Optimal PID Controller Tuning for DC Motor Speed Control Using Smell Agent Optimization Algorithm

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Abstract- This paper presents an optimal PID controller for speed control of DC motor using Smell Agent Optimization (SAO) Algorithm. DC Motor is an energy converter which transforms electrical energy into mechanical energy used in several industrial applications. A SAO based PID is proposed for optimal tuning of the parameters of the controller to improve speed control of the motor. The SAO uses the phenomenon of smell perception and the intuitive trailing behaviour of an agent to identify the source of smell. The integral of time multiplied absolute error (ITAE) is taken as the objective function for obtaining the parameters of the PID controller. It has been observed SAO-PID controller outperforms the GA based PID controller with less settling time, rise time and overshoot.

Keywords- DC motor, PID controller, rising time, settling time, smell agent optimization algorithm

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1 INTRODUCTION

DC Motor is an energy converter which transforms an electrical energy into mechanical energy (Kushwah & Patra, 2014). Speed control of DC motor can be done by either keeping the armature winding current constant or the field winding current constant to achieve an excellent speed performance over a wide range of values (Sabir & Khan, 2014). DC motors are used several applications as in robotics, electric cranes, electric vehicles, disk drivers (Agnihotri et al., 2018; Kumar & Dohare, 2014; Kushwah & Patra, 2014; Sabir & Khan, 2014; Taki El-Deen et al., 2015). Features of DC motor include high starting torque, portability, conformity with different types of tuning methods (Abdulameer et al., 2016). Among the merits of DC motors include: easy to control, low maintenance, cheap and also rugged (Sabir & Khan, 2014). Various types of controllers include: lead, lag, LQR (linear quadratic regulator), PID (Proportional Integral Derivative) and slide mode control, could be integrated in control applications (Sabir & Khan, 2014).

In industries, over 95% of the controllers used are PID controllers, this is due to its high efficiency and ease of implementation. It has been used for several decades in industrial process applications (Agnihotri et al., 2018; Kushwah & Patra, 2014; Purnama et al., 2019; Sabir & Khan, 2014; Taki El-Deen et al., 2015). It has a disadvantage of; unsuitable speed overshoot and slow response to sudden change in load torque and sensitivity to controller gains. Designing a PID controller mechanism requires tuning of three parameters; proportional gain k_p, integral gain k_i and derivative gain k_d.

For optimal operation of a controller, the main aim of the controller is to minimize steady state error, rise time, overshoot and settling time. The performance of the controller depends on the accuracy of system design parameters (Kushwah & Patra, 2014; Mirzaei & Moattar, 2015; Purnama et al., 2019). Techniques used for tuning a PID controller can classified into two categories namely: the classical approaches and the metaheuristics techniques (Bansal et al., 2012).

In the classical approaches, Assumptions are made on the plant and the desired output to obtain the design parameters analytically or graphically (Bansal et al., 2012). The advantages of these techniques are; they are computationally fast, simple to implement and are good at first iteration. A disadvantage of these techniques is that, skill and experience are required in tuning a PID controller using the classical approach (Bansal et al., 2012; Sabir & Khan, 2014). Examples of the classical include; Ziegler method, Cohen coon method and Nichols method. In recent years, metaheuristics optimization techniques had been applied in every discipline (Sabir & Khan, 2014). A wide range of metaheuristic algorithms have being developed over the last three decades, and many metaheuristics are increasingly becoming popular (Yang, 2011). These metaheuristics techniques have been applied on control systems, and the results obtained shows significant improvement over classical techniques (Agnihotri et al., 2018; Ekinci et al., 2019; Ibrahim & Mahmoud, 2014; Meena & Chahar, 2017; Obeng & Karam, 2018; Sabir & Khan, 2014; Solihin et al., 2011; Taki El-Deen et al., 2015).

Abdulameer et al., (2016) designed a PID controller for DC speed motor using the Ziegler-Nichols and Chien-Hrones-Reswick method. Results shows that the Ziegler-Nichols has a faster system response with acceptable overshoot, while the Chien-Hrones-Reswick method has lower overshoot with acceptable transient response. Meena & Chahar, (2017) design a speed control DC motor

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Section B- ELECTRICAL/ COMPUTER ENGINEERING & RELATED SCIENCES
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using Genetic Algorithm. The GA PID was compared to Ziegle-Nichols (ZN) methods, and the results shows, the proposed GA gives less overshoot and less settling time, thus, it performs better than ZN. Taki El-Deen et al., (2015) designed an optimal PID tuning for DC motor based on Genetic Algorithm (GA) and Active Set Optimization Algorithm (ASOA). Simulation results show that the system performance was enhanced for GA-PID as compared to the ASOA-PID.

Solihin et al. (2011) design a PID controller using Particle Swarm Optimization (PSO) algorithm. Results obtained shows has less overshoot compared to the ZN method. Agnihotri et al., (2018) designed a PID controller tuned by PSO and Improved Grey Wolf Optimizer (IGWO) for a DC motor. Results obtained shows that the PSO and IGWO improve the performance characteristics of the DC motor, however, the IGWO has a better performance and owns good robustness towards the PSO. Obeng & Karam, (2018) proposed a PSO to the PID speed control of a permanent magnet DC motor. The PSO-PID was successful in reducing the overshoot and settling time of the DC Motor speed response. Ekinci et al., (2019) designed a PID tuned controller for the regulation of the speed of DC motor using the Harris Hawk Optimization (HHO) algorithm. Results obtained shows the HHO PID controller outperforms the atomic search optimization PID and the sine cosine algorithm PID.

Sabir & Khan, (2014) proposed a PID controller for speed control in a DC motor using a hybrid of Nelder-Mead (NM) method and PSO, GA and simulated annealing (SA). Results obtained for metaheuristic techniques show substantial improvement on the rise time, settling time and peak overshoot as compared to classical methods. The NM-SA method is more robust as compared to NM-GA and NM-PSO, GA, PSO and SA technique. Ibrahim & Mahmoud, (2014) proposed an improved ant colony optimization (ACO) for optimal tuning of PID parameters. The results obtained shows that the ACO has self-adaptation and positive feedback process to escape the trap of local minimum and achieve the best solution. The aim of this paper is to design a PID controller for speed control in DC motor using smell agent optimization algorithm. The results are compared to GA-PID controller, which is one of the most robust PID Controller. The system design requirement for the DC Motor is to have a settling time of less than 2 secs, the overshoot should be less than 5% and steady state error of not more than 1%.

2 MATHEMATICAL MODEL

2.1 MODEL OF DC MOTOR

A separately excited DC motor is shown in Fig. 1.

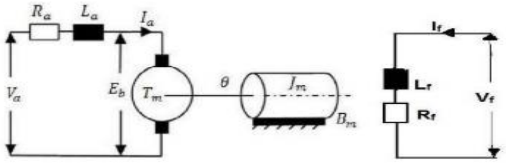

Fig. 1: Separately Excited DC Motor (Ibrahim & Mahmoud, 2014)

The equations governing the operation of a separately excited motor can be determined as:

$$V_a = I_a R_a + L_a \frac{dI_a}{dt} + E_b \tag{1}$$

V_a is the motor voltage, I_a is the armature current, R_a is the armature resistance, L_a is the armature inductance, E_b is back EMF

$$E_b = k_b \omega I_f \tag{2}$$

K_b is electromotive force constant, where ω is the speed of the motor, I_f is field current

$$T_d = k_t I_f I_a \tag{3}$$

T_d is motor developed torque, k_t is torque constant

$$T_d = J_m \frac{d\omega}{dt} + B\omega + T_L \tag{4}$$

J_m is the moment of inertia, B is damping ratio and T_L is load torque.

The transfer function of a DC motor considering the field current constant can be described as(Obeng & Karam, 2018):

$$G_m = \frac{\omega(s)}{V_a(s)} = \frac{k_t}{(J_m s + B)(R_a + L_a s) + k_t k_b} \tag{5}$$

The values of this parameters are adopted from the DC motor Pittman Model 9234S004 which are provided in Table 1 (Ibrahim & Mahmoud, 2014).

Table 1. DC Motor Parameters

Parameter	Value
k_t	$1.82 \times 10^{-2} NM/A$
k_b	$1.82 \times 10^{-2}\ vs/rad$
R_a	0.83Ω
I_a	$0.63mH$
J_m	$4.2 \times 10^{-6} kgm^2/rad$
B	$2.6 \times 10^{-6} Nms$

2.2 PID CONTROLLER

The PID controller is widely used in industries to solve various control problems. The main role of the PID controller is to make the plant less sensitive to changes in the surrounding (Taki El-Deen et al., 2015).The controller tries to minimize the error by adjusting the process control input(Kushwah & Patra, 2014). The PID controller calculation involves three constant parameters:k_p,k_i and k_d. Fig. 2 shows a block diagram of PID controller.

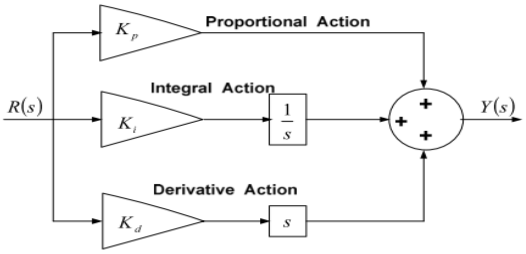

Fig. 2: Block diagram of PID Controller (Meena & Chahar, 2017)

The transfer function of PID controller is expressed as:

$$G_{PID} = k_p + \frac{k_i}{s} + k_d s \tag{6}$$

2.3 PID CONTROLLER DESIGN

In the design of PID controller using meta-heuristic techniques for PID tuning. The meta-heuristic techniques require cost functions for error minimization (Bansal et al., 2012). The four commonly used cost functions include: Integral Absolute Error (IAE), The integral square error

(ISE), The integral time absolute error (ITAE), Integral time square error (ITSE). In this paper, a SAO-PID controller was employed for speed control of a DC Motor. The ITAE was taken as objective function for tuning the PID controller as shown in Equation (7)

$$\left|1-\frac{G_m(s)G_{PID}(s)}{1-G_m(s)G_{PID}(s)}\right| \tag{7}$$

subject to the following constraint

$$(0.0001 \le k_p \le 100)$$
$$(0.0001 \le k_i \le 100)$$
$$(0.0001 \le k_d \le 50)$$

2.4 SMELL AGENT OPTIMIZATION

The Smell Agent Optimization (SAO) was developed in 2018 by Salawudeen *et al.* (2018). It uses the phenomenon of smell perception and the intuitive trailing behaviour of an agent to identify the source of smell. The algorithm was tested on standard bench mark test functions and compared to PSO, GA and Ant Bee Colony algorithm (ABC). The results observed shows the SAO is highly efficient and can also compete with meta-heuristic algorithms reported in the literature (Salawudeen et al., 2018). Table 2 shows the pseudo-code for SAO algorithm (Salawudeen et al., 2020). The SAO operates in three distinct modes (Salawudeen et al., 2020):

1) Sniffing Mode: The ability of an agent to perceive smell from a substance in an environment. The agent evaluates the concentration of the smell and decides to follow the smell molecules direction or not.
2) Trailing Mode: In the process of exploring the search space, the concentration of smell molecules may become higher than the current position of the agent, the agent moves towards that position.
3) Random Mode: The concentration of smell varies over time from one point to another, thereby confusing the agent, and the agent may lose the smell in trailing process. The agent may be trapped at local optimum, the agent then moves randomly hoping to find the smell molecule again.

Table 2. SAO Algorithm Pseudo-code

```
Let N: Number of smell molecules;
    D: Search space where the smell molecules evaporate
    a. Initialize SAO parameters $(k\ olf, T, m)$
    b. Randomly initialize smell molecules and its velocity
    c. For each molecule from 1 to N
        i. Update molecules velocity and position
        ii. Evaluate fitness
        iii. Determine agent position and worst molecules position
        iv. Evaluate the random mode and its fitness
        v. If ii is better than iv move to vi else move to d
        vi. Evaluate the random mode and its fitness
    d. Repeat step c until maximum iteration is reach
    e. Sort all molecules and determine the smell source.
```

3 RESULTS AND DISCUSSION

Referring to Equation (5), substituting the design parameters in Table 1, the transfer function of the DC motor was obtained as shown in Equation (8).

$$G_m = \frac{0.0182}{2.64\times10^{-10}s^2+3.486\times10^{-6}s+0.000334} \tag{8}$$

From Equation (8), it can be seen that the DC motor is a second order system. Figure 3 shows the open loop response of the DC Motor to a unit step input. The closed loop response of the DC Motor to a unit step input is presented in Fig. 4. It can be observed from Fig. 3 and Fig. 4, the DC Motor exhibit damped oscillation before attaining a steady state.

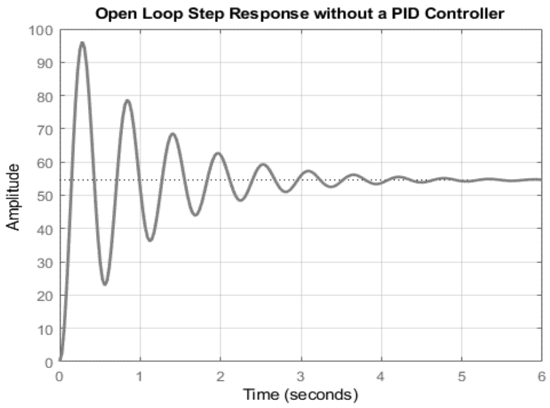

Fig. 3: Open loop step response of DC Motor

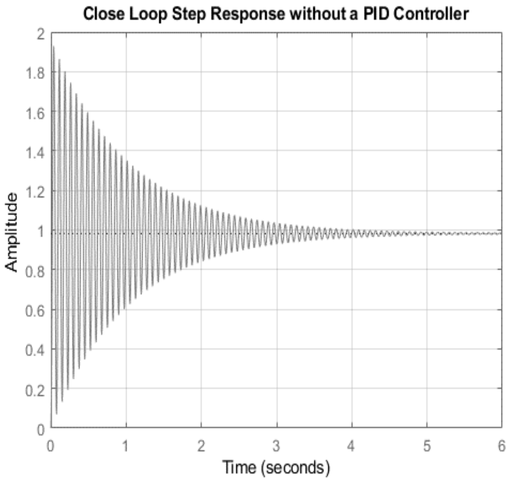

Fig. 4: Closed loop step response of DC Motor

Table 3 is the summary of the DC Motor characteristics for both the open and closed loop

Table 3. DC Motor Step Response

Parameter	Open Loop	Closed Loop
Overshoot (%)	76.18	96.43
Rise Time, (T_r)	0.099s	0.013s
Settling Time (T_s)	3.973s	4.019s

3.1 SAO PID CONTROLLER

The SAO- PID controller was designed for the optimal tuning of the controller parameters to reduce the error between the system output and the desired output. SAO-PID algorithm was implemented in MATLAB R2020A using Equation (7) as objective function to minimize the error and determine the PID gain parameters. The parameters for the SAO-PID algorithm are presented in Table 4. A total number of 50 iterations was considered, it was observed that the error between the system output and the desired output kept decreasing as the number of iterations increases as shown in Fig. 4, the optimal values of k_p, k_i and k_d are obtained at the 50th iteration.

Table 4. Parameters of SAO-PID

Parameter	Value
Population of smell molecules	50
Number of iterations	50

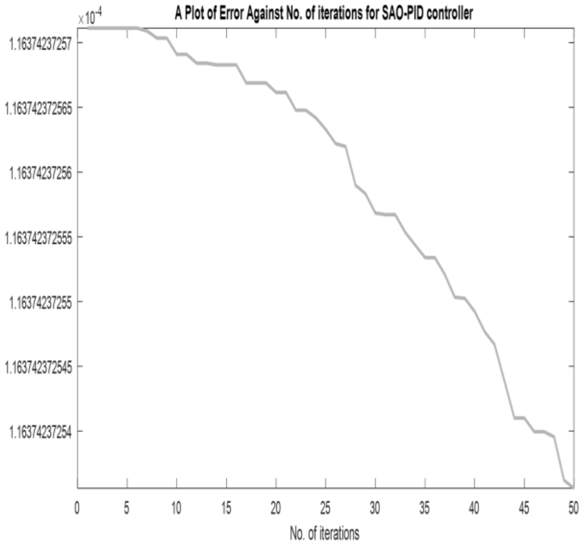

Fig. 5: Plot of Error against the Number of Iterations in SAO-PID Controller

Fig. 6 shows the step response of the DC Motor using the SAO-PID controller. It can be observed that the system overshoot is 0, rising time is 7.214×10^{-6} secs and the settling time 1.254×10^{-5} secs. The parameters for the optimal tuning of the SAO-PID algorithm are $k_p = 93.78, k_i = 45.39$ and $k_d = 44.28$

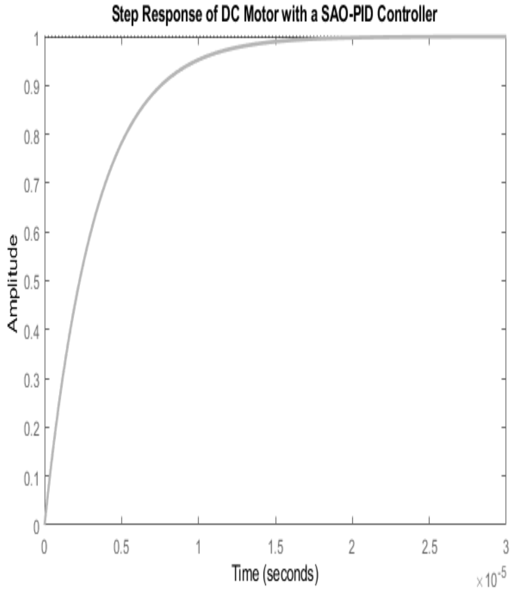

Fig. 6: Step Response of DC Motor Using SAO-PID Controller

3.2 GA PID CONTROLLER

The GA-PID Controller was implemented in MATLAB R2020A toolbox using Equation (6) as objective function to minimize the error and determine the PID gain parameters. The parameters for the GA-PID algorithm are presented in Table 5.

Table 5. Parameters of GA-PID

Parameter	Value
Population	50
Number of iterations	50

Fig. 7 shows the step response of the DC Motor using the GA-PID controller. It can be observed that the system overshoot is 0.6458, rising time is 2.311×10^{-4} secs and the settling time is 3.898×10^{-4} secs. The parameters for the optimal tuning of the GA-PID controller are $k_p = 99.997, k_i = 99.999$ and $k_d = 1.351$

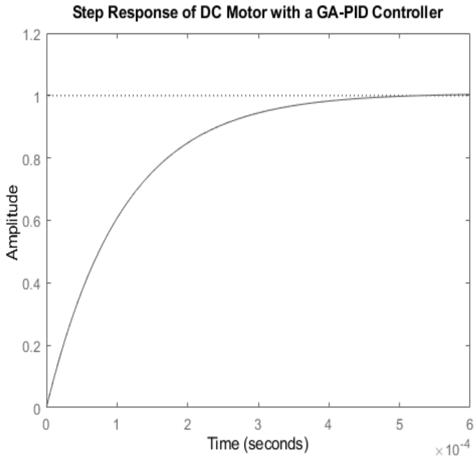

Fig. 7: Step response of the DC Motor using the GA-PID controller

3.3 COMPARISON BETWEEN SAO-PID AND GA-PID

Fig. 8 shows the comparison between the step response of the DC Motor using the SAO-PID controller and the GA-PID controller. it can be observed that both the SAO-PID and GA-PID satisfy the system design requirement of 2% overshoot and less than 1% settling time. The GA-PID controller converges faster than the SAO-PID controller, however the SAO-Controller is more robust than the GA-PID controller. Table 6 shows the system characteristics for both the SAO-PID and the GA-PID.

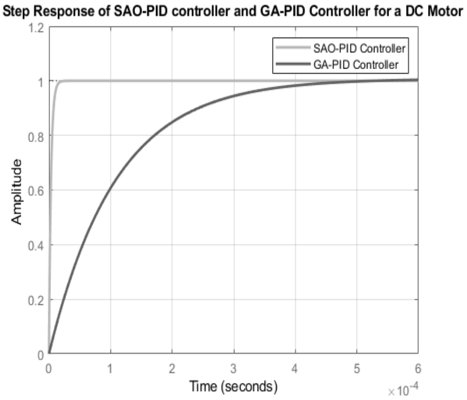

Fig. 8: Comparison between the step response of the DC Motor using the SAO-PID controller and the GA-PID controller

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Table 6. Comparison between SAO-PID and GA-PID

	k_p	k_i	k_d	e
SAO-PID	93.78	45.39	44.28	1.164×10^{-5}
GA-PID	99.997	99.999	1.351	4.969×10^{-5}

4 CONCLUSION

In this study, an optimal Smell Agent Optimization based PID Controller was developed. The ITAE is taken as the fitness function to study the rising time, settling time and overshoot of a DC Motor. The SAO-PID controller is applied to a DC Motor as a test benchmark for speed control. Results show that the SAO-PID has significantly enhanced the system performance and the system design goals are met. Further work could be carried out to study the performance of SAO on the optimal tuning of LQR controller.

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REFERENCES

Abdulameer, A., Sulaiman, M., Aras, M., & Saleem, D. (2016). Tuning Methods of PID Controller for DC Motor Speed Control. *Indonesian Journal of Electrical Engineering and Computer Science*, *3*(2), 343. https://doi.org/10.11591/ijeecs.v3.i2.pp343-349

Agnihotri, A., Rahul, S., & Pal, S. H. (2018). Performance Analysis of DC motor using PID controller tuned by Metaheuristic Techniques. *International Journal of Innovations in Engineering, Management and Science (IJIMES)*, *1*(3), 1–7. http://www.ijimes.org/wp-content/uploads/2019/12/131.pdf

Bansal, H. O., Sharma, R., & Shreeraman, P. R. (2012). PID Controller Tuning Techniques: A Review. *Journal of Control Engineering and Technology*, *2*(4), 168–176.

Ekinci, S., Hekimoglu, B., Eker, E., & Sevim, D. (2019). Hybrid Firefly and Particle Swarm Optimization Algorithm for PID Controller Design of Buck Converter. *2019 3rd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), December*, 1–6. https://doi.org/10.1109/ISMSIT.2019.8932733

Ibrahim, H. E. A., & Mahmoud, A. A. H. (2014). DC Motor Control Using PID Controller Based on Improved Ant Colony Algorithm. *International Review of Automatic Control (IREACO)*, *7*(1), 1–7. https://doi.org/10.15866/ireaco.v7i1.1283

Kumar, P., & Dohare, D. (2014). Comparison of Performance Measures of Speed Control for a DC Motor Using Hybrid Intelligent Controller and Optimal LQR. *Applied Mechanics and Materials*, *622*(May 2017), 23–31. https://doi.org/10.4028/www.scientific.net/AMM.622.23

Kushwah, M., & Patra, P. A. (2014). Tuning of PID controller for speed control of DC motor using soft computing techniques - A review. *Advances in Electronic and Electric Engineering*, *4*, 141–148.

Meena, D. K., & Chahar, S. (2017). Speed control of DC servo motor using genetic algorithm. *2017 International Conference on Information, Communication, Instrumentation and Control (ICICIC)*, *2018-Janua*, 1–7. https://doi.org/10.1109/ICOMICON.2017.8279122

Mirzaei, S. M., & Moattar, M. H. (2015). Optimized PID Controller with Bacterial Foraging Algorithm. *International Journal of Electrical and Computer Engineering (IJECE)*, *5*(6), 1372. https://doi.org/10.11591/ijece.v5i6.pp1372-1380

Obeng, B. B., & Karam, M. (2018). *PID Speed Control of a DC Motor Using Particle Swarm Optimization* (S. Latifi (ed.); Vol. 558, Issue October 2017, pp. 781–789). Springer International Publishing. https://doi.org/10.1007/978-3-319-54978-1_97

Purnama, H. S., Sutikno, T., Alavandar, S., & Subrata, A. C. (2019). Intelligent Control Strategies for Tuning PID of Speed Control of DC Motor - A Review. *2019 IEEE Conference on Energy Conversion (CENCON)*, 24–30. https://doi.org/10.1109/CENCON47160.2019.8974782

Sabir, M. M., & Khan, J. A. (2014). Optimal Design of PID Controller for the Speed Control of DC Motor by Using Metaheuristic Techniques. *Advances in Artificial Neural Systems*, *2014*, 1–8. https://doi.org/10.1155/2014/126317

Salawudeen, Ahmed T., Mu'azu, M. B., Sha'aban, Y. A., & Adedokun, E. A. (2018). *From Smell Phenomenon to Smell Agent Optimization (SAO): A Feasibility Study*. *Ci*, 79–85.

Salawudeen, Ahmed Tijani, Nyabvo, P. J., Nuhu, A. S., Akut, E. K., Cinfwat, K. Z., Momoh, I. S., & Imam, M. L. (2020). Recent Metaheuristics Analysis of Path Planning Optimization Problems. *2020 International Conference in Mathematics, Computer Engineering and Computer Science (ICMCECS), March*, 1–7. https://doi.org/10.1109/ICMCECS47690.2020.240845

Solihin, M. I., Tack, L. F., & Kean, M. L. (2011). Tuning of PID Controller Using Particle Swarm Optimization (PSO). *International Journal on Advanced Science, Engineering and Information Technology*, *1*(4), 458. https://doi.org/10.18517/ijaseit.1.4.93

Taki El-Deen, A., Mahmoud, A. A. H., & R. El-Sawi, A. (2015). Optimal PID Tuning for DC Motor Speed Controller Based on Genetic Algorithm. *International Review of Automatic Control (IREACO)*, *8*(1), 80. https://doi.org/10.15866/ireaco.v8i1.4839

Yang, X.-S. (2011). Metaheuristic Optimization: Algorithm Analysis and Open Problems. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 6630 LNCS* (pp. 21–32). https://doi.org/10.1007/978-3-642-20662-7_2