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Performance Analysis of an Improved Particle Swarm Optimization and the Standard Particle Swarm Optimization

Patrick O. M. Ogutu, Nicholas Oyie, Winston Ojenge

Abstract**:** ***Many industries employ different modes of control when it comes to PID parameter tuning. The problem of tuning a control system for linear and nonlinear systems has been undertaken by previous authors however the level of error reduction in the system performance has not been done quite well, hence the study on improved particle swarm optimization using improved Algorithm for PID parameter tuning. This paper tackled optimization of PID parameters based on improved PSO algorithm for the non-linear system. The particle swarm optimization is used to tune the PID parameters to ensure improved system response and operation. The PSO was deployed in a nonlinear system for application and validation of results achieved through PID tuning of the standard parameters on the MATLAB Simulink platform. The study ensured that the PID parameters were effectively tuned by applying improved PSO Algorithm to the plant process. The research used a standard nonlinear system depicting the real-life situation and an Improved Particle Swarm Optimization Algorithm to analyze and compare the improved behavior on the MATLAB/Simulink toolbox as applied to the PID parameters. Finally, it was logically realized that an improved PSO Algorithm system response was much better in comparison with the non-PSO tuned system. The simulation was performed on the plant transfer function using the MATLAB and Simulink platforms at various parameter choices and situations, and realizations were made from the data obtained. As the iteration was increased from 10, 50, and 100, there was a significant reduction in ITAE error from 0.054806 to a minimum of 0.01900, which is far better than the SPSO algorithm. SPSO reduces the error from 0.065143 to 0.020476. It was noted that the system behavior was far better in terms of settling time and peak overshoot for IPSO.***

Keywords: MATLAB Simulink, PID parameters, Iteration, nonlinear system, Particle swarm optimization Algorithm

I. INTRODUCTION

Particle Swarm Optimization (PSO) is a popular optimization algorithm that has been widely applied to a variety of non-linear systems.

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However, the traditional PSO algorithm can be limited in its ability to effectively solve complex optimization problems. Therefore, an improved version of PSO, known as Improved Particle Swarm Optimization (IPSO), has been developed to overcome some of these limitations. IPSO is a population-based optimization algorithm that uses a swarm of particles to search for the optimal solution to a problem. Like traditional PSO, IPSO starts by initializing a population of particles, each representing a potential solution to the problem. However, IPSO introduces several modifications to the PSO algorithm that enable it to better explore the search space and converge to a global optimum.

One modification that IPSO introduces is the use of a dynamic inertia weight. The inertia weight is a parameter that controls the impact of the particle's previous velocity on its current velocity. In IPSO, the inertia weight is adjusted dynamically during the optimization process, allowing for a more efficient search of the search space. [5]

Another modification is the use of a hybrid mutation operator. The mutation operator introduces random perturbations to the particles' positions to promote exploration of the search space. In IPSO, the mutation operator is combined with a local search method to ensure that the perturbations lead to improved solutions.

Furthermore, IPSO uses a novel boundary-handling technique to address the problem of particles moving beyond the search space. This technique helps to prevent premature convergence and improve the algorithm's ability to find global optima.

The effectiveness of IPSO has been demonstrated in a variety of non-linear system optimization problems, including neural network training, control system design, and feature selection in machine learning. The IPSO algorithm has been shown to outperform traditional PSO and other popular optimization algorithms in terms of convergence speed, accuracy, and robustness.

In summary, IPSO is an improved version of the PSO algorithm that overcomes some of the limitations of traditional PSO in solving non-linear system optimization problems. Its dynamic inertia weight, hybrid mutation operator, and novel boundary-handling technique make it a powerful optimization algorithm that can efficiently search for the optimal solution in a variety of complex optimization problems.

II. LITERATURE REVIEW AND MATHEMATICAL MODELLING

A. Literature Review

The author [2] studied the influence of energy and humidity control but did not come out effectively on the performance aspect. ACO and PSO techniques were used in designing a plant control where ACO was proved to be slightly better than PSO. The distancing function technique was implemented and the method was found to be easy, very fast, and easily implementable however [1] worked on the latest PID adjustment technique by using PSOSCALF as a form of optimization which resulted in Overshoot decreasing from 25% to 10% respectively. Optimal tuning of PID controller gain based on the PSO method using the ITSE performance index and the efficacy of the controller is tested with tri loop error at different transient conditions [1] [11]

A Modified Particle Swarm Optimization Algorithm for the Economic Dispatch Problem was proposed and a study on the use of PSO for solving the economic dispatch problem in power systems was done. The outcome revealed that the proposed method performed poorly compared to other optimization algorithms [8] [14] [15].

Performance Comparison of Various Evolutionary Algorithms for Optimal Reactive Power Dispatch was investigated and the authors compared the performance of PSO and other evolutionary algorithms for solving the reactive power dispatch problem in power systems. Their results showed that PSO performed poorly in terms of convergence speed and solution quality compared to other algorithms. [6]

A new approach to fuzzy tuning using the distancing function is a paper that proposes a novel method for tuning fuzzy systems based on the use of a distancing function. The approach is shown to have several advantages over traditional fuzzy tuning methods and is validated through simulation experiments on a several benchmark problems. [3]

Design of Symmetrical FIR Digital Filters using Particle Swarm Optimization as applied to the design of digital filters. However, their results showed that PSO performed poorly compared to other optimization algorithms for the same problem. [10]

These are just a few examples of authors who have studied PSO optimization with limited progress. It's worth noting that the performance of PSO [4] can be highly dependent on the specific problem being solved, the choice of parameters, and the quality of the fitness function. Therefore, it's important to carefully evaluate the performance of PSO and compare it with other optimization algorithms before drawing any conclusions about its effectiveness

A. Mathematical Modeling of the Process

The circuit diagram designed, as shown in Fig 1, displays the arrangement of several components that will give results for analysis when run on MATLAB/Simulink with the standard and improved particle swarm algorithms. The circuit consists of two operational amplifiers that will be injected with a step signal, a PID[7] block from which the initial proportional-integral-derivative parameters shall be set, an integrator and a derivative circuit connected to achieve ITAE, ISE, and IAE, a display unit to indicate the output values during the iterations, a multiplexer (mux) which is a digital circuit that selects one of several inputs and forwards the selected input to a single output line, and a CRO which deploys the output response of the signals.

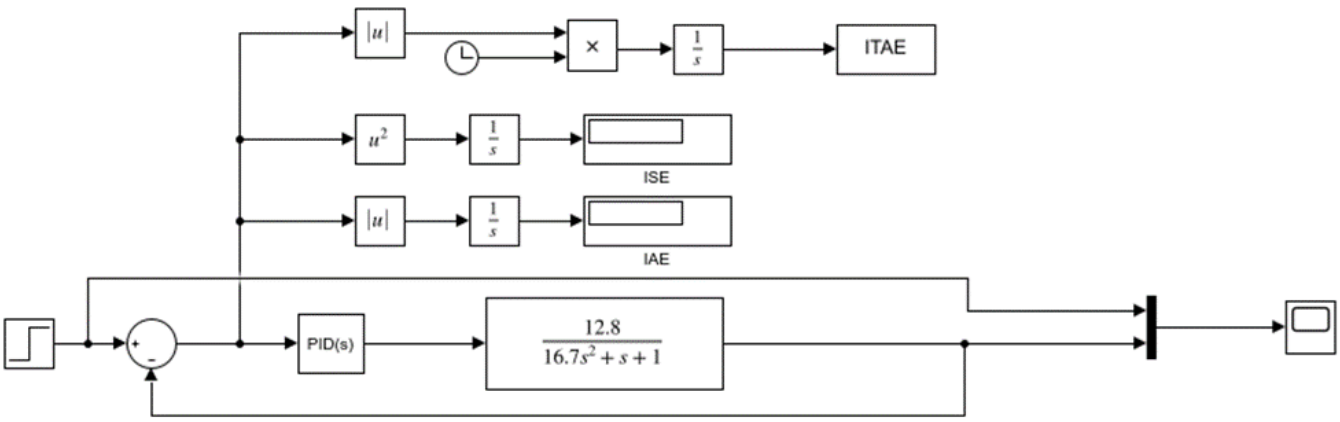

Fig: 1 Circuit Layout

B. Transfer Function

The plant mathematical model is arrived at after a series of calculations described below. Consider the Transfer function [9]

$$T.F = \frac{G}{1+GH} = \frac{Y(s)}{U(s)} = \frac{12.8}{16.7s^2+s+1} \quad (1)$$

Obtained from x Using state space representation the state vector can be defined as $X = [x_1\ x_2]^T$, Where x_1 and x_2 are the state variables, the function can be expressed in state space

$$\frac{dx}{dt} = Ax + Bu \quad (2)$$

$$y = Cx + Du \quad (3)$$

Where

A, B, C, and D are matrices that explain the dynamic behavior of the system. To obtain the matrix the following parameters are used:-

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A= [0 1;-1/16.7 -1/16.7]

B=[0;12.8/16.7]

C= [10]

D= 0

$$\frac{dx1}{dt} = x_2 \quad (4)$$

$$dx2/dt-= -(1/16.7)x1 - (1/16.7)x2 + (12.8/16.7)u \quad (5)$$

$$y = x_1 \quad (6)$$

The State equation describes the dynamic behavior of the system and the output equation relates to the output to the state vector. As realized above the state equation representation can easily be transferred to MATLAB.

C. PSO Tuning Process

The PID Controller: The PID controller is responsible for generating the control signal that is sent to the actuator. The controller calculates the error signal by comparing the set point with the current process value and generates the control signal based on the proportional, integral, and derivative terms.PSO Algorithm: The PSO algorithm is used to optimize the PID controller's parameters. The PSO algorithm searches for the optimal set of parameters that minimizes the error between the set point and the process value. The PSO algorithm iteratively updates the position and velocity of each particle in the search space to find the optimal solution.

Fitness Function: The fitness function evaluates the performance of the PID controller with a particular set of parameters. The fitness function calculates the error between the set point and the process value over a specified period.

Optimization: The PSO algorithm evaluates the fitness function for each set of parameters and updates the particles' positions and velocities based on the best-performing particles in the search space. The optimization process continues until the stopping criterion is met, such as reaching a maximum number of iterations or achieving a certain level of convergence.

Actuator: The actuator receives the control signal from the PID controller and applies it to the process to control its behavior. The actuator could be a valve, a pump, or any other mechanical or electrical component that can adjust the process's behavior. In summary, the block diagram of a process controlled by a PID controller optimized using PSO consists of a process, a sensor, a PID controller, a PSO algorithm, a fitness function, an optimization process, and an actuator. The PSO algorithm searches for the optimal set of parameters for the PID controller to minimize the error between the set point and the process value, and the actuator applies the control signal to the process to achieve the desired behavior.

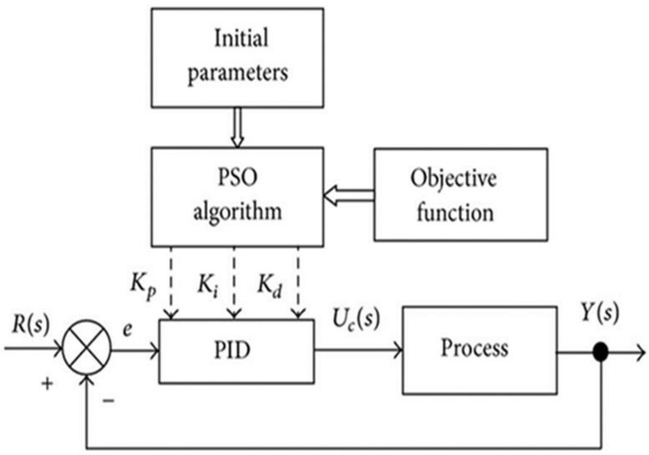

Fig. 2 PID and PSO Optimized Block Diagram.

III. MATERIALS & METHODS

The components that are used to accomplish the paper objectives are: - ITAE, ISE, IAE Blocks, step function, CRO, MATLAB Simulink software, MUX The process is then designed using the MATLAB simulation software operating at the Simulink model designing platform. The same design is connected to the PID controller and then also tuned using the PID tuning platform on the MATLAB SIMULINK as shown in Fig 1. The created Algorithm is inserted and stored at the MATLAB workspace then run as per the number of iterations and particles optimization. The sequence of activities is repeated while changing the PID parameters and the process repeated.

IV. RESULTS & DISCUSIONS

This section shows the simulation results using MATLAB/Simulink software for the system with the PID controller tuned using Ziegler-Nichols and PSO methods. Furthermore, the results obtained using different performance evaluation indices for the PSO-tuned PID controller are shown and compared [1] [11] [12] [13].

The optimization process of PID involves tuning the proportional, integral, and derivative gains to achieve the desired system response. IPSO and SPSO are optimization techniques that were used to automate this tuning process. IPSO used a hybrid approach that combines the standard PSO update equation with the gradient-based update equation, while SPSO included a self-organizing mechanism and a mutation operator. Both IPSO and SPSO result in faster convergence and improved performance compared to the standard PSO algorithm and PID, as revealed by the results in Table1.

Table 1: Simulation 1: 10 Iterations and 30 Particles

ITEM	K_P	K_I	K_D	ITAE	ISE	IAE
PID	2	0.170800	2	2.795100	0.31840	0.92270
SPSO	100	37.10776	100	0.061543	0.01141	0.03459
IPSO	100	15.26855	100	0.054806	0.01155	0.03159

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Table 1. Above shows that the Integral Time Absolute Error (ITAE) is very high for PID with a value of 2.7951 and very low at 0.0054866 for Improved Particle Swarm Optimization (IPSO). However, the Standard Particle Swarm Optimization (PSO) is also better in terms of error reduction compared to the conventional PID.For the case of ISE, PID performed dismally with a value of 031840, while Standard PSO performed better compared to IPSO. For IAE, the error is further reduced as the system runs from PID to SPSO and finally to IPSO.The system response curve, as shown in Fig 3 clearly shows that IPSO behaves much better compared to SPSO and the conventional PID. The magnified caption shows that the overshoot is much higher for SPSO as compared to IPSO. This directly shows that the behavior of IPSO has improved the system behavior as a result of the improved algorithm. For 10 iterations, convergence is achieved faster with IPSO compared to SPSO. IPSO settles much faster, while SPSO takes longer, as can be seen in the graphic representation in Fig 4

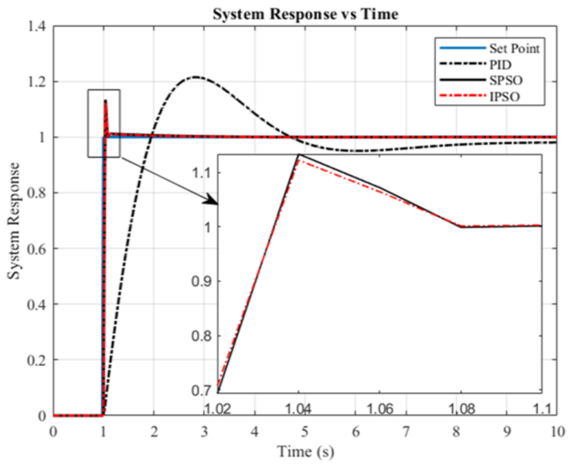

Fig: 3. System response for 10 iterations

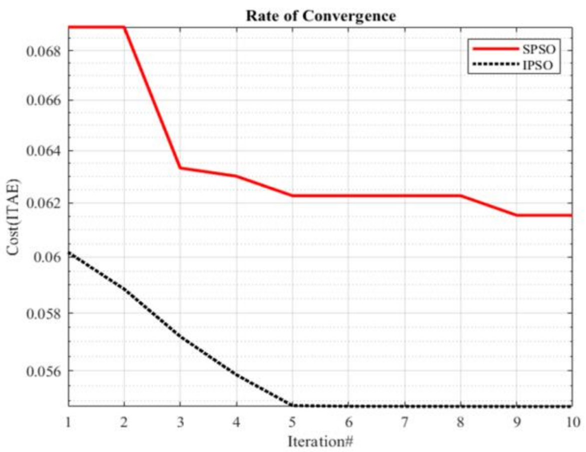

Fig: 4. Rate of convergence

Table 2: Simulation 2: 50 Iterations and 30 Particles

ITEM	K_P	K_I	K_D	ITAE	ISE	IAE
PID	2	0.170800	2	7.326000	0.32080	1.14900
SPSO	100	15.66876	100	0.054696	0.01140	0.03200
IPSO	100	15.23772	100	0.054806	0.00155	0.03158

Table 2 above shows that the Integral Time Absolute Error-ITAE is very high for PID with a value of 7.326000 and very low at 0.054696 for standard particle swarm optimization. However, the improved particle swarm optimization is better in terms of error reduction compared to the conventional PID, with a value of 0.054806.

For the case of ISE, PID performed dismally with a value of 0.32080. However, the improved PSO performed better compared to SPSO with values of 0.00155 and 0.01140 respectively. For IAE, the error is further reduced as the system is run from PID to SPSO and finally to the improved particle swarm optimization with values of 1.14900, 0.03200, and 0.03158 respectively. Overall, standard SPSO has better results compared to PID and IPSO while considering ITAE, however, for IAE, IPSO worked well compared to the rest.

The system response curve, as shown in the f Fig 5, clearly shows that IPSO behaves much better compared to SPSO and the conventional PID. The magnified caption shows that the overshoot is much higher for SPSO as compared to IPSO. This directly shows that the behavior of IPSO has improved the system behavior as a result of the improved algorithm.

For 50 iterations, convergence is achieved faster with IPSO compared to SPSO. IPSO settles much faster while SPSO takes longer, as can be seen in the graphic representation in Fig 6.

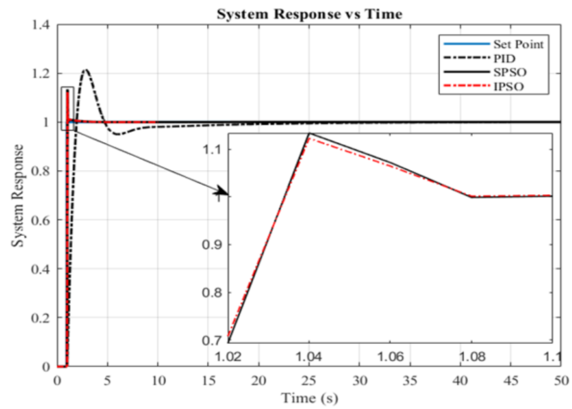

Fig: 5. System response for 50 iterations

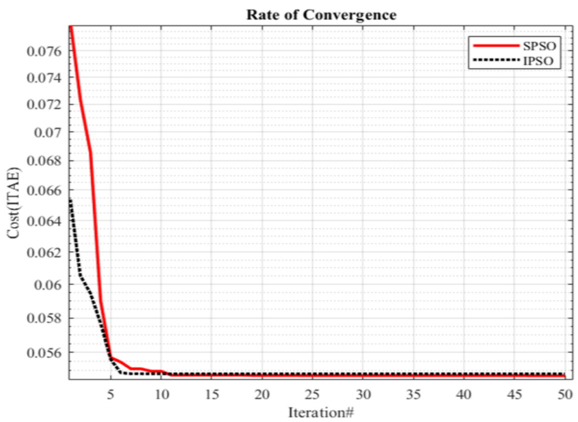

Fig: 6. Rate of Convergence 50 Iterations

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V. CONCLUSION

The paper has convincingly proved that particle swarm optimization is better in optimization compared to the conventional PID controller. Simulated results show that SPSO and IPSO have a good effect on PID controller parameters tuning. The PID controller parameter tuning method based on the IPSO Algorithm improves the situation while the traditional tuning method requires multiple attempts to select the optimum parameters compared to IPSO and SPSO, which select the parameters automatically as per the algorithm within a short time. This paper successfully developed an AI automatic PID tuning scheme using an IPSO algorithm that can automatically acquire or readapt the PID parameter during plant operation in a routine way. The results show the effectiveness of modern optimization such as IPSO in control applications. The simulation was performed on the plant transfer function using the MATLAB and Simulink platforms at various parameter choices and situations, and realizations were made from the data obtained. As the iteration was increased from 10 to 50, and 100, there was a significant reduction in ITAE error from 0.054806 to a minimum of 0.01900, which is also far better than the SPSO algorithm. SPSO reduces the error from 0.065143 to 0.020476. When considering the ISE, it was noted that PID increases the error factor significantly; however, SPSO and IPSO reduce the error at iteration 50 from 10 and then reduce the error at 100 iterations. For IAE, the PID error increases from 0.92270 to 1.1550; however, for SPSO and IPSO, the error factor is drastically reduced as the iterations are increased.

It can thus be concluded that the number of iterations improves the error both for SPSO-IPSO, and also the performance of IPSO is much better than SPSO and the conventional PID. When it came to convergence, IPSO also performed better than SPSO, and an increase in population from 15 to 30 while maintaining other parameters does not in any way affect the PID errors in terms of ITAE, ISE, and IAE. However, it has a great impact on the SPSO-ITAE, where it reduces the error on ITAE while it increases the error on ISE and IAE. The paper realized that IPSO using the improved algorithm can perform wonders compared with SPSO and PID; hence, it can be used in plant optimization.

Future researchers can use this study as a springboard for quality research in areas that have not been deeply undertaken by my study. The work contributes to the study of PID controller tuning methods and limitations while using Meta -heuristic algorithms that have not been deeply explored in PID parameter tuning in industrial applications. The authors do hereby declare that the work was a team effort. The study does not require ethical approval and consent to participate since it only dealt with simulations. No financial support was obtained. No conflict of interest is declared. Data was obtained from MATLAB/Simulink designed and Algorithm simulations.

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Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors having equal contribution for this article.

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