International Journal of Research and Review
www.ijrrjournal.com E-ISSN: 2349-9788; P-ISSN: 2454-2237

Research Paper

Optimization of PID Controller Using Crow Search Algorithm and Bat Algorithm

A. A. A. Wahab, S. S. N. Alhady, N. H. B. Sofik, W. A. F. W. Othman

School of Electric and Electronic Engineering, Universiti Sains Malaysia (USM) Transkrian, Nibong Tebal, Pulau Pinang, Malaysia

Corresponding Author: S. S. N. Alhady

ABSTRACT

Engineering field usually requires the best design for an optimum performance, thus optimization plays an important part in this field. Among optimization algorithms, crow search algorithm (CSA) and bat algorithm (BA) were chosen for this study. In this study, the effectiveness of CSA and BA were compared by analyzing the minimization of objective function and the step responses of the closed loop systems with proportional-integral-differential (PID) controller. The four criteria of objective functions are comprised as overshoot, settling time, rise time and steady state error. These are compared with acceptable solutions and the best one is selected with respect to optimized design. The parameters of PID controller i.e. K_p, K_i and K_d must be properly selected as the selection affects the transient response of a system. The best combination of parameters will reduce problems such as nonlinearities encountered by industrial plants. Then, comparisons and investigations were made based on the average and standard deviation of cost returned by the cost function. It can be seen that the ability to subdivide automatically in BA search was a short one in finding the optimal solutions. The results show improvement 1.06% in overshoot percentage after modification. The objective function value is increased for BA 1.443e-04 and the CSA is 7.5113e-07 considering the performance parameter needs to be optimized to minimize the error signal. Even though BA had a lower convergence rate compared to CSA but it managed to find the optimal solutions.

Keywords: *PID controller; Crow Search algorithm; Bat Algorithm; Error criteria*

INTRODUCTION

The main objective of this paper is to identify a suitable optimization algorithm to tune and to develop PID controller for brushed DC motor application. There is a lot of intelligent tuning methods such as genetic algorithm (GA), particle swarm optimization (PSO), bacterial foraging (BF) and many more (Ibrahim et al., 2014). There are a significant number of new algorithms created in recent years to solve complex problems.

Proportional-Integral-Derivative (PID) controller is widely used for speed and position control of DC motor (Jaiswal and Phadnis, 2013). DC motor has been a part of the industry despite the fact that its maintenance cost is higher than the induction motor.

In the optimization algorithm, the design objective could be simply to minimize the cost function or to maximize the efficiency of production. An optimization algorithm is a procedure which is executed iteratively by comparing various solutions till an optimum or a satisfactory solution is found (Wang et al., 2017).

Optimization algorithm is a procedure which is executed iteratively by comparing various solutions till an optimum solution is found, given a defined or sets of constraints domain. The space consists of potential solutions of a search problem is usually called search space. The algorithm continuously searches for the best solution until certain criteria are met. Optimization has become a part of computer-aided design activities.

There are two types of optimization algorithms widely used today. The first type of optimization is deterministic algorithms. They use specific rules for moving one solution to another. These algorithms are in use to suit some applications and have been successfully applied for many engineering design problems. Example is a state machine such as the Turing machine and deterministic finite automation. The second type of optimization is stochastic algorithms. The stochastic algorithms are in nature with probabilistic translation rules, generate and use random variables. Nature-inspired stochastic algorithms such as particle swarm optimization, ant colony optimization, bee colony optimization were realized based on swarm intelligence. These are gaining popularity due to certain properties which deterministic algorithms do not have.

There are various research papers identified with streamlining of PID controller utilizing CSA and BA for various types of branches of knowledge and frameworks. From the research papers, these were quickly checked on to improve the comprehension of fundamental destinations of optimizing algorithm in this investigation. The advantages and disadvantages of the exploration works were grasped for an extensive relative study (Lakshmi and Kumar, 2018).

The PID controller is broadly utilized as a part of business and has extraordinary assurances to the control business because of its ease-of-use and efficiency. It is recognized as a strong foundation to be associated in any process or plant. Before that, many research works were using CSA to optimize a solution to any problem. From the research paper by Gehad Ismail Sayed, the experiments aim to evaluate the performance of the proposed chaotic crow search algorithm or CCSA feature selection algorithm and to compare it with other metaheuristic algorithms (Sayed et al., 2017). From another research paper by Dina A. Zaki, it introduces a novel application of the CSA to improve the inverter based distributed generation system performance. The vector cascaded control scheme is the control strategy of the inverter which relies on the proportional-integral (PI) control. The proposed CSA is utilized to fine tune the PI controller parameters. The objective function of the optimization problem is created by the RSM (response surface methodology) (Zaki et al., 2017). Where, the fitness or objective function is the function responsible for evaluation for the obtained solution for each step. Then a second generation population of solutions is created through a combination of genetic operators such as crossover and mutation. CSA and GA techniques based on RSM are used for the optimization process.

BA is also used to tune controller of PID in the center of the system and plays a vital role in ensuring an optimal system output. It determines the stability, overshoot, steady state error, rise time and settling time. Among these research papers, research papers by Kelvinder Singh, were reviewed that the algorithm utilizes the frequency and loudness to achieve an ideal arrangement (Singh et al., 2015). There are certain standard functions to examine the efficiency of these said algorithms. From the Yang research, the BA recorded 100% in the terms of degree of correctness and effectiveness in the function of Rosenbrock. Also as new algorithms are optimized they are incorporated into the PID tuning. It is important that PID controller is appropriately adjusted to make sure that the system in question is operating in an acceptable level.

METHODOLOGY

Crow Search Algorithm Optimization

As metaheuristic algorithms, they

should provide a good balance between diversification and intensification. CSA provides this by controlling the awareness probability (AP) parameter. By decreasing of the AP value, CSA tends to localize the search region where a good solution is found and thus increasing intensification and vice versa (Zaki et al., 2017). In this study, selection of parameter values was made based on choice cited from research papers by Dina A. Zaki. The set of parameter values which returned best cost value was selected. Table 3.2 shows the sets of control parameters that were tested.

Table 3-2: Set of parameters CSA

Parameters	Crow Search
pd	10
N	20
Ap	0.1
fl	2

Bat Algorithm Optimization

This research looked into the parameters and concentrated their impact in light of the application in analyzing the benchmark capacities. A portion of the parameters can be instated with arbitrary numbers, yet others must be set up with proper numbers as indicated by the experiment and the model being settled (Fister et al., 2014).

The four parameters are used by PID controller to create the system output. The wanted system exhibitions are regarding overshoot, settling time, rise time and steady state error. It has achieved different strategies to tune the controller to the response desired. In this manner, the BA's existence as a feature of the system will lower the cost and time with which these parameters are tuned and enhance general execution of system. The set of parameter values which returned best cost value was selected. Table 3.4 shows the sets of control parameters that were tested.

Table 3-4: Set of parameters

Parameters	Bat Algorithm
N	40
A	3
ρ	4
D	3

Investigation on cost function and step response of PID controller

After the best of control parameters for every algorithm was chosen, the *m.files* were executed to separate information of cost value and parameters of *Kp, Ki* and *Kd*. Both algorithms were executed with 30 simulation-runs. The number of simulation runs is one of the stopping criteria in this algorithm. From all the simulation-runs, runtime which returned the least cost incentive with the best optimal solutions was chosen. The runtime in this experiment was set to 30 to check the optimum value of algorithm.

Each simulation-run has the number of iterations which were decided based on method. The last iteration usually returns least cost value of the objective function. Furthermore, every runtime has the quantity of cycles which were chosen on method clarified in the past section. The last iteration as a rule returns minimum cost value of the objective function. The last cost value estimation of every emphasis and runtime was contrasted with to get the slightest cost value (Aleem et al., 2017). The smallest value was chosen and a mix of the PID controller parameters was tested. The progression reaction delivered by the mix was analyzed whether it closely created a step input. At the first, it did not give the attractive output, and the mix of parameters of second smallest cost value was tested.

Last but not least, these algorithms were looked at regarding time taken, cost values and convergences. The combination of parameters obtained from every algorithm were tested on the systems, at that point the progression reaction were analyzed. Besides that, CSA and BA were compared comprehensively.

Comparative study on cost function and step response of PID controller

The best set of control parameters for each algorithm was selected, the *m.files* were executed to extract data of cost values and parameters of *Kp, Ki* and *Kd*. The number of simulation-run or runtime is one of the stopping criteria in this algorithm. The algorithms were executed with 30 simulation-runs. From all the simulation-runs, runtime which returned lowest cost value with the best optimal solutions was chosen. The parameters were then tested using both algorithms so that the step response of the systems can be analyzed. The runtime in this experiment was set to 20 to check efficiency of algorithm. To run the algorithm, the lower bounds and upper bounds set for both algorithms were the same.

The last cost function value of each iteration and runtime was compared to get the least cost value. The smallest value was selected and the combination of the PID controller parameters was tested. The step response produced by the combination was analyzed whether it closely produced a step input. If the first one does not give the desirable output, the combination of parameters of second smallest cost value was tested.

The cost values were significantly reduced through iterations and finally converged to a final best value. The solution improved in each iteration. This process continued until optimal solution was found. In addition, standard deviation was plotted against iterations to clearly visualize the variance between the data. High standard deviation indicates that the data has large variance from the average value whereas low standard deviation shows that the data has small variance from the average value. Besides, error bars were plotted in both graphs to indicate the variability of data.

The combination of parameters such as computational time, cost function values and convergence from each algorithm were tested on the systems, then the step response was analyzed. The graph plots were compared for CSA and BA comprehensively.

RESULTS AND DISCUSSION

This chapter discusses the results about comparison of optimization for both algorithms and analyzes the best result for tuning PID controller for the speed controller of a DC motor. It presents the simulation results obtained using methods in previous chapter.

It could be seen that the execution regarding peak overshoot, steady state error, rise and settling time are enhanced altogether from the results obtained. This research essentially centers on the algorithm which can tune the parameters of the PID controller so that the system can converge, consequently CSA and BA were executed to locate the best parameters of *Kp*, *Ki* and *Kd*. This simulation program is run on the MATLAB R2013a and it is executed on a Core i5 personal computer.

The control parameters of best selection

This section produces the different feedback results for CSA and BA for optimizing the speed control of the DC motor. The step response of both algorithms is shown in Figure 4.1 (a) and Figure 4.1 (b).

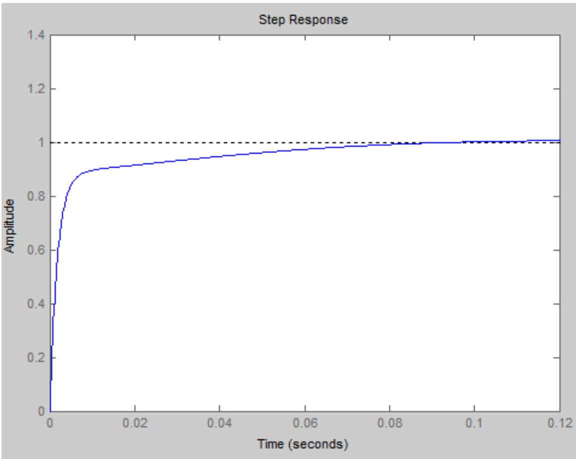

Figure 1(a): The CSA of step response.

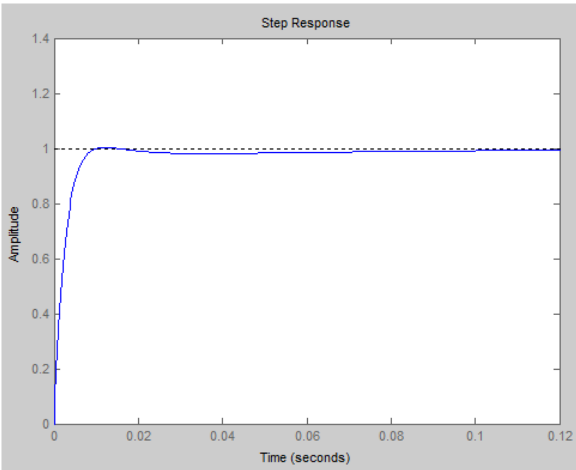

Figure 1(b): The BA of step response.

Figure 4.1(a) and Figure 4.1(b) shows the step responses obtained using BA and CSA respectively. Since this study mainly focuses on the algorithm which can tune the parameters of the PID controller, CSA and BA were implemented to find the good parameters of cost value, *Kp, Ki,* and *Kd*. Table 4.1 shows the parameters of both algorithms.

Table 4-1: The result parameters Bat Algorithm and Crow Search Algorithm

	CSA	BA
K_p	457.9951	572.7040
K_i	6888.9	6540.4
K_d	2.0603	3.6122
Cost Value	1.2634e-04	1.9880e-04

Both algorithms have step responses closely resembling the step input however with some transitory nature. The dynamic performance specifications of the algorithms are tabulated in the Table 4.2. The dynamic performance specifications include the values of peak overshoot, *Mp*, rise time *Tr*, settling time *Ts* and steady state error *ess*.

Table 4-2: The result transient response Bat Algorithm and Crow Search Algorithm

Transient Response	CSA	BA
$T_r(s)$	0.0059	0.0046
$T_s(s)$	0.0395	0.0134
$e_{ss}(s)$	0.0014	0.0077
$M_p(\%)$	1.27%	1.06%

Based on the step responses obtained in Figures 4.1(a) and Figure 4.1(b) and the values of the transient response Table 4.2, it can be shown that PID controller makes the system to behave towards desirable performance. This study mainly focuses on the algorithm which can tune the parameters of the PID controller so that the system can behave at its best, hence CSA and BA were implemented to find the best parameters of *Kp*, *Ki* and *Kd*.

Analysis on step responses

From runtimes executed, runtime which returned lowest cost value with the best optimal solutions were chosen. The parameters of the chosen runtime were tested with CSA and BA hence, the step responses obtained was analyzed. Figure 4.6 depict corresponding step response of this system with both algorithms respectively.

Based on the step response Figure 4.6, both algorithms have equally good dynamic performance specifications with slight variation in cost values. It can be shown that both algorithms managed to find nearly optimal solutions which returned low cost values. It is noted that the cost values obtained by BA was much lower than that for CSA. It can be shown that BA works well with the selected control parameters and defined objective function. Factors such as choice of control parameters and choice of objective function had greatly influenced the performance of both algorithms.

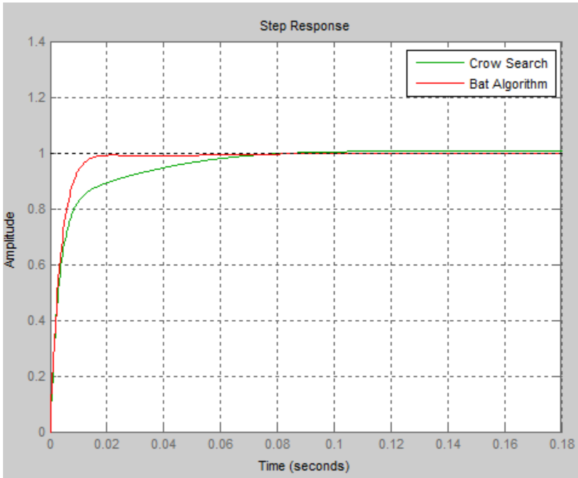

Figure 4.6 : Step response of Crow Search Algorithm and Bat Algorithm

For the simulation-run, taking as example from Table 4.5, it can be seen that BA has a rise time and settling time of 0.0079 seconds and 0.0140 seconds respectively. Whereas from Table 4.5 the CSA has a settling time and rise time 0.0671 seconds and 0.0062 seconds respectively which are longer compared to the other algorithm. Furthermore, result for the peak overshoot and steady-state error for BA was low and it influences the performance of the algorithms optimization.

Table 4-5 : Dynamic performance specifications of Crow Search and Bat Algorithm

	Crow Search Algorithm	Bat Algorithm
T_r (s)	0.0062	0.0079
T_s (s)	0.0671	0.0140
e_{ss} (s)	7.5113e-07	1.443e-04
M_p (%)	1.4	0

From these analyses, CSA and BA have shown that these techniques fitted in well with the fitness function selection and control parameters which consequently resulted in good minimization. It can be said that selection of the fitness function and control parameters have matched with the algorithms. Furthermore, both algorithms have performed well. However, BA outperformed CSA in terms of convergence rate. The good performance of CSA can be attributed to its control parameters. The standard deviation of objective function value is increased such as for BA 1.443e-04 and the CSA is 7.5113e-07 considered the performance parameter to be optimized despite minimizing the error signal.

Therefore, if the cost value is slower it can take a short time to find the optimal solutions. It is necessary that the PID controller be tuned properly to make sure that a system in question is operating at an optimum level. The entire performance of the BA is lower than CSA which generated a more acceptable accuracy in rise time and settling time of 0.0079 seconds and 0.0140 seconds respectively. On top of that, there are two important key factors that greatly influenced the performance of these algorithms. Each algorithm has a set of control parameters to be set. The appropriate choice of the control parameters was one of the factors which contributed to its success of searching for best solutions.

CONCLUSION

The aim of this research, in the earlier stage was to compare CSA and BA in terms of effectiveness for tuning PID controller parameters. The data was analyzed for the minimization of objective function and the step responses of the closed loop system for control differential DC motor. In order to make comparison, minimization of cost function and step responses of the systems were analyzed for performance evaluation. The algorithms were tested and validated by using the tuned PID controller parameters, *Kp, Ki* and *Kd.* Based on the results and analyses, CSA outperformed BA in terms of convergence rate which can be attributed to its advantage of automatic subdivision. However, in this research it can be concluded that BA is potentially a better tool to tune PID parameters. It seems to be a promising optimization algorithm due to the effect on objective function. There is certainly more testing issues that can be solved by utilizing BA in the future if more studies are directed on this algorithm. The standard deviation of objective function value is increased such as for BA 1.443e-04 and the CSA is 7.5113e-07 considered the performance parameter to be optimized despite minimizing the error signal.

ACKNOWLEDGMENT

This work was supported by Ministry of Science, Technology and Innovation (MOSTI) Malaysia, under the Science Fund grant scheme; grant number USM/305/PELECT/6013112.

REFERENCES

- Aleem, S. H. A., Zobaa, A. F. & Balci, M. E. 2017. Optimal resonance-free third-order high- pass filters based on minimization of the total cost of the filters using Crow Search Algorithm. *Electric Power Systems Research,* 151**,** 381-394.
- Askarzadeh, A. 2016. A novel metaheuristic method for solving constrained engineering optimization problems: crow search algorithm. *Computers & Structures,* 169**,** 1-12.
- Díaz, P., Pérez-Cisneros, M., Cuevas, E., Avalos, O., Gálvez, J., Hinojosa, S. & Zaldivar, D. 2018. An Improved Crow Search Algorithm Applied to Energy Problems. *Energies,* 11**,** 571.
- Fister, I., Fister, I., Yang, X. S., Fong, S. & Zhuang, Y. Bat algorithm: Recent advances. 2014 IEEE 15th International Symposium on Computational Intelligence and Informatics (CINTI), 19-21 Nov. 2014 2014. 163-167.

- Ibrahim, H., Hassan, F. & Shomer, A. O. 2014. Optimal PID control of a brushless DC motor using PSO and BF techniques. *Ain Shams Engineering Journal,* 5**,** 391-398.
- Jaiswal, M. & Phadnis, M. 2013. Speed control of DC motor using genetic algorithm based PID controller. *International Journal of Advanced Research in Computer Science and Software Engineering,* 3(7);247-253.
- Kamal, M. M., Mathew, L. & Chatterji, S. Speed control of brushless DC motor using intelligent controllers. Engineering and Systems (SCES), 2014 Students Conference on, 2014. IEEE, 1-5.
- LAKSHMI, M. & KUMAR, A. R. 2018. Optimal Reactive Power Dispatch using Crow Search Algorithm. *International Journal of Electrical & Computer Engineering (2088-8708),* 8.
- M. Zahir, A. A., Alhady, S. S. N., Othman, W. A. F. W. & Ahmad, M. F. Genetic Algorithm Optimization of PID Controller for Brushed DC Motor. *In:* Hassan, M. H. A., ed. Intelligent Manufacturing & Mechatronics, 2018// 2018 Singapore. Springer Singapore, 427-437.
- OU, C. & Lin, W. Comparison between PSO and GA for parameters optimization of PID controller. Mechatronics and Automation, Proceedings of the 2006 IEEE International Conference on, 2006. IEEE, 2471-2475.
- Said, G. A. E.-N. A., Mahmoud, A. M. & EL-Horbaty, E.-S. M. 2014. A comparative study of meta-heuristic algorithms for solving quadratic assignment problem. *arXiv preprint arXiv:1407.4863*.
- Sayed, G. I., Hassanien, A. E. & Azar, A. T. 2017. Feature selection via a novel chaotic crow search algorithm. *Neural Computing and Applications***,** 1-18.
- Singh, K., Vasant, P., Elamvazuthi, I. & Kannan, R. 2015. PID tuning of servo motor using bat algorithm. *Procedia Computer Science*, 60**,** 1798-1808.
- Tan, W., Marquez, H. J. & Chen, T. 2004. Performance assessment of PID controllers. *Control and intelligent systems,* 32**,** 158-166.
- Wang, X., YAN, X. & LI, D. A PID controller with desired closed-loop time response and stability margin. 2017 36th Chinese Control Conference (CCC), 26-28 July 2017 2017. 64-69.
- XIA, C., GUO, P., SHI, T. & WANG, M. Speed control of brushless DC motor using genetic algorithm based fuzzy controller. Proceeding of the 2004 International Conference on Intelligent Mechatronics and Automation, Chengdu, China, 3rd edn. A Treatise on Electricity and Magnetism, 2004. 68-73.
- Zaki, d. A., Hasanien, H. M., El-amary, N. H. & Abdelaziz, A. Crow search algorithm for improving the performance of an inverter-based distributed generation system. Power Systems Conference (MEPCON), 2017 Nineteenth International Middle East, 2017. IEEE, 656-663.

How to cite this article: Wahab AAA, Alhady SSN, Sofik NHB et.al. Optimization of PID controller using crow search algorithm and bat algorithm. International Journal of Research and Review. 2018; 5(10):101-107.

******