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AN IMPROVED ARTIFICIAL FISH SWARM ALGORITHM (AFSA) FOR PID CONTROLLER PARAMETER TUNING

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ABSTRACT

PID controllers find a range of applications, especially in the process industry. This paper presents the performance of weighted Artificial Fish Swarm Algorithm (AFSA) algorithm for PID parameter tuning when applied to a DC motor. The AFSA algorithm is modelled after the preying, swarming and chasing behaviour of fish in search for food. The standard AFSA's challenge of being stuck at local minima has reduced its effectiveness. In the paper, we employed a modified AFSA to tune the parameters; Kp,Ki,Kd of a PID controller. A comparison of the standard and modified AFSA PID controller parameters indicate the superior performance of the modified AFSA tuned PID controller for a DC motor application, as represented by the response to a step input function on 4 of the 5 key performance parameters.

1. INTRODUCTION

Design of control system employing the simple but robust Proportional, Integral and Derivative (PID) controller; also called a three-modecontroller, is often a search for optimized values of the Proportional, Integral and Derivative parameters (PID) of the controller, using any practical strategy [1, 2]. Conventional tuning; a tedious approach, often fails to achieve satisfactory results, because industrial plants are often burdened with problems of high orders, time delays and nonlinearities [2-4].

Among the performance metric used for PID controller parameter tuning, the criterion to keep the controlled variable response close to the desired closed-loop response has gained widespread acceptance in the process industries because of its simplicity, robustness, and successful practical applications. The architectural simplicity, the availability of a large number of highly efficient, reliable, and cost-effective commercial PID control modules, and their acceptance from the operators are among the reasons for their popularity [5].

The performance of a PID controller depend largely on the designer's choice of proportional gain (K_p), integral gain (K_i) and derivative gain (K_d). The proportional controller gain K_p, has the effect of reducing the rise time and steady state error, but never eliminate the error. The integral controller gain K_i will have the effect of eliminating the steady state error, however, it may make the transient response worse. The derivative controller gain, K_d will have the effect of increasing the stability of the system, reducing the overshoot and improving the transient response [6, 7]. The K_p, K_i, K_d need to be selected optimally for a closed loop system to give a desired closed-loop response. The selection of these controller gains has to be performed as fast as possible for each given system in order to prevent system failure [8-10].

The determination of the gains of a PID controller is called parameter tuning and the classic method, requiring minimal analysis is the manual parameter tuning which involves trial and error, observations and experience on an actual system or by simulation [11].

Analytical methods were subsequently developed e.g. the Ziegler-Nichols tuning method [12]. With recent advances in computational power and associated algorithms, several attempts have been made to deploy new approaches for PID parameter tuning.

Computational intelligent algorithms like Particle Swarm Optimization (PSO), Genetic Algorithm (GA) [13], Ant Colony Optimization (ACO) [14], Fire-Fly Algorithm (FFA) [15], Bacterial Foraging Algorithm (BFA) [16], Cultural Algorithm (CA) [17], Artificial Bee Colony (ABC)[18] and Artificial Fish Swarm Algorithm (AFSA)[19, 20] possess the capabilities of solving nonlinear high dimensional and complex problems with little or no information about the problem.

This research presents an intelligent optimized PID controller parameter selection using an improved AFSA.

The optimized PID controller is employed for the position control of a DC motor, which is one of the widely used test beds for control systems.

2. LITERATURE REVIEW

Some literature related to AFSA and similar algorithms, its improvement and limitations, and its application in PID tuning are discussed in this section.

The authors in [21] presented a parameter tuning of robust PID controller using artificial fish swarm optimization algorithm. The analysis of the robust PID controller based on min-max principle was carried out. A method based on AFSA was developed to address the non-linear nature of the conventional method. Simulation results showed that the proposed technique can tune the parameters of robust PID controllers quickly, and the controller exhibited good control performance. However, the constant effects of parameters associated with AFSA were not considered in this work. In [22] the optimization of PID controller parameters using the artificial fish swarm optimization algorithm was proposed. The preying, swarming and chasing behaviours of AFSA were used to model the proposed controller which was applied to a single loop control system; a vehicle ramp control system. The simulation results showed that the optimization algorithm is valid and effective.

Reference [23] presented a comparative study of artificial intelligence based optimization methods to optimize the gains of PID controller for Automatic Voltage Regulator (AVR) system. The dynamic performance of the controller which was optimized by the ABC algorithm and compared with Particle Swarm Optimization (PSO) and others. The maximum overshoots and the settling times of the control system which was optimized with ABC algorithm were as small compared to the PSO algorithm. The study indicated that the ABC algorithm showed a better performance than other population-based optimization algorithms.

[24] implemented a novel optimal PID tuning,based on ABC algorithm for a 2 DOF robotic manipulator. The ABC algorithm approach was introduced in PID tuning and online tuning as a novel technique for optimum adaptive control in the pesensce of a distrubance. The PID parameters were designed using the proposed dynamic inertia weight artificial bee colony algorithm. At the end, ABC was efficient and robust for PID control tuning and optimizes the movement of the robot's end effector for a robust perfromance in the presence of external disturbances.

[25] developed an efficient method based on ABC meta-heuristic for PID controller tuning. The performance indices and time delays were controlled by PID controller with optimum gains. The study clearly demonstrated that the employed method outperformed other techniques such as fuzzy modelling and GA with minimum steady state error, overshoot and settling time. The individual behaviour of a bee which could result into fitness stagnation and poor convergence of ABC algorithm for optimization efficiency was not considered in this research.

2.1 PID Controller

The proportional-integral-derivative controller is one of the most widely used controllers in process industries. The popularity of the PID controller can be attributed to their good performance in a wide range of operating conditions, simplicity with few parameters and ease of implementation; which provides a good performance despite variations in the plant's parameters [26].

In PID controller design, proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is utilized to adjust the process via a control element. By tuning the three constants in the PID controller algorithm, the controller can provide control actions designed for specific process requirements [27]. The simple structure of a plant-PID controller design is given in Fig 1.

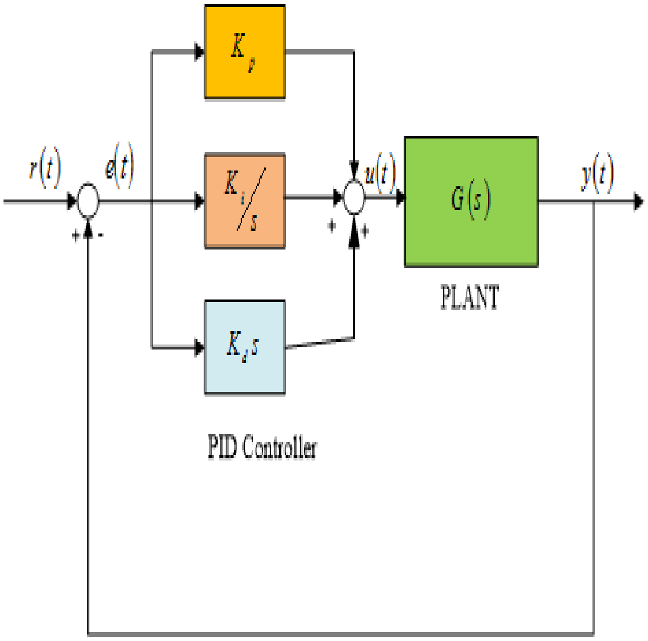

Fig. 1. PID controller and Plant System

A typical closed loop system controlled by PID controller is given in Fig.1.The *r(t)* is the reference input to the controller, *u(t)* is the controller output and *e(t)* is a measured error (which is the difference between *r(t)*and *y(t)*). PID is the controller whose parameters (K_p, K_i, K_d) needs to be determined optimally. While the plant is the system that needs to be controlled which will be a DC motor in the case of this study.

In practice, the output of a PID controller is given by [27]:

$$u(t) = K_p \times e(t) + K_i \times \int_0^t e(t)dt + K_d \times \frac{de(t)}{dt} \quad (1)$$

K_i and K_d can be written as:

$$K_d = K_p \times T_d, \qquad K_i = K_p \times \frac{1}{T_i}$$

$$u(t) = K_p\left[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}\right] \quad (2)$$

$$G(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{S} + K_d \quad (3)$$

$$S = K_p\left(1 + \frac{1}{T_i S} + T_d S\right) \quad (4)$$

In equations (1) - (4), $K_p$is the proportional tuning constant, $K_i$is the integral tuning constant,$K_d$is the derivative tuning constant, T_i is the integral time, T_d is the derivative time, G(s) is the transfer function of the system and error is the difference between the set-point and the process variable at a time.In this paper, the tuning constants suitable for the optimal control of a DC motor's position are optimized using the developed improved artificial fish swarm optimization algorithm.

2.2 D.C motors

Direct Current (DC) motors, mostly known as DC-motors are widely used control platforms for validating the performance of control algorithms for the PID controller. The adjustable speed, good speed regulation, position control, frequent starting, braking and reversing are among the reason for their widely acceptance [20, 28]. There are numerous applications where control of speed is required, as in rolling mills, cranes, hoists, elevators, machine tools, transit system and locomotive drives. These applications may demand high-speed control accuracy and good dynamic responses. To reduce the loading effect and minimize time delay, PID controllers are required. The position of the motor is the rotation of the motor shaft or the degree of the rotation, which is to be controlled by giving the feedback to the controller, which rectifies the controlled output to achieve the desired position.

In the DC motor, the angular velocity ω(t) is controlled by the input voltage V_a.The equivalent block representation of the DC motor is given in Fig. 2.

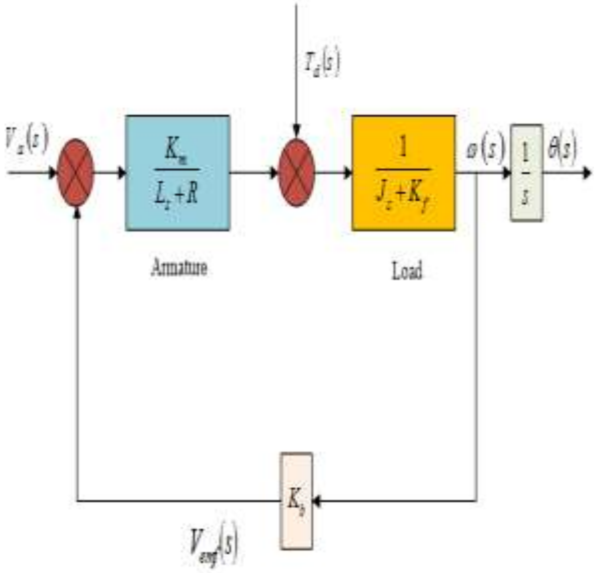

Fig.2. Mathematical model of DC motor

The equivalent transfer function of the DC motor model of Fig. 2 is derived as follows [29].

$$G(s) = \frac{\theta(s)}{V_a(s)} = \frac{K_m}{s\left[(L_s + R)(J_s + K_f) + K_b K_m\right]} \quad (5)$$

where $K_b = K_m$ (Back EMF constant), K_f is the frictional force.

The objective function which was optimized using the improved algorithm, is given as [30]:

$$f(t) = \int_0^\infty |r(t) - y(t)|dt = \int_0^\infty |e(t)|dt$$

shows a time domain representation of integral of absolute error. An optimized value of the PID controller gains can obtain a good system behavior capable of minimizing the performance criteria in the time domain.

3. METHOD

3.1 Improved Artificial Fish Swarm Algorithm

In order to address problem such as blindness of search space associated with the standard AFSA, this research introduces an iterative behavior based global best information to penalize the constant effect of guiding parameters (such as: visual distance and step size). The modified preying, swarming and chasing behaviors of AFSA given in Fig 3, are discussed in [19, 20].

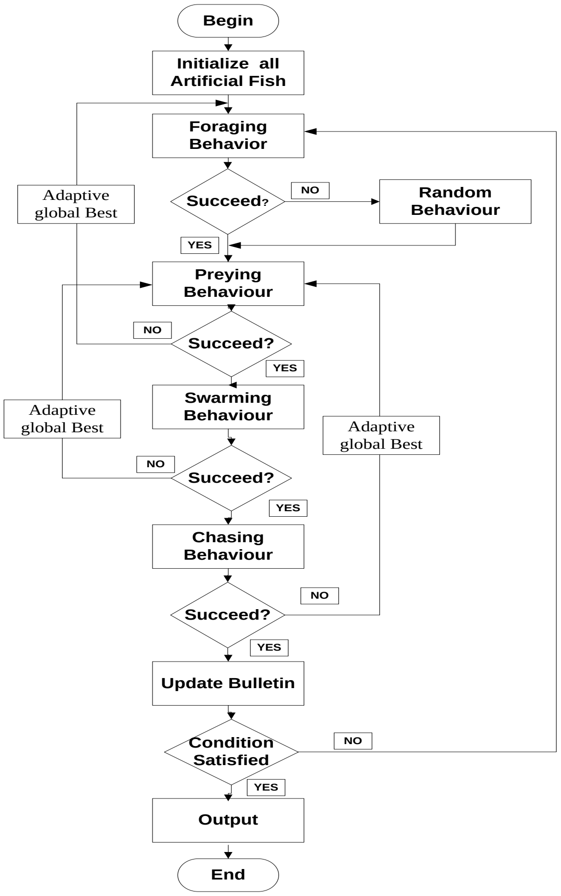

Fig 3: Flow Chart of Modified AFSA

Table 1: Adopted values for the Physical Parameters

SN	Parameters	Values
1	Moment of inertial of the rotor (J)	$0.01kg.m^2s^{-2}$
2	Damping ratio of the mechanical system (b)	0.1 Nms
3	Electromotive force constant ($K=K_e=K_t$)	0.01Nm/Amp
4	Electric Resistance (R)	1 ohm
5	Electric inductance (L)	0.5 H
6	Input (V)	Source Voltage
7	Output	Position of shaft

4. RESULTS

Based on the approach discussed previously, the PID parameter gains obtained using the standard AFSA and those obtained through the modified AFSA are shown in Table2.

Table 2: Obtained PID Gains Using the Standard AFSA Algorithm vs Modified AFSA

SN	Parameter	Standard AFSA	Modified AFSA
1	Ki	0.0423	3.351
2	Kp	8.9730	3.042
3	Kd	0.1892	0.03895

The position response of the DC motor with PID tuning using the standard AFSA strategy is given in Fig 5. The performance of the AFSA and Modified AFSA based PID controller is listed in Table 2. The step response of the open loop and AFSA based PID control of the DC motor is given in Fig. 4 and Fig 5, respectively.

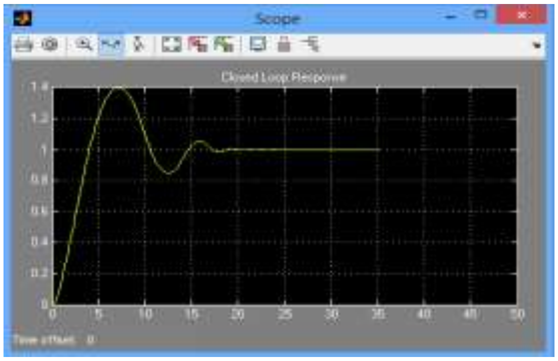

Fig. 4: Open loop response

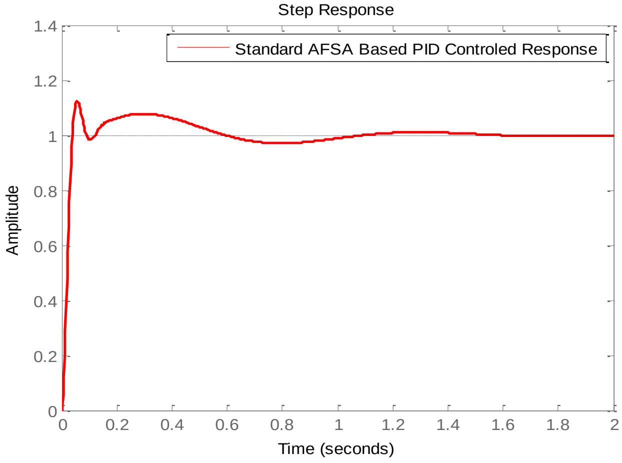

Fig. 5: AFSA based Response

The position response of the DC motor PID tuning using the modified AFSA PID controller is giving in the Fig 6. In order to show the effectiveness of the proposed method, a comparison is made with the designed PID controller using the standard AFSA. The comparative result is presented in Table 3.

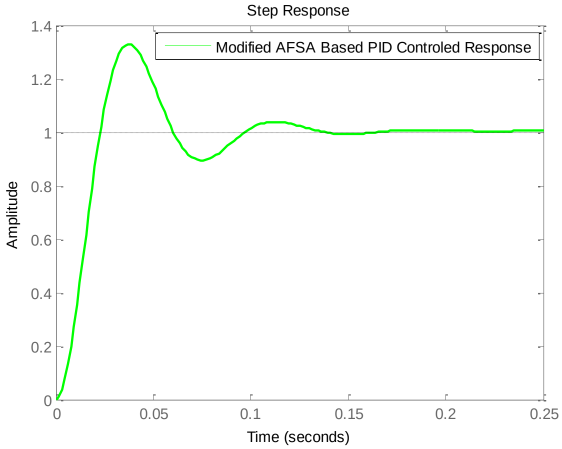

Fig. 6: Modified AFSA based Response

From Figure 4.7 and Figure 4.8, it can be said that, the later settles the system faster than the former. This is expected due to the introduction of the global best information. The following table shows the comparative analysis of the two algorithms.

Table 3. Performance of the Proposed Controller Methods

SN	Performance Measure	Standard AFSA PID	Modified AFSA PID
1	RiseTime	0.0263	0.0154
2	SettlingTime	0.9329	0.1265
3	SettlingMin	0.9579	0.8949
4	SettlingMax	1.1241	1.3290
5	Overshoot	12.4067	14.9046
6	SteadyState Error	0	0
7	PeakTime	0.0564	0.0371

Table 3 shows that, the dynamic quality of step response obtained using the modified AFSA is optimized in terms of settling time and rise time while the standard AFSA method shows a slightly better performance in terms of the overshoot. However, the overshoot in both cases are within the design specification of being < 20%.

3. CONCLUSION

The study highlights the improved performance of a PID controller whose parameters were tuned using an improved AFSA strategy, on 4 of the 5 key performance measures of the controller; rise time, settling time, overshoot and peak time, when applied to the control of a DC motor. The proposed AFSA strategy is expected to find applications in other control or optimization areas.

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