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Modified Approach of Firefly Algorithm for Non-Minimum Phase Systems

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Abstract

Background/Objectives: When conventional PI controllers are used to control non linear processes, the controllers must be tuned very conservatively in order to provide stable behavior over the range of operating conditions. The conservative controller tuning can result in serious degradation of control system performance. Therefore it is necessary to go for optimizing techniques. **Methods/Statistical Analysis**: In this paper a modified approach of firefly algorithm is compared with the firefly algorithm. The modified approach is derived from the impact of the tuning parameters over the objective function peak overshoot. This modified approach using firefly algorithm is validated through simulation results. The transfer functions employed here are stable second order system, second order with inverse response and higher order systems, particularly non minimum phase systems. **Findings:** For the stable second order systems and for the higher order non minimum phase systems the modified approach based on firefly algorithm outperforms the existing firefly algorithm. The modified approach not only reduces the considered objective functions such as PO, ITAE but also the other functions such as ITAE and settling time. **Application/Improvements:** The modified approach can also be extended for unstable systems. The modified approach is discussed with third order systems here. However it can be extended for still higher order systems.

Keywords: Firefly Algorithm, Non-Minimum Phase Systems, PID Controller Tuning, Peak Overshoot Reduction

1. Introduction

For a variety of control engineering problems heuristic algorithms provide a novel way[1–8]. Design of GA tuned two degree freedom of PID controller was proposed by Meena R and Kumar S[6]. A PSO based fuzzy controller for 4 phase SRM motor was proposed by Poorani et al[7]. A new model to improve productivity had been designed using fuzzy goal programming method[7]. An Enhanced Artifical Bee Colony had been proposed by Vijayakumar and Manigandan[8]. Thus heuristic algorithms are widely used because of their competency, operational ability and better computational ability. Methods such as Particle Swarm Optimization(PSO)[3], Bacterial Foraging Algorithm(BFO)[4], had been discussed by the researchers for the wide variety of control system problems.

Comparative performance analysis of various binary coded PSO algorithms on optimal PI and PID controller design for MIMO process is stated by Muhamed Illayaset al[9]. Various algorithms have been compared for the MIMO process of binary distillation column and it is stated that PBBPSO is the simple and competent method. The multivariable control in a nonlinear process is discussed by Kamala et al.[10] for a CSTR process.

A Gain scheduled PSO based internal model control for tank level system is proposed by Sabura et al[11]. Comparison of PSO and a proposed method based on PSO has been discussed by Meena et al[12]. The tech-

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niques for optimization have been developed and still research is being done in the optimization techniques. In Section 2 firefly algorithm is given and in section 3 the proposed approach has been discussed. The proposed algorithm is validated through the results discussed in section 4.

2. Firefly Algorithm

Inspired by the behavior of fireflies Xin-She Yang formulated the firefly algorithm. The other flies are attracted by the brighter one and here the brightness is associated with the objective function.

The features of the algorithm is:

- All the flies are unisexual.
- Attraction and the brightness are associated with each other and the less bright one will be attracted towards the brighter one.
- Randomly the fireflies will move when both are with the same brightness.

The Pseudocode is

```
While(s<maxgeneration)
for i=1:n(n-number of fireflies)
        for j=1:n
        if(Ii>Ij)
                fireflyj move towards fireflyi;
```

The brightness of fireflyj is chnaging with respect to the distance using the expression $e^{-\gamma * r}$;

Find the new velocities and find out new solution;

```
        End for j;
End for i;
End for while;
End;
```

The velocity updation formula for any two fireflies is

$$X_i^{t+1} = X_i^t + \beta e^{-\gamma r_{ij}^2}\left(X_j^t - X_i^t\right) + \alpha_t \varepsilon_t$$

Where

The initial population of fireflies is X_i; β order is one; γ is absorption coefficient; α_t is the parameter controlling the step size and ε is the vector.

It is inferred that the firefly algorithm outperforms the other metaheuristic algorithm such as PSO in optimizing noisy problems[13,14] and stochastic test functions[15].

3. Proposed Firefly Algorithm

It is a well-known fact that the updating brightness of the firefly decides the speed of the optimization or how fast the process reaches its objective function.

It is known that the objective functions determine the brightness, the parameters (fireflies) that satisfy the objective functions are moving with higher brightness and other fireflies would get attracted towards the brighter firefly. Thus a global solution is obtained. Therefore this modified approach modifies the existing updating equation which is

$$\beta = \left(\beta_0 - \beta_{\min}\right) * e^{-\gamma * r.^2} + \beta_{\min}$$

Usually $\beta_{\min}$ is constant. In the proposed algorithm $\beta_{\min}$ is updated with the change in the intensity of brightness (brightness of firefly$_i$-brightness of firefly$_j$). That is the same may be added or subtracted depending on the impact of the parameters to be tuned over the considered objective functions.

In the processes considered here the objective functions are Peak overshoot (PO) and ITAE. Increase in the tuning parameters K_p & K_i increases the objective functions and decrease in the parameter K_d increases the objective functions. Therefore to reduce the PO and ITAE the weightage factor $\beta_{\min}$ is reduced by and increased by K_d. The modified updating equation is

$$\beta = \left(\beta_0 - \beta_{\min}\right) * e^{-\gamma * r.^2} + \beta_{\min} * \Delta K_p + \beta_{\min} * \Delta K_i - \beta_{\min} * \Delta K_d$$

4. Results and Discussions

The proposed method is compared with the firefly algorithm for various transfer functions by Vijayan et al.[13] and Rajinikanth et al[12]. For both the firefly and the proposed the population of fireflies considered is 50, the dimension for the problem is 3 and the number of iterations is 10. The procedure is repeated number of times independently and the best tuning parameter is selected among

Table 1. Performance results of example1

Process and Results	Parameters	Firefly Algorithm	Modified Firefly Algorithm
$G(s) = \frac{e^{-0.1S}}{(S+1)^2}$		-0.0225	0.8762
		0.2320	0.3930
		-0.4797	-0.0054
Performance Indices	PO	0	0
	ISE	3.2140	1.3920
	ITAE	11.3175	6.8155

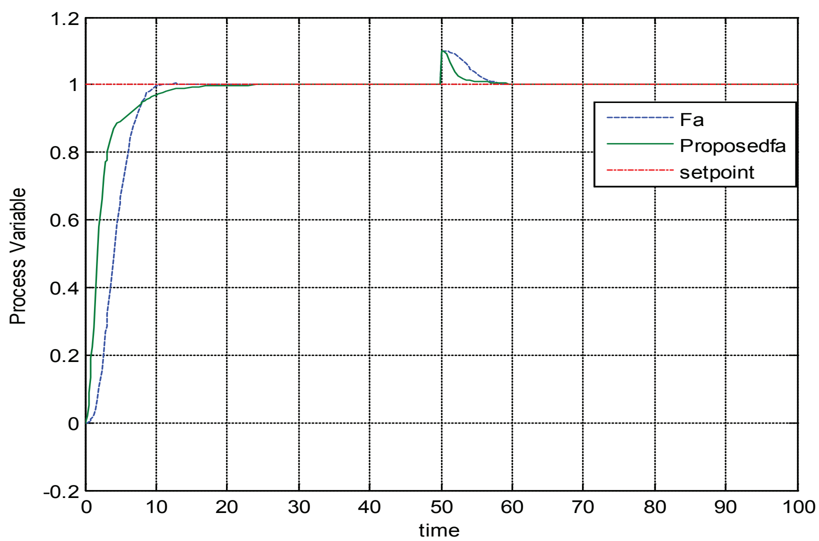


Figure 1. Response of example1.

them. The obtained optimal tuning parameter for both the firefly and the proposed method and also the associated results were given in the following tabular columns. The responses for the corresponding transfer functions are given below the tabular column.

4.1 Example 1

The process considered here is a stable second order system which was discussed by Rajinikanth and Latha[16]. The proposed method is compared with the FA. The load disturbance is given at 50th sampling instant.

It is obvious from Table 1 and Figure 1 the modified approach is better in both set point tracking and disturbance rejection. It is also inferred that the modified approach outperforms the firefly algorithm in all the aspects such as PO, ISE and ITAE.

4.2 Example 2

The process considered here is a second order plus dead time with inverse response which was discussed by Vijayan and Panda[17]. It is shown that the Set point filter is used to reduce the peak overshoot[17–19]. The proposed method is compared with the FA and the load distur-

Table 2. Performance results of example 2

Process and Results	Parameters	Firefly Algorithm	Modified Firefly Algorithm
$G(S) = \frac{(-0.2S+1)e^{-0.1S}}{(S+1)^2}$		0.6090	0.6371
		0.1858	0.4693
		0.1789	0.0177
Performance Indices	PO	0	1.05
	ISE	2.6238	1.7234
	ITAE	32.7181	3.8780

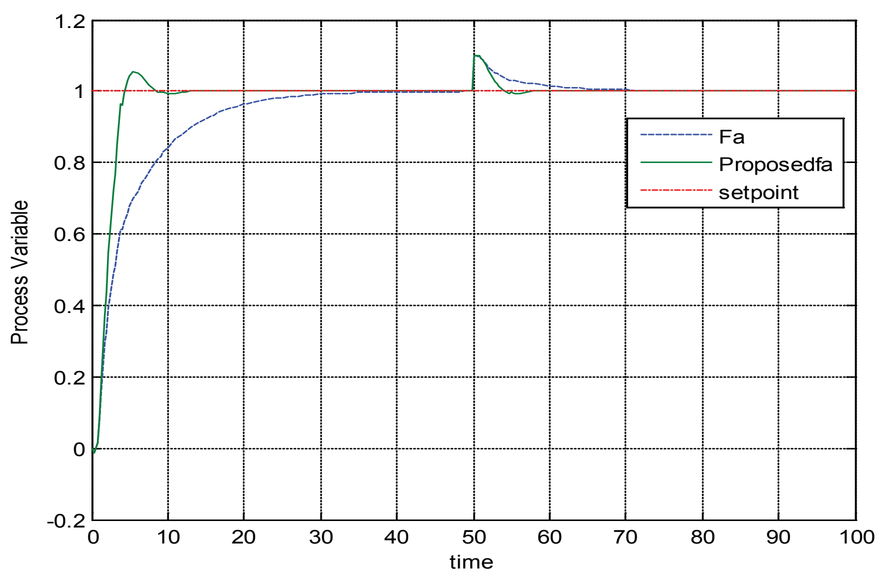


Figure 2. Response of example 2.

bance is given at 50^{th} sampling instant. From the Table 2 and from the given response in the Figure 2 it is known that the modified approach is better than firefly in all the aspects such as PO, ISE, and ITAE. The approach is good at set point tracking and at disturbance rejection.

4.3 Example 3

The process considered here is a second order steady state model of a bioreactor which was discussed by Kumar et al.[2] and Rajinikanth and Latha[16]. Kumar proposed a GA based PID controller and Rajinikanth et al. proposed a multiobjective PSO based tuning procedure[16,20]. The proposed method is compared with the FA and the load disturbance is given at 50^{th} sampling instant. From the Table 3 and form the given response in Figure 3, it is known that the modified approach is better than firefly in all the aspects such as PO, ISE, ITAE. The approach is good at set point tracking and at disturbance rejection.

Table 3. Performance results of example 3

Process and Results	**Parameters**	**Firefly Algorithm**	**Modified Firefly Algorithm**
$G(S) = \frac{(-1.35\ S - 0.4588)e^{-0.1S}}{(s^2 + 2.564S + 0.6792)}$		-0.4323	-0.3237
		-0.9188	-0.9583
		-0.2462	-0.1580
Performance Indices	PO	0	0
	ISE	0.8895	0.9119
	ITAE	2.0411	1.9086

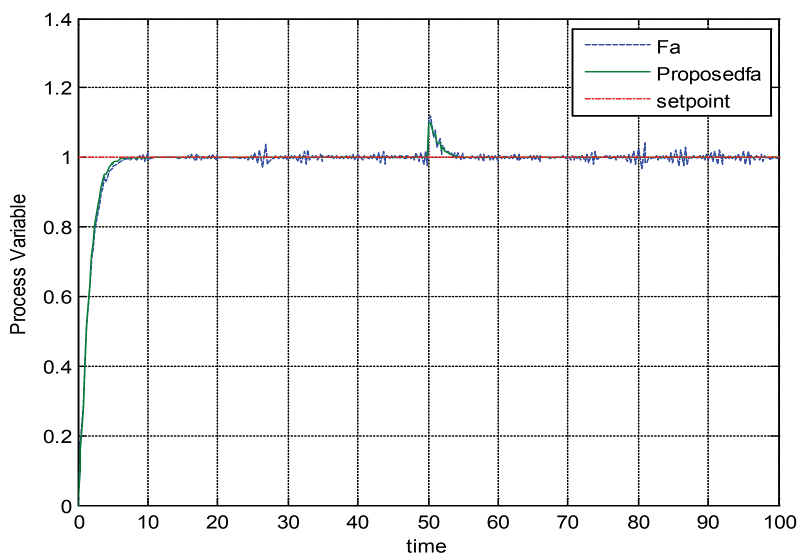


Figure 3. Response of example 3.

Also from the Table 3, it is well known that the modified approach improves the performance for non-minium phase systems than firefly algorithm.

4.4 Example 4

The process considered here is a third order with a zero at right half of S plane. For the given process both the

Table 4. Performance results of example 4

Process and Results	**Parameters**	**Firefly Algorithm**	**Modified Firefly Algorithm**
$G(S)=\dfrac{(-S+2)e^{-0.1S}}{S^3+9S^2+23S+15)}$		-0.0306	0.4144
		0.3337	0.3837
		1.5228	-0.1466
Performance Indices	PO	1.31	0
	ISE	3.3210	1.2853
	ITAE	46.2492	3.0239

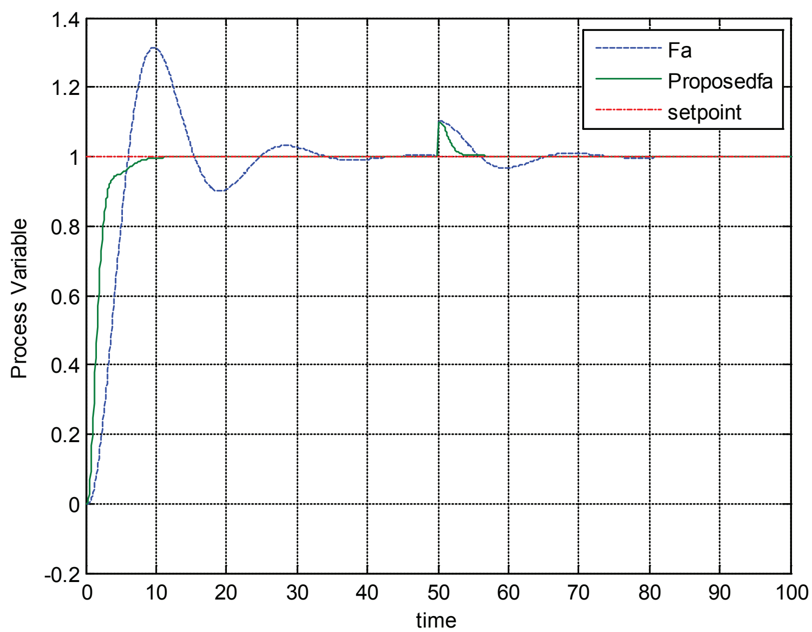
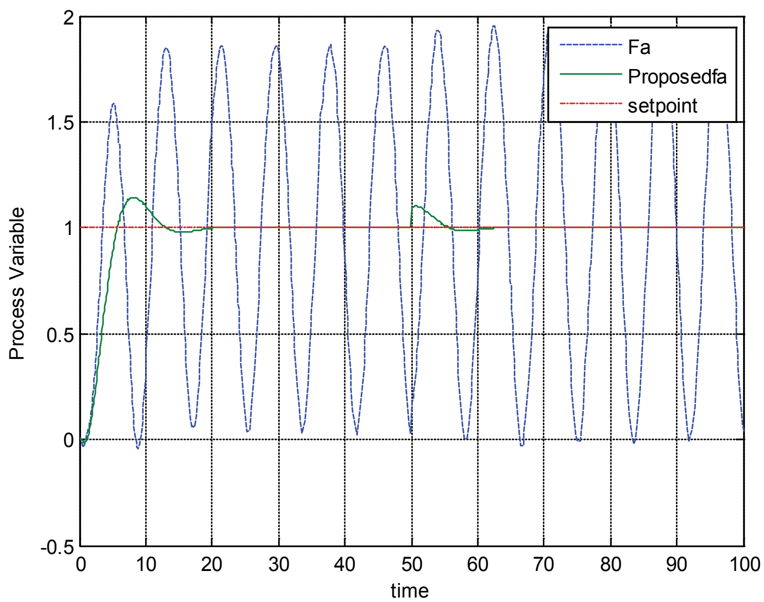


Figure 4. Response of example 4.

firefly and the modified approach is applied. Through the simulation results it is revealed that the proposed method outperforms the existing firefly not only in its objective functions such as PO, ITAE but also in ISE and settling time. The results are tabulated in Table 4. The corresponding response is given in Figure 4.

Table 5. Performance results of example 5

Process and Results	Parameters	Firefly Algorithm	Modified Firefly Algorithm
$G(S) = \frac{(S-3)(S-5)e^{-0.1S}}{(S^3+9S^2+23S+15)}$		0.2776	0.0817
		0.3792	0.3495
		-1.3005	0.1538
Performance Indices	PO	Obtaining Sustained oscillations	1.14
	ISE	79.4768	2.7932
	ITAE	1.1350e4	13.6980



4.5 Example 5

The process considered here is a third order with two zeros at right half of S plane. For the given process both the firefly and the modified approach is applied. Through the simulation results it is revealed that the proposed method provides a stable output whereas the existing firefly provides an oscillatory output. The results are tabulated in the Table 5 and the response is given in Figure 5.

5. Conclusion

The paper gives us a novel way of obtaining PID tuned parameters for any second order system with a modified approach using firefly algorithm. From the above discussions it is inferred thatthis modified approach based on firefly leads to a reduction of PO, ISE and ITAE considerably, particularly in the processes with unstable zeros.

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