulator responses are conspicuous only by their absence. One possible reason for this is that simple, yet sufficiently general tuning rules for second-order or higher models are extremely difficult to arrive at. Many of the tuning relations are derived from extensive computer simulations, where the PID parameters are obtained by solving an optimization problem for various parameterizations of the plant model. The data resulting from repeated optimizations is then empirically fitted into correlated equations using, for example, a least squares method. This approach has led to the development of relatively simple relations for FOLPD models e.g. Zhuang & Atherton [15], but for more complex models tends to result in cumbersome expressions, e.g. Hwang [7], Huang *et al*. [6], the application of which are both tedious and error-prone.

The foregoing depicts one situation where the use of the GA based optimization is advantageous – the case where tuning rules do not exist, or – more likely – cannot be readily located. However, there are other reasons why the GA based technique might be preferred, principal among these is that the rules available for SOSPD may yield less accurate results than was found with their FOLPD counterparts. To demonstrate this consider the following second-order model

$$G_{SO}\left(s\right)=\frac{e^{-\tau s}}{(s+1)(0.1s+1)} \qquad (6)$$

Where, $\tau=1$sec.

A PI controller was designed, using the rules proposed by Shinskey [13], to minimize the IAE regulator response. The application of this tuning algorithm leads to the controller coefficients of table 3 and the associated response illustrated in figure 1. This figure depicts the controlled response to a unit step input which was applied at time, t=0, and also to a unit step load disturbance which occurred at time t=30.

In table 3 the controller gains which resulted when the GA was used to minimize the IAE regulator response are also tabulated. Clearly the true optimum is achieved by the GA technique.

Table 3: IAE regulator optimized SOSPD

	Genetic Algorithm	Tuning Rule
K_P	0.95	1.10
K_I	0.63	0.29
E_{Total}	1.67	3.28
$P_{OS}\,(\phi)$	0.70	0.70

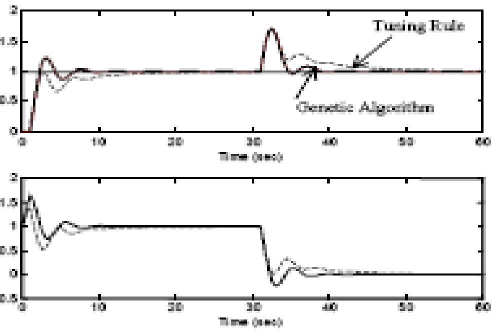

Figure 1: Minimum IAE regulator response for SOSPD

The real power of the GA methodology comes to the fore when tuning processes which are traditionally characterized as ‘difficult to tune’. Examples include, but are not limited to, the following:

$$G_{HO}(s)=\frac{e^{-0.5s}}{(s+1)(0.1s+1)(0.01s^2+1)(0.001s^3+1)},$$
$$G_{NMP}(s)=\frac{(-2s+1)e^{-0.5s}}{(s+1)^3}, G_{US}(s)=\frac{-e^{-0.5s}}{(-s+1)} \qquad (7)$$

Since the GA utilizes a Simulink scheme to evaluate the fitness of each gain set in the population, optimization of any of the above process models simply consists of modifying the **LTI System Block** in the Simulink scheme to reflect the current model. Beyond specifying the desired error criterion no further adjustments to the GA are required. This is in stark contrast to the use of conventional tuning rules where a laborious and perhaps unfruitful search for a suitable tuning algorithm must be undertaken. In the unlikely event of one being found, the user has no guarantee that the resultant parameters are the true optimum ones.

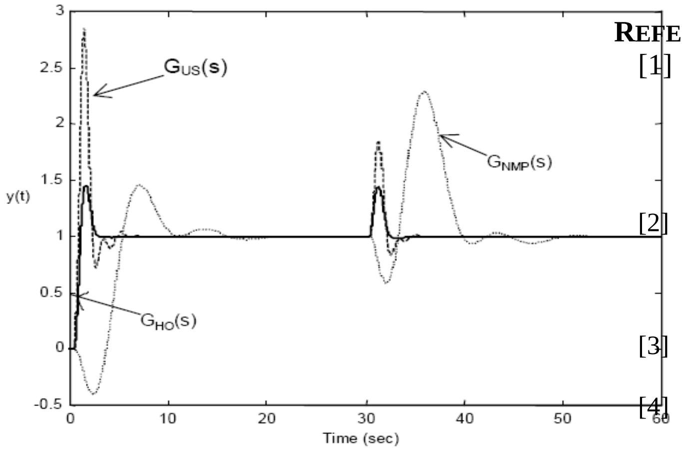

Figure 2: Min. ITAE regulator response tuned using GA

Figure 2 illustrates the performance of the PID controller when applied to each of the process models above. As before the reference is a unit step input and a unit step is applied to the process input at time t=30 sec. The PID parameters were tuned by utilizing the GA to minimize the ITAE regulator response. While the results are not ideal, they must be viewed within the context of the PID controller’s capabilities. Classic limitations regarding optimal servo v’s optimal regulator tracking are clearly visible for the open-loop unstable time-delayed system. However, considering the nature of the process the regulator response is quite acceptable. The performance of the high-order process, $G_{HO}(s)$, is good on both counts. The performance of the non-minimum phase time-delayed process is likewise poor on both counts. One possible reason for this is the use of a single criterion in the optimisation function.

IV. CONCLUSION

This paper presents a methodology for tuning PI and PID controllers using Genetic Algorithms and the inherent advantages of such a technique. Fundamentally, it was demonstrated that the GA technique is independent of the process model and consequently can be used to obtain consistent performance for a wide variety of process models.

The use of a GA avoids the necessity to maintain a ‘database’ of potentially useful rules and overcomes the difficulties associated with finding them in the first place. In addition the complexity of the approach is greatly reduced through the combination of MATLAB and the availability of quality source code and specialized Toolboxes. The generality of the technique, combined with its intuitiveness, fast convergence, modest processing requirements and perhaps most importantly minimal system specific information should result in increased use of this technique for both off-line and on-line controller running.

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