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Genetic Algorithm and Fuzzy Tuning PID Controller Applied on Speed Control System for Marine Diesel Engines

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Abstract: The degree of speed control of ship machinery effects on the economics and optimization of the machinery configuration and operation. All marine vessel ranging need some sort of speed control system to control and govern the speed of the marine diesel engines. The main focus of this study is to apply and comparative between two specific soft-computing techniques. Fuzzy logic controller and genetic algorithm to design and tuning of PID controller for applied on speed control system of marine diesel engine to get an output with better dynamic and static performance. Simulation results show that the response of system when using genetic algorithm is better and faster than when using fuzzy tuning PID controller.

Keywords: Genetic algorithm, marine diesel engine, self-tuning fuzzy PID controller, simulink

INTRODUCTION

Diesel engines have been widely used as power sources in practice. Diesel engine driven systems include automobiles, ships and backup power generating units (Jiang, 1993). Marine propulsion and traction engines are large diesel engines, which require accurate and robust speed control. The control of this large diesel engine accomplished through several components: the camshaft, the fuel injector and the governor. The camshaft provides the timing needed to properly to inject the fuel, the fuel injector provides the component that meters and injects the fuel and the governor regulates the amount of fuel that the injector is to inject. Together, these three major components ensure that the engine run at the desired speed (Zheng and Ching, 2003; Astrom and Hagglund, 1995).

As is well known, diesel engines are highly nonlinear devices and their characteristics vary as a function of power output, speed, ambient temperature, etc. Such nonlinear behaviour makes the design of engine control systems a very difficult task. Traditionally various forms of the PID controller have been used for speed control in diesel engines due to their simplicity. A great deal of research has also gone into providing more robust and optimal PID controllers through various tuning techniques including Zeigler Nichols, Cohen-Coon and the Chien, Hrones and Reswick (CHR) methods (Astrom and Hagglund, 1995), although in practice these techniques usually only provide a starting point for further manual tuning by experienced engineers (Lynch *et al*., 2005). Otherwise, all researchers have shown that Fuzzy Logic and Fuzzy PID controllers can provide improved control and robustness over traditional PID (Astrom and Hagglund, 1995; Golob and Tovornik, 1999). As a result FLCs have found use in the speed control of various marine/traction engines (Amer *et al*., 2004; Bose *et al*., 1997).

The fuzzy control systems are rule based systems, which a based on expert knowledge. The fuzzy theory based on fuzzy sets and fuzzy algorithms provides a general method of expressing linguistic rules so that they may be processed quickly by a computer. This study presents a development of speed and power control of marine diesel engine by using a self-tuning fuzzy PID controller to overcome the appearance of nonlinearities and uncertainties in the systems. The self-tuning fuzzy PID controller is the combination of a classical PID and fuzzy controller. The mathematical model of the diesel engine is also done by using System Identification technique.

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METHODOLOGY

Mathematical model of marine diesel engine system: The actuator of marine diesel engine is a direct current servomotor, which is used for the control of diesel engine governor and it is a typical second order system. The transfer function is described as (Xu and He, 2008):

$$\frac{h(S)}{H_g} = \frac{\omega_{nd}^2}{S^2 + 2\xi_{nd}\omega_{nd}S + \omega_{nd}^2} \tag{1}$$

Hg(S) = The link of given opening extent of fuel oil throttle
H(S) = Link of actual opening extent of fuel oil throttle
ω_{nd} = The natural oscillation frequency of actuator
ξ_{nd} = The damping coefficient of actuator. And its value is between 0.4 and 0.8

The differential equation of marine diesel engine without turbocharger is:

$$T_a \frac{dy(t)}{dt} - y(t) = \eta(t - \tau) - \lambda(t) \tag{2}$$

where, y(t) is the rotation speed of marine diesel engine, $\eta(t)$ is the link of opening extent of fuel oil throttle, $\lambda(t)$ is disturbance, T_a is the time constant of marine diesel engine and τ is the link of time delay of fuel throttle opening. And the corresponding Laplace's equation is described as (Xu and He, 2008):

$$\frac{Y(S)}{e^{-\tau S}H(S) - \lambda(S)} = \frac{1}{T_a S + 1} \tag{3}$$

where, Y(S) is the Laplace transform of y(t), H(S) is the Laplace transform of $\eta(t)$ and $\lambda(S)$ is the Laplace transform of $\lambda(t)$.

For the same reason, the transfer function of marine diesel engine with turbocharger is described as:

$$\frac{Y(S)}{e^{-\tau S}H(S) - \lambda(S)} = \frac{\varpi_n^2}{S^2 + 2\xi_n\varpi_n S + \varpi_n^2} \tag{4}$$

where, ϖ_n is the non-damping natural frequency of marine diesel engine, ξ_n is the damping factor of marine diesel engine.

Therefore, the transfer function of a whole marine diesel engine system without disturbance is obtained. Equation (5) is the transfer function of marine diesel engine with a turbocharger:

$$\frac{Y(S)}{H_g} = \frac{\omega_{nd}^2}{S^2 + 2\xi_{nd} + \omega_{nd}S + \omega_{nd}^2} \cdot \frac{\varpi_n^2}{S^2 + 2\xi_n + \varpi_n S + \varpi_n^2} \cdot e^{-\tau s} \tag{5}$$

Design and structure of GA tunning PID controller: Genetic algorithm is a robust optimization technique based on natural selection. The basic objective of GA is to optimize fitness function. In genetic algorithms, the term chromosome typically refers to a candidate solution to a problem. Gas have been proved capable of solving large scale or complex problems and they are commonly used as search mechanism when direct search in impossible (Houck *et al*., 1996).

The advantages of GA over traditionally parameter optimisation techniques are: GA do not need gradient information of the search space (which usually is not available for the designer anyway) as opposed to classical gradient search methods

- GA do not require any a priori information about the search space, i.e., there is no need for choosing an appropriate starting point since the starting points are chosen at random
- GA are able to avoid local minima because they operate over a population of points, as opposed to conventional optimisation techniques that tackle one point at a time
- GA perform a guided search, as opposed to enumerative schemes that set a grid over the search space and search all the points in the grid

The steps involved in creating and implementing a genetic algorithm are as follows:

- Generate an initial, random population of individuals for a fixed size (according to conventional methods K_P, T_I, T_D ranges declared)
- Evaluate their fitness (to minimize integral square error)
- Select the fittest members of the population
- Reproduce using a probabilistic method (e.g., roulette wheel)

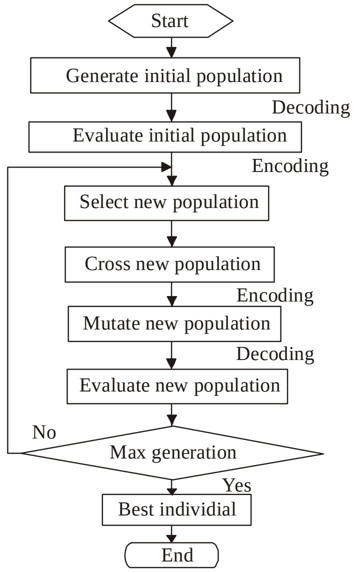


Fig. 1: Flow diagram of genetic algorithm

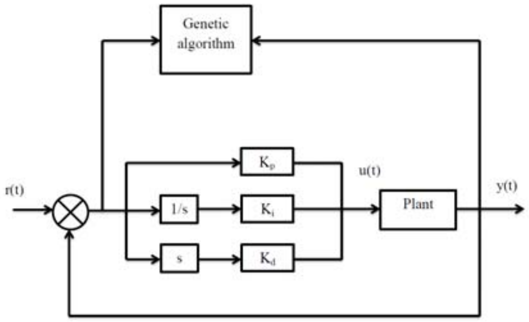


Fig. 2: Structure of GA-PID controller

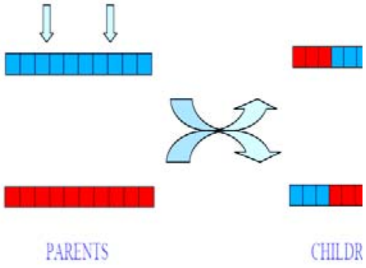


Fig. 3: Two points crossover mechanism

- Implement crossover operation on the reproduced chromosomes (choosing probabilistically both the crossover site and the mates)
- Execute mutation operation with low probability
- Repeat step 2 until a predefined convergence criterion is met

The summary of the process will be described in Fig. 1.

Structure and design of GA-PID controller: The structure of a control system with GA-PID as a controller as shown in the Fig. 2. It consists of a conventional PID controller with its parameter optimized by genetic algorithm. The initial population of size N is generated randomly to start the optimization process. The next generation can be obtained through the genetic operators. The genetic opearators are the most important features of genetic algorithm.

Genetic operators:

Selection: There are many mating techniques available to pick two parent chromosomes to produce child chromosome.

Roulette wheel selection: Parents are selected according to their fitness. The better chromosomes are, the more chances to be selected they have. Imagine a roulette wheel where are placed all chromosomes in the population, every have its place big accordingly to its fitness function (Goldberg, 1989).

Rank selection: Rank selection first ranks the population and then every chromosome receives fitness from this ranking. The worst will have fitness 1, the second worst 2 etc and the best will have fitness P (where P is the number of chromosomes in population). After this all the chromosomes have a chance to be selected (Jain and Jain, 1997).

Crossover: The crossover operator combines the features of two parents to create new solutions. One or several crossover points are selected at random on each parent and then, complementary fractions from the two parents are spliced together to form a new chromosome (Back, 1996; Liu *et al*., 2008; Arumugam *et al*., 2005; Michalewicz, 1992). In Fig. 3, two points crossover as shown blow.

Variations in the crossover operator in the literature include not only modifications to the operator itself but also to its probability of occurrence.

Mutation: After a crossover is performed, mutation takes place. This is to parent falling all solutions in population into a local optimum of solved problem. Mutation changes randomly the new offspring (children). There are many types of accomplishing mutation (binary mutation and real mutation). Real mutation is used according to the following equation:

$$d_i^{/} = \{r(L_0, U_0) \text{ If } z^{/} \le P_m,\ d_i \text{ otherwise} \qquad (6)$$

where,

$z^{/}$ = Random number.
$r(L_0, U_0)$ = Random number with limited range (L_0, U_0).

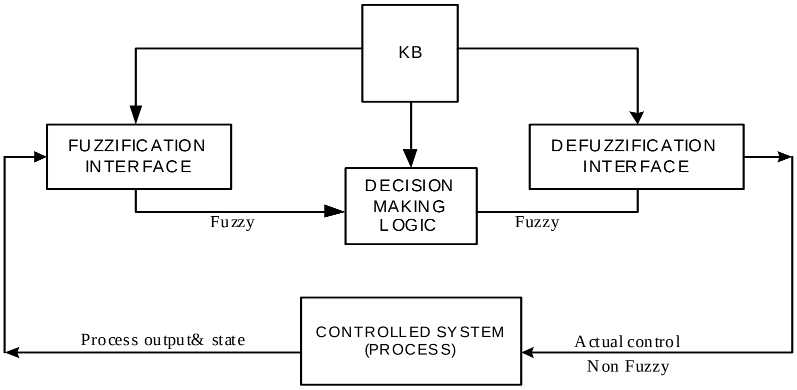


Fig. 4: Basic configuration of Fuzzy Logic Controller (FLC)

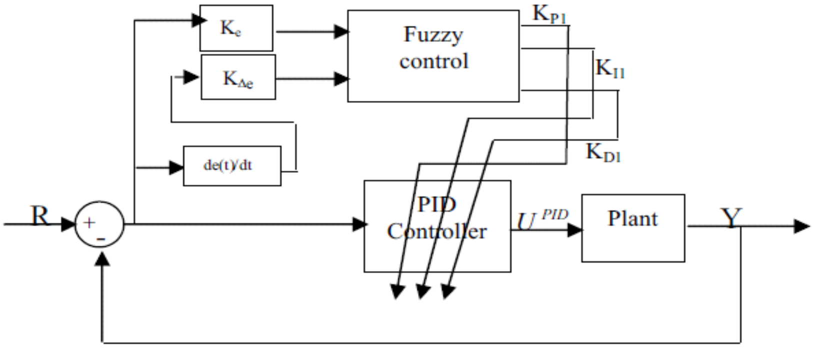


Fig. 5: Self-tuning fuzzy PID controller

d_i = The value of genetic before mutation
$d_i^{/}$ = The value of genetic after mutation
P_m = Probability of mutation equal to (0.5-1%)

Proportional Integral Derivative (PID) controller: The basic structure of the PID controller is described in the flowing equation:

$$G(s) = K_p + K_I \frac{1}{2} + K_D s \tag{7}$$

where,
K_P = The proportional gain
K_I = The integral gain
K_D = The derivative gain

The performance specifications of the systems such as rise time, overshoot, settling time and error steady state can be improved by tuning value of parameters K_P, K_I and K_D of the PID controller, because each component has it's own special purposes.

The design algorithm of PID controller in this study is to adjust the K_P, K_I and K_D parameters online trough fuzzy inference based on the error e(t) between desired position set point and the output and the derivation of error de(t) to make the controlled object attain the good dynamic and static performances.

Design and structure of the self-tuning fuzzy PID controller: Figure 4 shows the basic configuration of a Fuzzy Logic Controller, which comprises four principal components: a fuzzification interface, a Knowledge base, decision making logic and a defuzzification interface (Chuen, 1990).

The self-tuning of the PID controller refers to finding the fuzzy relationship between the three parameters of PID, K_P, K_I and K_D and "e" and "de" and according to the principle of fuzzy control modifying the three parameters in order to meet different requirements for control parameters when "e" and "de" are different and making the control object produce a good dynamic and static performance. The structure of the self-tuning fuzzy PID controller as shown in Fig. 5.

Fuzzifier and rule-base formation: The fuzzifier transforms the measured crisp input X to the fuzzy sets defines in Vx, where Vx is characterized by a membership function $\mu f : Vx \rightarrow [0, 1]$ and is labeled by a linguistic term such as "Negative Big (NB)," "Negative Medium (NM)," "Negative Small (NS)," "Zero (Z)," "Positive Small (PS)," "Positive Medium (PM)" and "Positive Big (PB)."

Usually, the fuzzifier may transform the measured value into a fuzzy value (i.e., a fuzzy number) as an input fact.

Assume that all the control rules have the same form, each of which is given by:

IF situation THEN action (8)

Stating a local relationship between the current control situation and the corresponding control action suggested by the expert.

e(t) and de(t) are selected as input variables of the fuzzy inference and defined as two variables representing the situation. K'P, K'I and K'D are selected as output of the fuzzy system and defined as a variable representing the action. Notice that variables for e(t), de(t), K'_P, K'_I and K'_D assume linguistic terms as their values such as positive-big, negative-small and zero, etc. Thus, rule (7) may be formally expressed for our fuzzy system by Rule i: If e(t) is Ai and de(t) is Bi then:

$$K'_P = Ci \text{ and } K'_I = Di \text{ and } K'_D = Fi \quad (9)$$

where, Ai, Bi, Ci, Di and Fi are linguistic terms which in this study can be NL, NM, NS, Z, PS, PL and PB, respectively.

The rules designed are based on the characteristic of the marine diesel engine and properties of the PID controller. Therefore, based on these principles, a set of rules have been derived and are summarized in Table 1:

$$k_p = k'_p + \Delta k_p$$

$$k_i = k'_i + \Delta k_i$$

$$k_d = k'_d + \Delta k_d$$

Here K'_p, K'_i and K'_d refer to the previous value of the PID parameters whereas K_P, K_i and K_d refers to the new corrected values of the parameters after a particular tuning step was completed.

Table 1: Rule base of the fuzzy logic controller (k_p, k_i, k_d)

E\ec	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	Z	Z
	NB	NB	NM	NM	NS	Z	Z
	PS	NS	NB	NB	NB	NM	PS
NM	PB	PB	PM	PS	PS	Z	NS
	NB	PB	NM	NS	NS	Z	Z
	PS	NS	NB	NM	NM	NS	Z
NS	PM	PM	PM	PS	Z	NS	NS
	NB	NM	NS	NS	Z	PS	PS
	Z	NS	NM	NM	NS	NS	Z
Z	PM	PM	PS	Z	NS	NM	NM
	NM	NM	NS	Z	PS	PM	PM
	Z	NS	NS	NS	NS	NS	Z
PS	PS	PS	Z	NS	NS	NM	NM
	NM	NS	Z	PS	PS	PM	PB
	Z	Z	Z	Z	Z	Z	Z
PM	PS	Z	NS	NM	NM	NM	NB
	Z	Z	PS	PS	PM	PB	PB
	PB	PS	PS	PS	PS	PS	PB
PB	Z	Z	NM	NM	NM	NB	NB
	Z	Z	PS	PM	PM	PB	PB
	PB	PM	PM	PM	PS	PS	PB

For simplicity, the same universe of discourse and the same fuzzy set are adopted for fuzzy input/output variables. The membership functions of isosceles triangles are used as the fuzzification function which is used to convert a crisp value into a fuzzy singleton within the universe of discourse.

Fuzzy inference engine and defuzzifier: In a fuzzy inference engine, fuzzy logic principles are used to synthesize the fuzzy IF-THEN rules in the rule base into a mapping from the family of fuzzy subsets in $V \times V$ to the family of fuzzy subsets in W. Mamdani model is applied as structure of fuzzy inference with some modification to obtain the best value for K_P, K_I and K_D. Fuzzy inference block of the controller design as shown in Fig. 6.

In the approximate reasoning, the max-min compositional operators are often adopted. The defuzzifier performs a mapping from fuzzy subsets in W to a crisp point y W. Here, the center average method is used as the defuzzifier, which is defined as in Eq. (10):

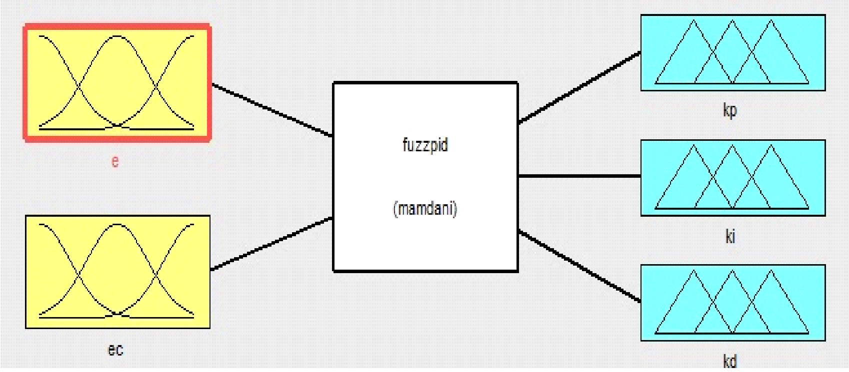


Fig. 6: Fuzzy inference block

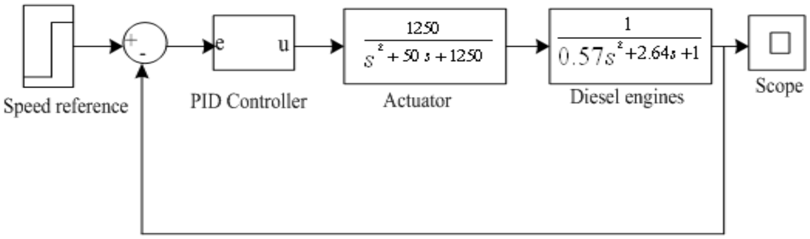


Fig. 7: Simulink model of marine diesel

$$T_i = \frac{\sum_{l=1}^{N} T_i^l\left(\mu_{rs}\left(T_i^l\right)\right)}{\sum_{l=1}^{N}\left(\mu_{rs}\left(T_i^l\right)\right)} \quad (10)$$

where, T_i^l is the center of the fuzzy subset and μ_{rs} is the membership function of the output variable.

SIMULATION RESULTS AND DISCUSSION

The Simulink of MATLAB software is used to the whole system simulation. The parameters of marine diesel engine model are $\omega_{nd} = 35.4$, $\xi_{nd} = 0.707$, $\varpi_n = 1.324$, $\xi_n = 0.707$ and $\tau = 0.24$, so the model of our diesel engine become as in Eq. (11):

$$\frac{Y(S)}{H_g} = \frac{1250}{S^2 + 50S + 12501} \cdot \frac{1}{0.57S^2 + 2.64S + 1} \cdot e^{-0.24S} \quad (11)$$

Therefore, the closed loop controller for speed control of diesel engine, after ignoring $e^{-0.24S}$, is as shown in Fig. 7.

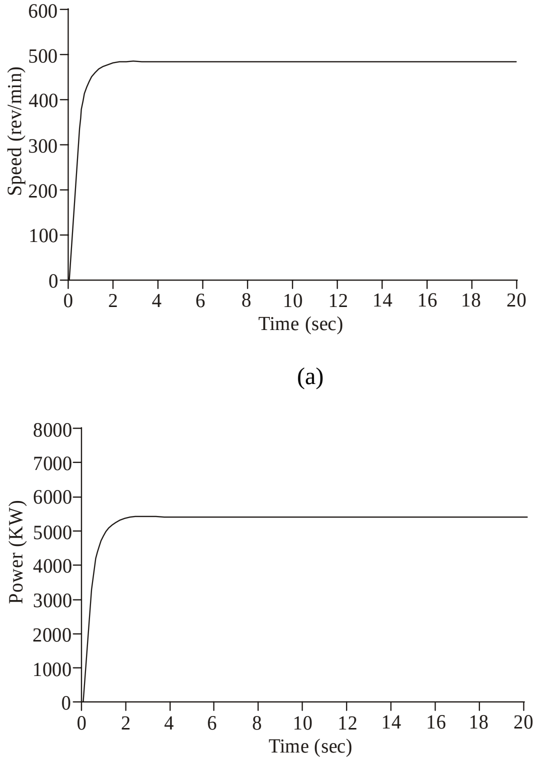
The transfer function describing the plant for our example (Fig. 7) is as follows:
For Actuator

$$G(s) = \frac{1250}{S^s + 50s + 1250} \quad (12)$$

For diesel engine:

$$G(s) = \frac{1}{0.56_S{}^2 + 2.64s + 1} \quad (13)$$

Ship with the host 12E390V, the main technical parameters is: Bore = 390 mm, rated speed = 480 rev/min, output power = 5292 kw. For genetic algorithm the maximum of 100 generations are used. The population size, crossover probability and mutation probability are chosen as 30, 0.75 and 0.02, respectively. The code implementing the algorithm in this study takes about 3-5 min to run on MATLAB with the full 100 generations of the GA. After 100 generations we obtained the optimal parameters of PID controller; $K_p = 13.8339$, $K_i = 2.1971$, $K_d = 3.8141$, Fig. 4. Shows that the settling time is less and the system is almost no overshoot, Fig. 8.



(a)

(b)

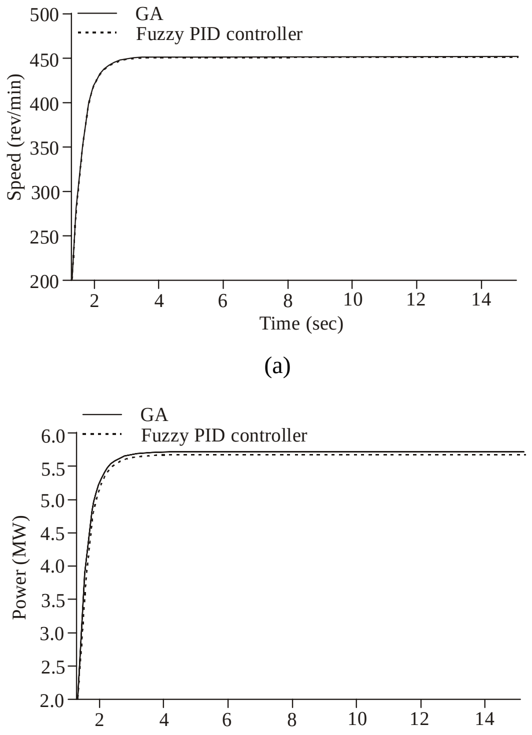
Fig. 8: Simulation results of diesel engine after application of GA

The response of the fuzzy self-tuning PID controller is obtained using Matlab Program. A two-input and three-output fuzzy controller is created and the membership functions and fuzzy rules are determined.

The simulation results as obtained by Matlab Program as shown in Fig. 9.

From Fig. 9, we illustrate the response of the systems is faster by applied GA, continues line (-) present tuning of PID using GA and dashed line (……) present Fuzzy tuning of PID.

According to the Simulation results shown in Fig. 9, we shows that the settling time is less and the system is



(a)

(b)

Fig. 9: Simulation results of diesel engine using PID fuzzy logic controller comparing with genetic algorithm

almost no overshoot, it can be concluded that the application of Genetic Algorithm (GA) to the rotation speed regulation of marine diesel engine is able to improve the transient process of system performance and The response of the system was also faster by using GA.

CONCLUSION

In this study, we design and tuning methods for PID controller using fuzzy logic and Genetic algorithm. Simulation was carried out using Matlab Program to get the output response of the system to a step input. According to the profiling results, the application of fuzzy logic to the PID controller imparted it is the ability to tune itself while operating on-line. Similarly, Genetic algorithm enabled the PID controller to get an output which is robust and has faster response than fuzzy logic controller.

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REFERENCES

Amer, A., S. Eweda and M. Eweda, 2004. Speed control of marine diesel engine using fuzzy approach part (II). Proceedings of the 14th International Conference on Computer Theory and Applications.

Arumugam, M.S., M.V.C. Rao and Palaniappan, 2005. New hybrid genetic operators for real coded genetic algorithm to compute optimal control of aclass of hybrid systems. Appl. Soft Comput. J., 6(1): 38-52.

Astrom, K. and T. Hagglund, 1995. PID Controllers: Theory, Design and Tuning. Instrument Society, America.

Back, T., 1996. Evolutionary Algorithms in Theory and Practice. Oxford University Press, New York.

Bose, B., M. Simoes and R. Spiegel, 1997. Fuzzy logic based intelligent control of a variable speed cage machine wind generation System. IEEE T. Power Electr., 12: 87-95.

Chuen, C.L., 1990. Fuzzy logic in control systems: Fuzzy logic controller-Part II. IEEE T. Syst. Man Cyb., 20(2): 419-435.

Golob, L. and B. Tovornik, 1999. Real time fuzzy PID Controller Structures: Computational Intelligence and Applications. World Scientific and Engineering Society Press, Greece, pp: 205-210.

Goldberg, D.E., 1989. Genetic Algorithms in Search, Optimization and Machine Learning. Addison-Wesley, Boston, MA, USA.

Houck, C.R., J. Joines and M. Kay, 1996. A genetic algorithm for function optimization: A MATLAB implementation. ACM Trans. Math. Software, DOI: 10.1.1.22.4413

Jiang, J., 1993. Optimal gain scheduling controller for a diesel engine. IEEE Conference on Control Applications, Vancouve, British Columbia, Canda, September 13-16.

Jain, L.C. and R.K. Jain, 1997. Hybrid Intelligent Engineering Systems. World Scientific Publishing, Singapore.

Lynch, C., H. Hagras and V. Callaghan, 2005. Embedded type-2 FLC for real-time speed control of marine and traction diesel engines. 2005 IEEE International Conference on Fuzzy Systems, pp: 347-352.

Liu, S., G.Y. Li, J. Song and T.Y. Sun, 2008. Research on optimization efficiency of genetic algorithms. 2008 2nd International Symposium on Systems and Control in Aerospace and Astronautics, ISSCAA 2008.

Michalewicz, Z., 1992. Genetic Algorithms + Data Structure = Evolution Programs. Springer-Verlag, New York.

Xu, X.Y. and M. He, 2008. On adaptive control applied to speed regulation of marine diesel engine. Proceedings of the 27th Chinese Control Conference, July 16-18, Kunming, Yunnan, China, pp: 56-59.

Zheng, Y., G. Ming and I.L. Ching, 2003. Non linear dynamics and control of chaos for a rotational machine with a hexagonal centrifugal governor with a spring. J. Sound Vib., 262: 845-864.