A Multi-Subpopulation PSO Fusion based Optimal Tuning of PID Controller

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ABSTRACT
In conduct the design problem optimization algorithms, particle swarm optimization (PSO) could be conceivably stuck at a local minimum in a non-proper region of the search. This led to the need of developing a new class of solution method that can overcome this deficiency. For boots out such problems, this paper presents a fusion algorithm of a multi-subpopulation particle swarm optimization (MS-PSO). The main idea lies in dividing the main search space into multi-subpopulation regions. The fusion is based on performance measurements of the individuals of these multi-subpopulations for finding the optimal solution. The results are obtained by testing the particle swarm optimization and multi-subpopulation particle swarm optimization on the tuning of PID controller to a given system to improve its step response parameters. The result is compared with the performance of PID controller tuned using conventional methods. The proposed PSO based PID controller has significant improved performance.

General Terms
Intelligent Control, Optimal Control.

Keywords
PID, Step Response, Particle Swarm Optimization (PSO), Data Fusion, Multi-Subpopulation.

1. INTRODUCTION
Particle swarm optimization (PSO) is an experiential global optimization method which is based on swarm intelligence. PSO technique was invented in the mid-1990s. It comes from the study on the fish and bird group movement actions. The PSO is considered as one of the auspicious optimization techniques [1-3]. The algorithm is widely used and rapidly developed for its easy implementation and few particles required to be tuned. A comprehensive description of the PSO algorithm and the implication of the different parameters of its update rule is given in [4]. Swarm intelligence is considered as a family of decentralized stochastic algorithms enthused by the conduct of swarms [5]. Comparing with other intelligent algorithms, PSO algorithm has less variables to adjust and is easy to achieve, so it is widely used in engineering [6]. In addition, PSO is employed for finding stable reduced order models of large-scale linear interval systems [7]. The PSO algorithm is used in many trends, controller design, image processing, pattern recognition, finding some threshold for classification problems, and data mining [8-10]. Moreover, PSO is applied in the area of electric power systems to minimize the real power losses of an electric power grid [11]. Interesting application in electrical distribution systems assuming uncertainty in load demand incorporating distributed generation is developed as a multi-objective planning. Two objectives in system planning. The first, is the cost minimization of total installation and operation. The second, is the lowest risk factor [12]. Also, PSO is applied in medical image processing to improve the efficiency of medical image segmentation [13]. However, like many other optimization algorithms such as [8,9], there exist two common drawbacks of using PSO that foil it to find the best optimal solution. First, is when the individual good solutions pull in the population too rapidly. It would cause the population to converge on a suboptimal solution. The second one, refers to too much diversity that may be detrimental to the success of the algorithm. To boot out such two problems, this paper presents a MS-PSO fusion based optimal tuning PID controller. The proposed fusion algorithm relates to apply the PSO algorithm to multi-subpopulation which their union represents the whole population. This search way, help to avoid from getting locked in a suboptimal solution. It goes with two processes. Frist, is partition the main population into some number of subpopulations to search over different particular domain of the assigned population. The second, is to fuse amid the best particles selected from the subpopulations by selecting the particle with the best fitness. The performance of MS-PSO compared to PSO with respect to the performance measurements of dynamical response of the controlled system is validated. This paper is organized as follows: Section-1 gives an introduction to different applications of using PSO algorithm and section-2 introduces the details of the PSO algorithm. While, section-3 explore the controlled system performance indices and section-4 gives the details of the proposed MS-PSO algorithm. Moreover, section-5 explore the simulation result of a practical controlled system and section-6 explore the benefits of the proposed MS-PSO algorithm compared with classical tuning of PID and standard PSO algorithm. Finally, section-7 reconnoiter the conclusion of the proposed work.

2. PSO ALGORITHM
In PSO algorithm, the collection of particles in search space purpose to optimize a fitness function, inspired by the observation of social interaction and animal behaviors such as fish schooling and bird flocking inspiring by the movement of flocks of fish schooling or bird flocking [5]. PSO relies on the exchange of data between particles of the population called swarm. The particles are sited randomly in search space, and they evaluate their quality or fitness at that position. Then, for a predestine number of iterations, each particle moves to a new location which bounces improved fitness than the forgoing position. This new position is gained based on the history of particles own best and current positions with those of the best positions got by other particles in the swarm, with around random perturbations. Thus, in consequent iterations the swarm attains the most optimum solution to the fitness function in the defined space, with a definite number of particles functioning together [6]. The fitness or objective function in PSO algorithm is a performance evaluation measure that is determined by the application field of the algorithm. The performance criterion is usually defined by a mathematical formulation to measure the system performance attained through a performance index. The basic particle swarm optimization algorithm consists of a swarm of "Np" particles, and the position of each particle represents a

possible solution of the fitness function in M- dimensional search space [9].

The speed and position of each of the particles in a swarm of PSO algorithm, updates by the following equations:

$$\vartheta_{im}^{k+1} = w\vartheta_{im}^k + c_1 r_1^k \left(pbest_{im}^k - x_{im}^k\right) + c_2 r_2^k (gbest_m^k - x_{im}^k) \tag{1}$$

$$x_{im}^{k+1} = x_{im}^k + \vartheta_{im}^{k+1} \tag{2}$$

Where,

x_{im}^k, ϑ_{im}^k, $pbest_{im}^k$, and $gbest_m^k$ denotes represents position, velocity, personal best position, and global best position of ith particle of Np particles at m-dimension out of M dimensions in kth iteration respectively.

w Represents the inertial weight attached to the particles in advances attained position.

c_1, c_2 Represent acceleration constants.

r_1^k, r_1^k Represent random numbers in the range of [0,1].

The velocity update in PSO contains three terms [10]:

❖ Momentum "$w\vartheta_{im}^k$"where it signifies the tendency of particle to move in the same direction as it was moving in the previous iteration. It incorporates the effect of previous velocity on current velocity of the particle.

❖ Cognitive part "$c_1 r_1^k \left(pbest_{im}^k - x_{im}^k\right)$" where it signifies the pull to particle's velocity towards its own personal best. Referred to as "memory", "self-knowledge" or "remembrance".

❖ Social part "$c_2 r_2^k (gbest_m^k - x_{im}^k)$" where it signifies the pull to particle's velocity towards swarm's best. Referred to as "cooperation", "social knowledge" or "shared information". Fig. 1 shows the chart that expresses the procedures of a basic PSO algorithm.

3. PERFORMANCE INDICES FOR THE PSO ALGORITHM

The controller performance can be estimated using an objective function based on the error criterion. The following functions are the most conjoint and used in this work:

i. Integral of Absolute Errors (IAE) criterion

In IAE, the error criterion can be calculated using the following equation:

$$I_{IAE} = \int_0^{T_s} |e(t)| dt \tag{3}$$

ii. Integral Square of Errors (ISE) criterion.

In ISE, the error criterion can be calculated using the following equation:

$$I_{IsE} = \int_0^{T_s} e(t)^2 dt \tag{4}$$

iii. Integral of Time multiplied by Absolute Errors (ITAE) criterion

In ITAE, the error criterion can be calculated using the following equation:

$$I_{ITAE} = \int_0^{T_s} t|e(t)| dt \tag{5}$$

Where, T_s is the predictable settling time.

4. A MS-PSO BASED OPTIMAL TUNING OF PID CONTROLLER ALGORITHM

In the population based evolutionary algorithms, untimely convergence of population is the most conjoint problems is concerned. In the practical engineering application of evolutionary algorithms, it is a very important research direction on how to avoid individual falling into the local optimum and its untimely convergence. Impose a certain diversity in population will lead to improve the exploration capability during the process of development. In this work paper he proposed algorithm relates to apply the fusion model of algorithms with PSO. It concerns with two processes: one is dividing a particle population into some number of subpopulations to search over several different domains of a particle space; the other is using a fusion mechanism of the global best particles selected from the different subpopulations. This is done by selecting the particle with the best fitness among the set of global best of different subpopulations. The MS-PSO processes are carried out as demarcated in Fig. 2.

5. SIMULATION AND EXPERIMENTAL RESULTS

An example of a high-performance drilling process [14] is used to explore the effectiveness of the proposed multi-subpopulation PSO algorithm. The drilling process is modeled as a third-order system given by the transfer function described by equation (6), where s is the Laplace operator, f is the command feed, and F is the cutting force.

$$H_p(s) = \frac{F(s)}{f(s)} = \frac{1958}{s^3 + 17.89s^2 + 103.3s + 190.8} \tag{6}$$

In order to explore out the control system performance, the simulation studies are implemented, in Matlab/Simulink. The tuning of PID controller is adjusted using the classical method Ziegler-Nichols, direct application of the standard PSO algorithm with population size =100 and number of iterations =100 [14], and the proposed multi-subpopulation PSO method. PID controller was formed based upon the respective parameters, subpopulation size, Ns=8, population size, N_{pop}=25, and two reduced number of iterations, Nitr = 50 and N_{itr} = 25. Table 1 shows the PID controller parameters. The step response of the drilling-force signal is shown in Fig. 3.

6. RESULTS AND COMPARISION

Analysis reflects that the design of proposed controller gives a higher robustness and stability. Simulation results show performance improvement in time domain specifications for a step response. Comparison of time domain specifications using the classical method Ziegler-Nichols, direct application of the standard PSO algorithm, and the proposed multi-subpopulation PSO method is given by table-3. The proposed MS-PSO algorithm does not require a large number of population in each subpopulation and with lower number of iterations a better performance can be obtained. It reflects that the proposed MS- PSO based controller drastically reduces the overshoot by a large value. Moreover, a comparison for the best performance indices ITAE, IAE, and ISE are obtained for all configuration of the PID controllers are given in Table -3 which ensure the advantage of the proposed controller.

Table-1. PID controller parameters

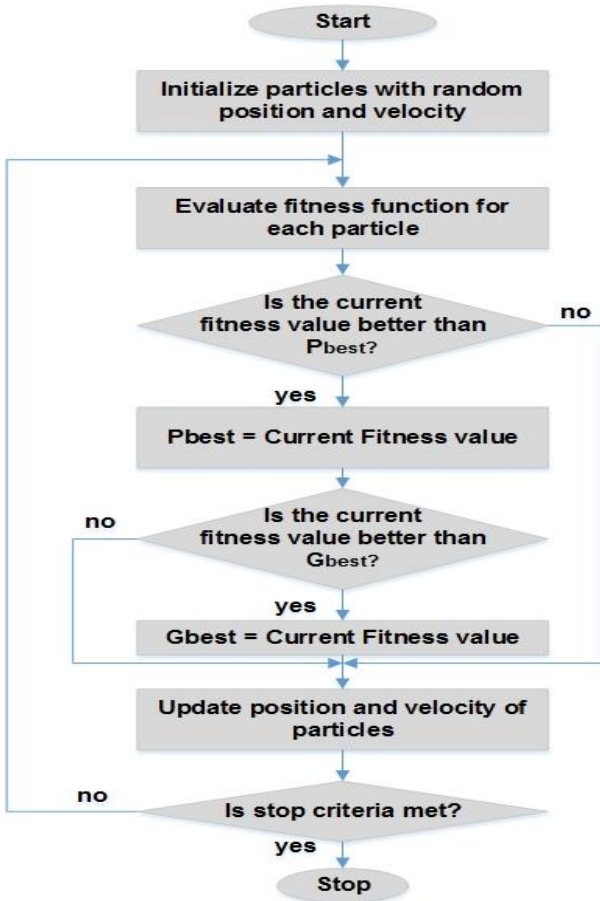| Tuning method		PID Controller Parameters		
		P	**I**	**D**
Ziegler-Nichols		0.5128	1.6649	0.0395
Standard PSO [12]		0.7164	1.4665	0.0984
MS-PSO	Npop= 50, Nitr= 25	0.4452	1.1091	0.1075
	Npop= 25, Nitr= 25	0.4066	0.9787	0.1154

Fig 1: Chart of a basic PSO algorithm.

Table-2. Comparison of time domain specifications

Tuning method		Time Domain Specifications		
		Rise Time	**Sett. Time**	**PO**
Ziegler-Nichols		0.1470	1.6069	42.34%
Standard PSO [12]		0.1055	0.5923	22.82%
MS-PSO	N_{pop}= 50, N_{itr}= 25	0.1191	0.5752	6.29%
	N_{pop}= 25, N_{itr}= 25	0.1175	0.6461	3.63%

Table-3. Comparison of performance index

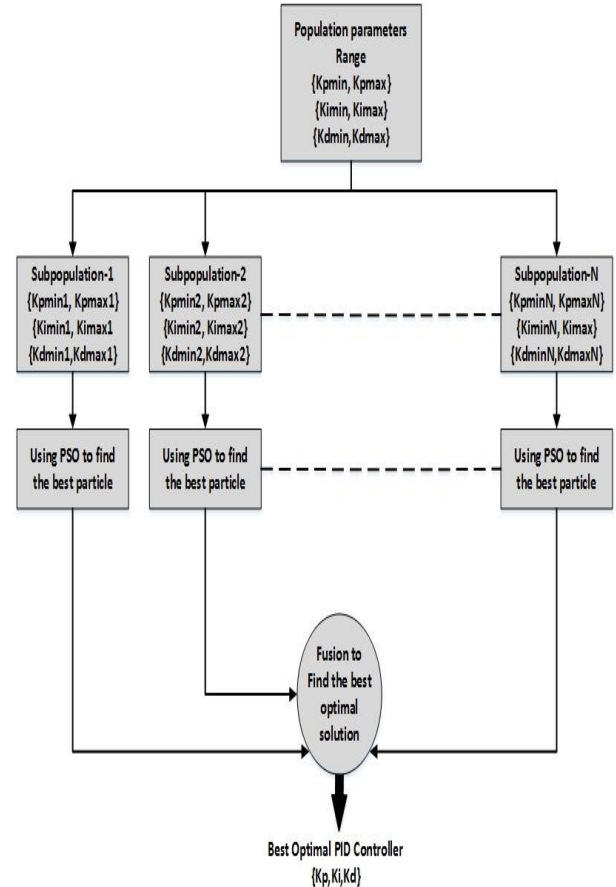| Tuning method		ITAE	IAE	ISE
Ziegler-Nichols		0.1040	0.1463	0.2973
Standard PSO [12]		0.0309	0.0828	0.1595
MS-PSO	Npop= 50, Nitr= 25	0.0256	0.0700	0.1266
	Npop= 25, Nitr= 25	0.0282	0.0691	0.1303

Fig. 2: The chart that expresses the processes of MS-PSO algorithm

7. CONCLUSIONS

In this paper a fusion algorithm of MS-PSO has been introduced. It is shown analytically and graphically that there is a substantial improvement in the time domain specification in terms of a lower overshoot with comparable rise time and settling time compared with the existing traditional techniques of tuning the controller. The performance indices for different error criterions; ITAE, IAE, and ISE; have is proved to be the lowest using the proposed controller. Moreover, it can be concluded that with a lower number of total population in subpopulations with lower iterations number would result in a better PID controller time domain specifications and lowest performance index for different error criterions. Parallel computing can be set up to optimize of the time of PID tuning which can be reflected in real time applications
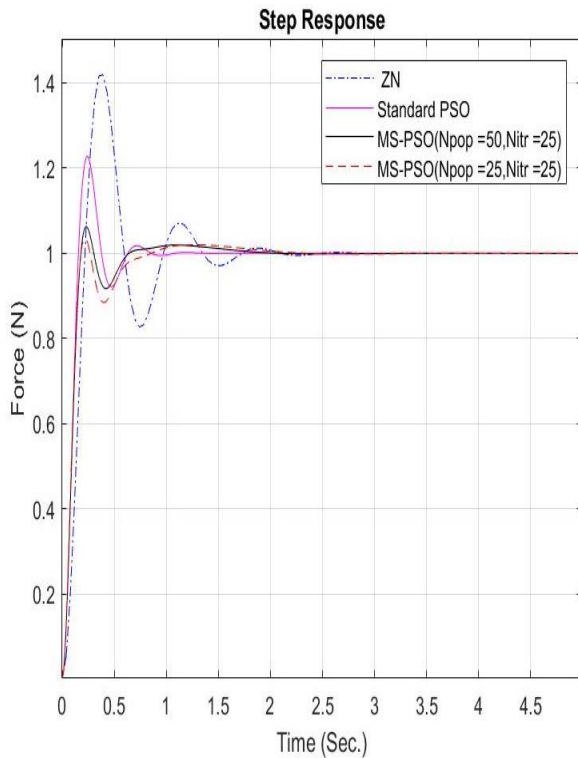
Fig 3: Unit step response with Z-N controller, standard PSO based controller, and MS-PSO based controller

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