RESEARCH ARTICLE OPEN ACCESS

Levy PSO and GREY Wolf Optimization Techniques of PID Controller Tuning For 2nd Order Temperatue Process

Marimuthu C[1*], Poovizhi S[2], Subaranjani P[2]
[1*] *Assistant Professor/ EIE, Government College of Technology, Coimbatore, Tamil Nādu, India*
[2] *UG student/EIE, Government College of Technology, Coimbatore, Tamil Nādu, India*

ABSTRACT:
Temperature control is increasingly playing an important role in industrial Heat Exchanger System. Recently, lots of researches have been investigated for the temperature control system based on various control strategies. Tuning of PID controller can be done by optimization techniques. Levy flight is a random walk determining step size using Levy distribution. Being used Levy flight, a more efficient search takes place in the search space thanks to the long jumps to be made by the particles. In the proposed method, a limit value is defined for each particle, and if the particles could not improve self-solutions at the end of current iteration, this limit is increased. If the limit value determined is exceeded by a particle, the particle is redistributed in the search space with Levy flight method. To get rid of local minima and improve global search capability are ensured via this distribution in the basic PSO. The performance and accuracy of the proposed method called as Levy flight Particle Swarm Optimization (LFPSO) are examined on well-known unimodal and multimodal benchmark functions. The performance indices are measured using PSO and GWO techniques and those performance indices are compared with each other to find the better optimization for the temperature control of Heat Exchanger.

Keywords: Heat Exchanger Temperature Control, Levy-PSO, GWO, PID controller Tuning

---

Date of Submission: 02-04-2023 Date of acceptance: 12-04-2023

I. Introduction

The temperature control is the important parameter in process industry like power plant, chemical and food industries. In the above industry maintaining constant temperature for a particular application is the needed one for smooth operation of the plant. From the literature, for good control action the accurate transfer function model of the process is obtained by using first principle method, based on system size and parameters which is approximated with second order transfer function. Normally PID controller with traditional tuning is used to control the linear system but for nonlinear process the traditional method provides robustness, steady state error and long settling time for the process also not providing good control action.

To overcome this issue, many optimization techniques are used to collect the controller tuning parameter. To obtain the constant temperature the approximate model of the temperature control station is designed and the model is validated in MATLAB using PID controller. The controller tuning Parameter is obtained from various method like ZN tuning, Cohen-Coon and different optimization technique. The optimization technique finds the better tuning parameter for PID controller than the traditional methods. In this paper, GWO method is used to find the controller tuning parameter for different performance indices and the results are compared with PSO technique.

Optimization algorithms can also be classified as deterministic or stochastic. If an algorithm works in a mechanical deterministic manner without any random nature, it is called deterministic. For such an algorithm, it will reach the same final solution if we start with the same initial point. Hill-climbing and downhill simplex are good examples of deterministic algorithms. On the other hand, if there is some randomness in the algorithm, the algorithm will usually reach a different point every time the algorithm is executed, even though the same initial point is used. GWO and PSO are good examples of stochastic algorithms.

This paper mainly focuses on designing PID algorithm in order to control temperature. The purpose is to improve the performance of the system and decrease the temperature fluctuation. The outline of the paper is as follows: the model of the system is presented in Section II. The design of

GWO based PID controller is provided in Section III. The design of levy- PSO based PID controller is provided in Section IV. Simulation results on analysis of the algorithms are presented in Section V. Finally, concluding remarks are made in Section VI.

II. The model of the system

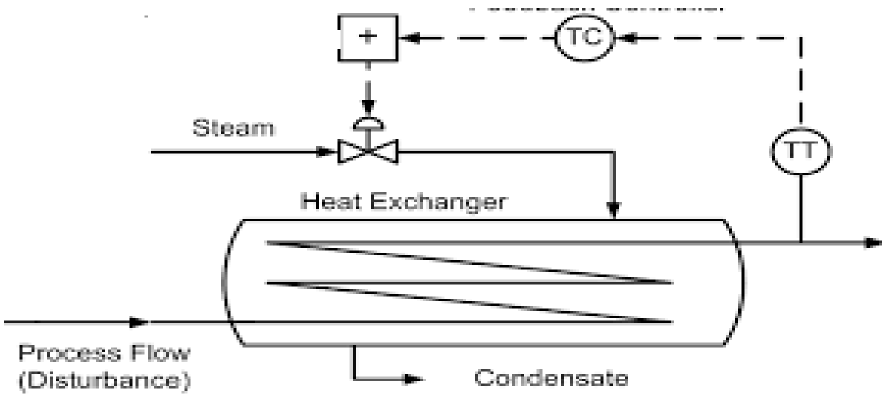
From the above description, the control object of the Heat Exchanger is a typical Under-damped Second -order delay system in the view of control. It can be expressed as follows

$$G(s) = \frac{K w_n^2 e^{-\sigma s}}{s^2 + 2 \in w_n s + w_n^2}$$

Where K is a static gain and σ is the pure lag time of the controlled object, Wn is natural Frequency

and $\in$ is damping ratio of Under-damped system.

The outlet temperature of a heat exchanger can be measured and used for feedback control. The feedback controller will manipulate the steam flow to the heat exchanger and keep the outlet temperature as close to set point as possible. changes in process flow rate will be a major source of disturbances to the outlet temperature. If the process flow rate through the heater is increased, the original steam flow rate will not be enough to heat up the increased amount of process liquid and the outlet temperature will decrease. Feedback control will eventually increase the steam flow rate and bring the outlet temperature back to its set point, but not until there has been a significant deviation in temperature.



The closed loop system of heat exchanger is controlled by PID controller. There are variety of controller tuning methods are available in which optimization technique is used to tune the PID controller. The transfer function model of the PID controller is

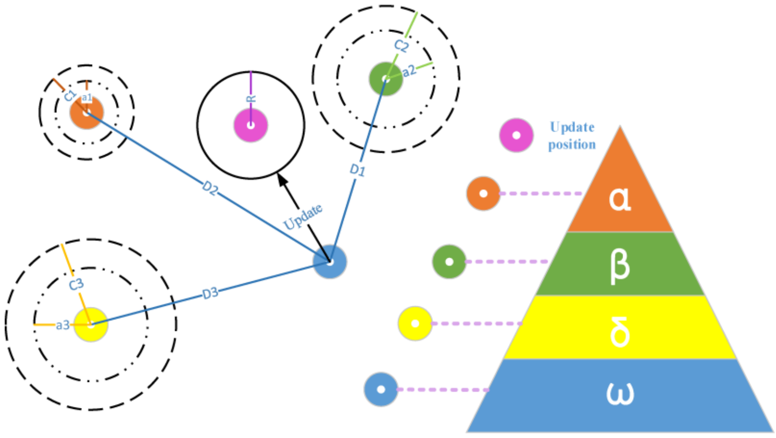
$$C(s) = K_p + \frac{K_i}{S} + K_d S$$

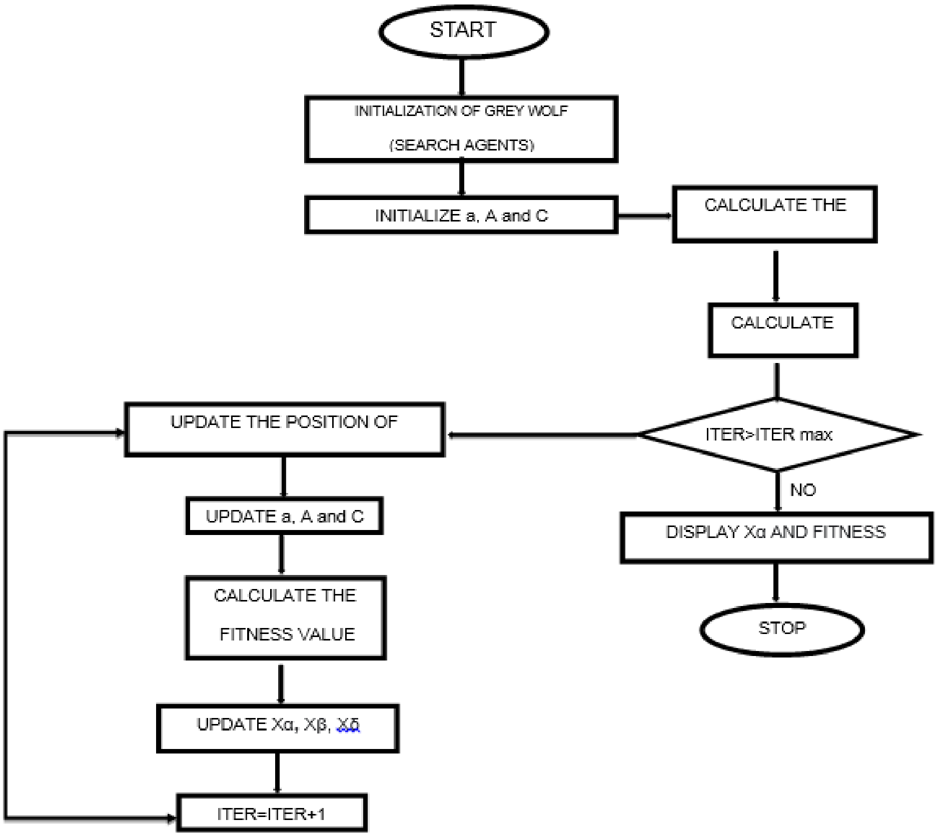
The performance of the PID controller is estimated using performance evaluation criteria (IAE, ISE, and ITAE).

III. GWO based PID controller

Grey wolf (Canis lupus) belongs to Canidae family. Grey wolves are considered as apex predators, meaning that they are at the top of the food chain. Grey wolves mostly prefer to live in a pack. The group size is 5-12 on average.

This social hierarchy plays a critical role in hunting process. Leaders, designated as α, often lead the hunting process. In the hunting process, wolves search, track, chase, and approach the prey according to team model. Then, they continue, encircle and harass the prey so that it stops moving. When enclosure is adequately small, wolves' β and δ closest to the prey start attacking, and the rest of wolves serve as supplements.
When a prey makes itself free, supplements update the encirclement based on position of the prey. This lets uninterrupted attack on the prey so that the prey is captured.





To solve optimization problems using GWO, some points may be noted:

- The proposed social hierarchy assists GWO to save the best solutions obtained so far over the course of iteration
- The proposed encircling mechanism defines a circle-shaped neighbourhood around the solutions which can be extended to higher dimensions as a hyper-sphere
- The random parameters A and C assist candidate solutions to have hyper-spheres with different random radii
- The proposed hunting method allows candidate solutions to locate the probable position of the prey
- Exploration and exploitation are guaranteed by the adaptive values of a and A
- The adaptive values of parameters a and A allow GWO to smoothly transition between exploration and exploitation

- With decreasing A, half of the iterations are devoted to exploration (|A|≥1) and the other half are dedicated to exploitation (|A|)

IV. Levy PSO based PID controller

Particle swarm optimization (PSO) is one of the well-known population-based techniques used in global optimization and many engineering problems. Despite its simplicity and efficiency, the PSO has problems as being trapped in local minima due to premature convergence and weakness of global search capability. To overcome these disadvantages, the PSO is combined with Levy flight in this study. Levy flight is a random walk determining step size using Levy distribution. Being used Levy flight, a more efficient search takes place in the search space thanks to the long jumps to be made by the particles. In the proposed method, a limit value is defined for each particle, and if the particles could not improve self-solutions at the end of current iteration, this limit is increased. If the limit value determined is exceeded by a particle, the particle is redistributed in the search space with Levy flight method. To get rid of local minima and improve global search capability are ensured via this distribution in the basic PSO. The performance and accuracy of the proposed method called as Levy flight Particle Swarm Optimization (LFPSO) are examined on well-known unimodal and multimodal benchmark functions. Experimental results show that the LFPSO is clearly seen to be more successful than one of the state-of-the-art PSO (SPSO) and the other PSO variants in terms of solution quality and robustness. The results are also statistically compared, and a significant difference is observed between the SPSO and the LFPSO methods. Furthermore, the results of proposed method are also compared with the results of well-known and recent population-based optimization.

In the original PSO algorithm, update procedures may be performed according to the best value found by each particle until the iteration at that moment (pbest) and the best value found by all particles until the iteration at that moment (gbest). The principle behind the PSO is that each particle owns the learning ability from itself (pbest) and its best neighbour (gbest). The PSO performs velocity change through being affected by both local and global conditions. Although this circumstance, since particles resemble each other after a certain number of iterations (loss of diversity), velocity changes drop to very little values and lead to loss of global search ability. This causes trapping of the PSO in local minima, one of its biggest problems. There are many studies in the literature aimed at preventing this problem (such as change of velocity updates or using in hybridization with other algorithms). J. Liang et al. diversified the swarm and targeted to prevent early convergence by making velocity update using gbest, or particle's best or pbests of different particles and selecting one of them randomly instead of learning from pbest and gbest of the particles in the original PSO [19]. Zhao Xinchao changed the velocity update procedure to prevent loss of diversity, and proposed perturbed particle swarm algorithm based on the perturbed gbest updating strategy [20]. In another study, different velocity update techniques were combined, and it was ensured to continue use of the technique by which update is made better [21]. Ioannis G. Tsoulos added stopping rule, similarity check and a conditional application of some local search method modifications to enhance velocity and effectiveness of PSO [22].

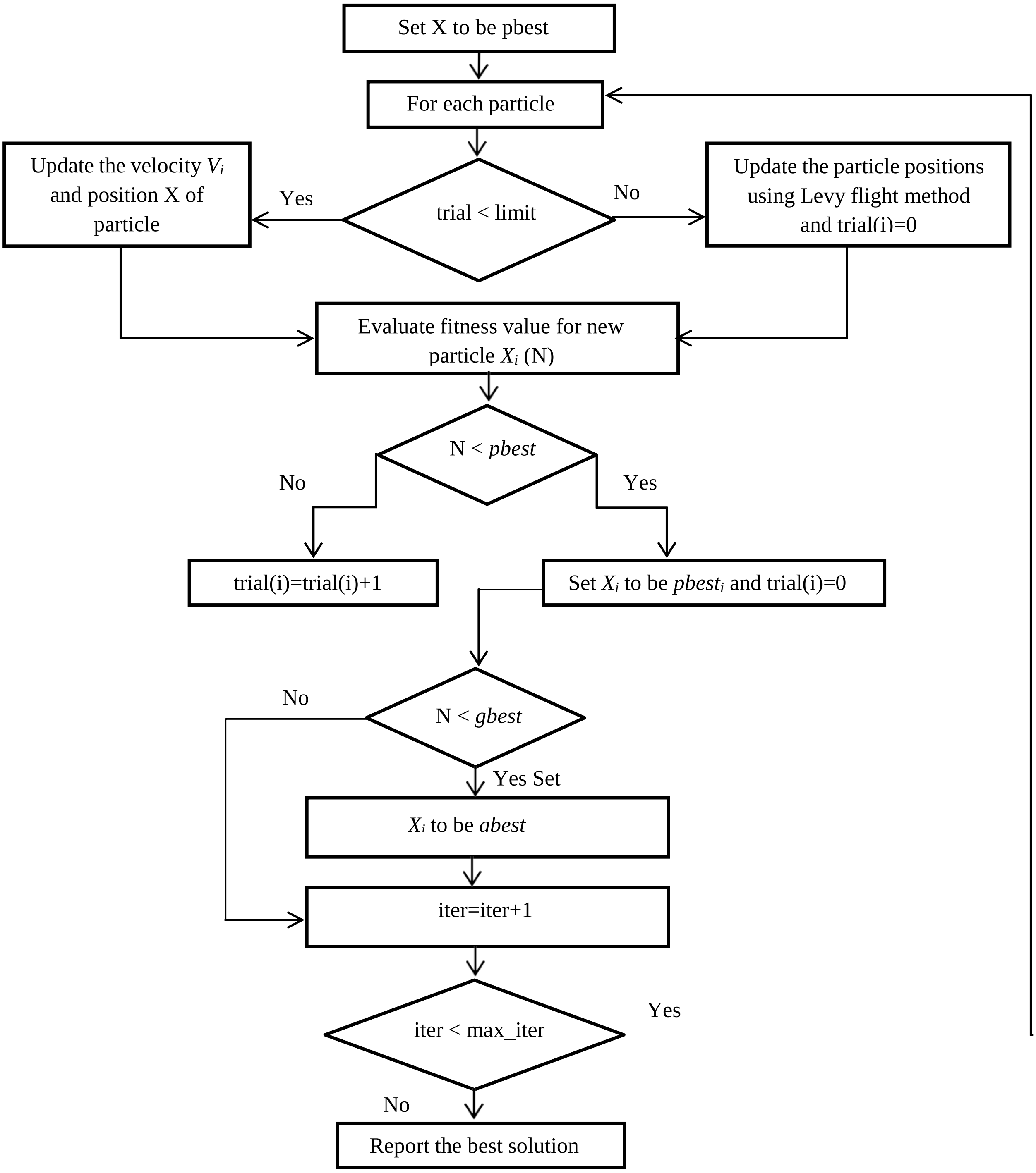
To strengthen global search of PSO and overcome the problem of being trapped in local minima, PSO was combined with Levy flight in this study. A Levy flight is a class of random walk, which is generalized Brownian motion to include non-Gaussian randomly distributed step sizes for the distance moved [26]. There are many natural and artificial facts that can be depicted by Levy flight, such as fluid dynamics, earthquake analysis, the diffusion of fluorescent molecules, cooling behaviour and noise etc. [27]. Levy flight was also used by Pereyra and Hadj in the field of Ultrasound in Skin Tissue [28], and by Al-teemy in Ladar Scanning [26].

The Proposed Algorithm LFPSO

A limit value is set for every particle, and this limit value is incremented by 1 in case the particles could not improve self-solutions for each new iteration.

The particles exceeding the limit value are redistributed in the search space using Levy flight (using Levy distribution) method.

One of the important points to be considered while performing distribution by Levy flights is the value taken by the β parameter. Yang and Deb mentioned that the β parameter gave different results at different values in the trials conducted in the study named Multiobjective cuckoo search for design optimization [34]. Accordingly, it can be concluded that a different β parameter for each benchmark function gave a more effective result. Moreover, in the Evolutionary Algorithms with Adaptive Levy Mutations study of Chang-Yong Lee, different constant values were set of the β parameter, procedures were conducted by calculating the distribution for each of these values and selecting the best of the offspring produced [36]. As seen in these two examples, β parameter substantially affects distribution. In this study, no constant value is taken for the β parameter, but a random value in the (0,2] interval is taken for Levy flight distribution procedure. PSO performs velocity change through being affected by both local and global conditions. Although this circumstance, since particles resemble each other after a certain number of iterations (loss of diversity), velocity changes drop to very little values and lead to loss of global search ability. The LFPSO intend to prevent loss of diversity and improve the global search ability. It performs long jumps for small values of the β parameter, and this eliminates the global search deficiency in PSO prevents which we always mention about, and prevents being trapped in local minima.



V. Analysis of Optimization Techniques

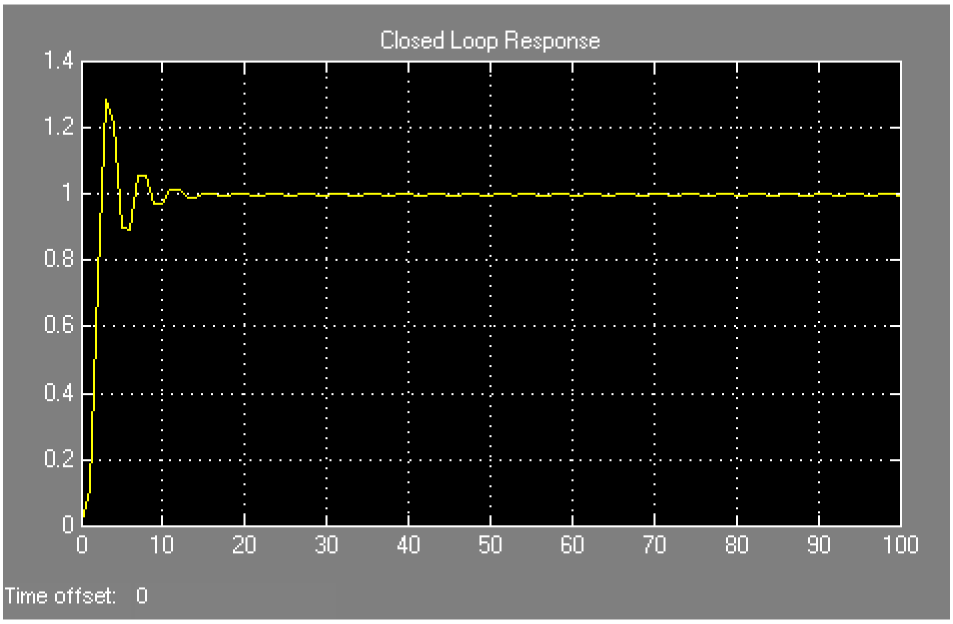


Table 1. Optimized PID controller parameters obtained with different algorithms

Type of Controller	**Objective Function Values ($J*10^{-4}$)**	**K_{P1}**	**K_{i1}**	**K_{d1}**
LFPSO	55	1.9800	1.5968	0.9999
PSO	158	0.9390	0.7988	0.5638
GWO	169	0.8016	0.8595	0.6896

The settling time, overshoot and undershoots are given in Table 1 f by different optimization algorithms. The dynamic performances in terms of peak deviations, magnitude of oscillations and settling times exhibited by the proposed LFPSO PID controllers are better compared with recently published GWO and PSO optimized PID controller.

Table 2. Undershoots, overshoots and settling times of Δω1, Δω 2, ΔP for different algorithms

Type of PID Controller	**$\Delta\omega_1$**			**$\Delta\omega_2$**			**ΔP_{tie}**		
	U × 10^{-4}	**O × 10^{-4}**	**Ts sec**	**U × 10^{-4}**	**O × 10^{-4}**	**Ts sec**	**U × 10^{-4}**	**O × 10^{-4}**	**Ts sec**
LFPSO	-52.21	1.8292	2.71	-6.1512	0.0000	6.78	-74.5129	0.0000	20.15
PSO	-70.87	2.5745	9.23	-11.0258	0.0000	9.56	-134.108	0.0000	22.09
GWO	-67.14	3.3540	9.67	-11.1277	0.0000	10.42	-137.221	0.0000	23.44

For more clarity, comparison of steady state error, settling times, overshoots and undershoots of $\Delta\omega_1$, $\Delta\omega_2$ and ΔP_{Tie} for the proposed hybrid LFPSO optimized PID controller, PSO tuned PID controller and GWO based PID controller.

VI. Conclusion and Future Work

In order to overcome the original GWO and PSO algorithm's problem of being trapped in local minima and being unable to perform well global search due to early convergence, PSO is combined with Levy flight in this study. The proposed method was observed to give better average results in functions tested, and to be more robust in most of them. Furthermore, in order to consider the performance of the LFPSO algorithm, it is compared with GWO and PSO variants. When evaluated experimental results of the PSO variants, LFPSO is more successful than the PSO variants. Moreover, the results of proposed method are also compared with the results of well-known and recent population-based optimization methods.

As future work, since success on the function of the proposed methods, the proposed method will be used to different optimization problems such as training neural networks, scheduling problems, image segmentation etc. Also, because Levy flight method isa good tool for providing diversification in the population, it will be used for the other nature-inspired algorithms.

REFERENCE

[1]. S.Mirjalili,S.M.Mirjalili, and A. Lewis, "Grey Wolf Optimizer".,Advances in Engineering Software. 69, 46-61(2014).
[2]. Muangkote, Nipotepat, Khamron Sunat, and Sirapat Chiewchanwattana, "An improved grey wolf optimizer for training q-Gaussian Radial Basis Functional-link nets" in Computer Science and Engineering Conference (ICSEC). IEEE, (2014).
[3]. Wong, Lo Ing, et al., "Grey Wolf Optimizer for solving economic dispatch problems" in Pow- er and Energy (PECon), IEEE, (2014).
[4]. James Kennedy and Russell Eberhart, "Particle Swarm Optimization" in Purdue School of Engineering and Technology Indianpolis, IEEE,(2018).5)
[5]. C Somasundar Reddy1 and K Balaji, "Comparison of PID Controller Tuning Methods for Shell and Tube Type Heat-Exchanger System", Control Theory and Applications, IEE Proceedings - Jan 2002.
[6]. F. Marini and B. Walczak, "Particle swarm optimization (PSO). A tutorial Chemom Intell. Lab. Syst., vol 149, pp. 153-165, 2015, doi: 10.1016/j.chemolab 2015.08.020.
[7]. Robinson J, Sinton S, Rahmat-Samii Y (2002) Particle swarm, genetic algorithm, and their hybrids: optimization of a profiled corrugated horn antenna. In: Proceedings of 2002 IEEE international sympo- sium on antennas propagation, pp 31–317, San Antonio, Texas, USA, June 16–21, 2002.
[8]. T.Sekara and M. Matausek, "Optimization of PID controller based on maximization of the proportional gain under constraints on robust- ness and sensitivity to measurement noise," Automatic Control, IEEE Transactions on, vol. 54, no. 1, pp. 184–189, Jan 2009.
[9]. Bratton D, Kennedy J. Defining a Standard for Particle Swarm Optimization. Proceedings of the IEEE Swarm Intelligence Symposium. 2007: 120–127.
[10]. Gong D, Lu L, Li M. Robot Path Planning In Uncertain Environments Based On Particle Swarm Optimization. IEEE Congress on Evolutionary Computation. 2009: 2127–2134.
[11]. Gao H, Kwong S, Yang J, Cao J. Particle swarm optimization based on intermediate disturbance strategy algorithm and its application in multi-threshold image segmentation. Information Science. 2013: 1–31.
[12]. M. Lee, M. Shamsuzzo ha, and T.N. Luan Vu, "I MC-PID Approach: An Effective way to get an Analytical Design of Robust PID Controller. International Conference on Control, Automation and Sy s ems, Seoul, Korea, pp. 2861-2866, 2008.