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Intelligent PID Controller Tuned by Bacterial Foraging Optimization Algorithm for Vibration Suppression of Horizontal Flexible Structure

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***Abstract*—Flexible structure offers various advantages such as being lightweight, efficient, quick system response and low energy consumption. However, this structure produces too much vibration which leads to system failure. To overcome this drawback, this project developed an intelligent vibration controller based on Bacterial Foraging Optimization (BFO) and incorporated into a Proportional-Integral-Derivative (PID) controller. BFO is a metaheuristic approach categorized as an evolutionary algorithm recently developed, and a nature-inspired optimization algorithm. BFO has been successfully applied to solve some engineering problems due to its simplicity and ease of implementation. Therefore, by introducing BFO to the PID controller, the desired parameters to control vibration experienced by a horizontal flexible plate can be easily found. The performance of the intelligent PID controller was compared to the conventional tuning method known as Ziegler-Nichols (ZN). It was noticed that the PID controller tuned by BFO successfully outperformed the PID controller tuned by ZN by achieving a high attenuation at the first mode of vibration of 44.65 dB as compared to the latter which was only attenuated at the first mode of vibration at 12.8 dB. The developed PID controller was also able to maintain a good performance level even when this system was introduced to multiple sinusoidal disturbance.**

***Keywords*—Horizontal flexible plate, PID controller, Bacterial foraging optimization algorithm, Active vibration control, intelligence controller**

I. INTRODUCTION

Flexible structure is widely used in engineering applications such as the construction of bridge decks, satellite panels, electronic circuit board design, solar panels, winglet part in the airplane and automotive parts in various industries. Flexible structure consists of plates, shells, beams and frames which gives many advantages such as being lightweight, low energy consumption, safer operation, faster system response and reduced maintenance requirements. However, when subjected to disruptive forces such as external vibrations, the flexible flat thin plates are easily altered. Thus, this undesirable vibration needs to be removed to maintain the performance of the system. Recently, many researchers have had their attention drawn to replace such structures with flexible plate structure as it offers some advantages such as being lightweight, minimum power consumption, small actuator criteria and low rigidity specifications [1,2].

To suppress unwanted vibrations, researchers have come up with many vibration control techniques such as passive, semi-active and active [3-5]. Passive vibration control (PVC) was extensively by many researchers to suppress the excessive vibration on the structure. However, it does experience some limitations due to its heavy structure. Then, in the early 1930s, Lueg introduced active vibration control (AVC) to tackle the limitations of PVC [6].

AVC became prominent among earlier researchers as it was able to address the shortcomings of PVC. Various research were conducted to study AVC in a system. Wang and Mak (2017) investigated the use of a portable active vibration control on a moving raft to regulate time-varying disturbances [7]. On the other hand, Liu (2019) proposed prototypes of wind tunnels using an active damping vibration control system [8]. Proportional-Integral-Derivative (PID) controller has been used to provide an appropriate parameter to suppress external disturbances. Previously, the well-known loop tuning approach for adjusting PID parameters, commonly known as the ZN tuning rules, was devised by John G. Ziegler and Nathaniel B. Nichols in 1942. This technique has been widely used in various industrial applications and has been effectively applied into feedback control systems [9].

However, when applied to industrial facilities, the ZN formula still has problems to determine the parameter gains of a PID controller. Currently, many researchers have considered the uses of optimization algorithms to tune the parameters of PID controller, for instance the Artificial Bee Colony (ABC) Algorithm, particle swarm optimization (PSO) Algorithm, Genetic Algorithm (GA), Bio-Inspired Algorithm, Reactive Evolutionary Algorithms and Bacterial Foraging Optimization (BFO) Algorithm [10]. Recently, BFO has received remarkable attention among researchers due to its simplicity and fast convergence in problem solving. Inspired by its simplicity, this study aims to develop an intelligence PID controller tuned by the BFO Algorithm for vibration suppression of a horizontal flexible plate structure and the performance is to be compared to the Ziegler-Nichols tuning method, a more traditional tuning technique.

II. METHODOLOGY

First and foremost, the presented control strategy for the implementation of the flexible plate system AVC. AVC is a technique that used in a development of a PID controller. AVC will apply an electromechanical device that employs superposition waves and destructive interference to reduce vibrations at specific areas [11]. After that, when the system's sensors identify undesired disturbances, the AVC reacts by using the controller to assess the vibration, thus dampening the oscillation exerted on the flexible plate system. Figure 1 illustrates a closed loop system's block diagram for a flexible plate utilizing AVC configuration.

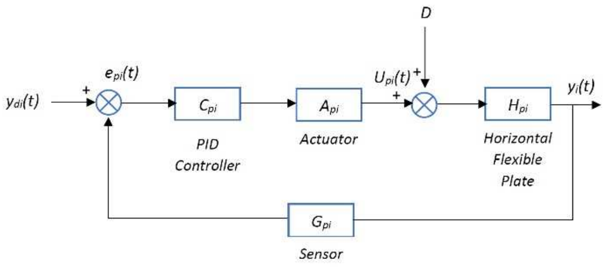

Fig. 1. Closed loop system's block diagram for flexible plate AVC configuration.

All whilst, the intelligent PID was optimised offline using the bioinspired optimizer, BFO algorithm. BFO algorithm is rooted on the foraging behaviour of *E. Coli* [12]. Despite being in the infancy of development, the BFO algorithm surpasses numerous different heuristic schemes by means of convergence speed and exploitation of the search space. This effectively monitors the optimum vibration attenuation for the proposed system. Further to that, offline computation was used to explore the effectiveness of the BFO optimizations on the horizontal flexible plate system. Then, the simulation of the system was validated through several methods. Validation of the model is a vital technique to ensure that the best and suitable model is used to characterise the system's structure. In this study, the minimum Mean Squared Error (MSE) was used to determine the best model outcome. MSE is the difference between the system's real performance and the forecasted performance. Fig. 2 presents a flowchart of the BFO used in this study.

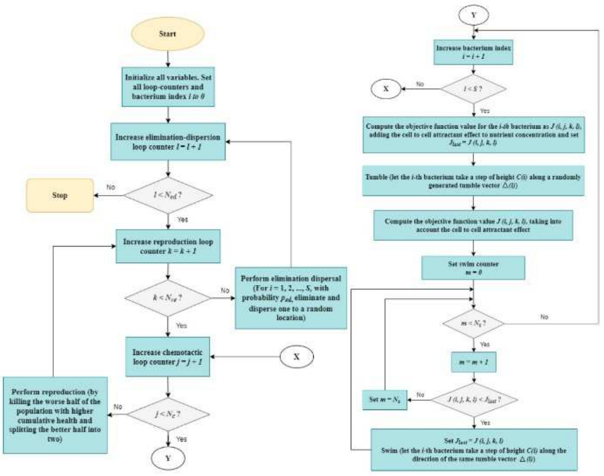

Fig. 2. Flowchart of BFO algorithm

The discrete transfer function of the horizontal flexible plate system used in the controller development was derived using PSO modelling. Equation (1) presents the discrete transfer function based on PSO modelling used in the PID controller [1].

$$H(z)_{PSO} = \frac{0.3483z^{-1} - 0.0022z^{-2}}{1 - 1.414z^{-1} + 0.9931z^{-2}} \tag{1}$$

Ziegler-Nichols is one of the common conventional methods used to adjust the parameters of a PID controller. In this study, the second approach was used to tune the parameter of the PID controller. The gain value of the integral, *I* and derivative, *D*, are firstly set to zero. The gain value of the proportional, *P* is then raised from zero to an optimal value of K_P, defined as K_U. The oscillation response was in sustaining mode, and the frequency period of its oscillations was measured and designated as T_U. The value of K_U and T_U obtained based on ZN method are 1.11 and 0.036, respectively.

For the intelligent PID controller tuned by the BFO algorithm, the parameter of algorithm was tuned properly based on the objective function set in the algorithm known as lowest MSE. The parameters of the BFO algorithm consists of run length (*C(i)*), number of bacteria (*S*), number of reproduction steps (*Nre*), number of elimination-dispersal events (*Ned*), and the number of chemotactic steps (*Nc*). Initially, the number of bacteria was tuned from 10 to 40 and value of other parameters was fixed. Next, the tuning step was continued by varying the reproduction value (*Nre*) from 2 to 8. Then, the numbers of elimination-dispersal (*Ned*) were varied from 10, 30, and 50. This value demonstrates how the BFO algorithm works to identify a good position inside the search space. Finally, the value of chemotactic steps (*Nc*) was altered from 5, 8, 9 and 10. The best parameter of BFO algorithm used in this study are shown in Table 1.

TABLE I. THE BEST PARAMETER OF BFO ALGORITHM

Initialized parameters	**Value of parameters**
Dimension of search space, *p*	3
The number of bacteria, *S*	10
Number of chemotactic steps, *Nc*	5
The length of a swim, *Ns*	4
The number of reproduction steps, *Nre*	4
The number of elimination-dispersal events, *Ned*	50
The number of bacteria reproductions (splits) per generation, *Sr*	5
The probabilty that each bacterium will be eliminated/dispersed, *Ped*	0.25
The run length, *C(i)*	0.05

III. RESULT AND DISCUSSION

This section discuss on the simulation result of PID controller tuned by Ziegler-Nichols (PID-ZN) and PID controller tuned by bacterial foraging optimization (PID-BFO). The performance of the developed controller was then compared in term of attenuation level at the first mode of vibration and lowest mean squared error. The robustness of the developed controller was then validated by exerting different types of disturbances onto the system.

A. *Simulation Result of PID controller Tuned by Ziegler-Nichols*

Initially, the performance of the controller was evaluated based on a single sinusoidal disturbance. The findings indicates that the PID-ZN controller successfully attenuated the first mode of vibration with a 12.8 dB attenuation which is equivalent to 12.37 % suppression. The controller suppressed the magnitude of the vibration from 103.47 dB to 90.56 dB with a 0.1710 MSE value when the controller was activated. Table II presents the parameters obtained for the PID using ZN tuning method. Figs. 3 and 4 illustrate the simulation results of PID-ZN controller under single sinusoidal disturbance in time and frequency domains, respectively.

TABLE II. PID PARAMETERS USING ZN TUNING METHOD

controller	**Parameter**			**MSE**
	K_P	***K_I***	***K_D***	
PID-ZN	0.66	36.67	0.00297	0.1710

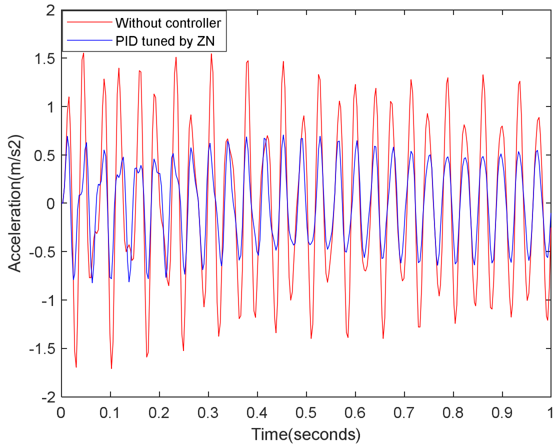

Fig. 3. PID-ZN controller under sinusoidal disturbance in time domain.

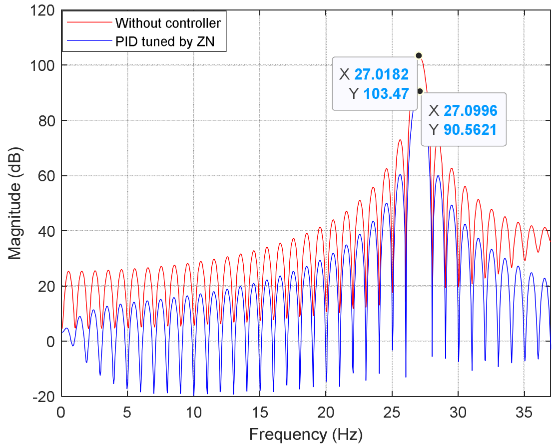

Fig. 4. PID-ZN controller under sinusoidal disturbance in frequency domain.

To verify the robustness of the developed controller, the controller was tested by exerting multiple sinusoidal disturbance in the controller block diagram with the same PID parameters used in sinusoidal disturbances. It was noticed that the controller successfully reduced the excessive vibrations under multiple sinusoidal disturbances. It was also noticed that the controller has successfully attenuated 12.8 dB at the first mode of vibration which is equivalent to 10.91 % suppression. The magnitude of the frequency decreased from 117.24 dB to 104.43 dB with a best MSE value obtained at 0.6842. Figs. 5 and 6 illustrate the simulation results of PID-ZN controller under multiple sinusoidal disturbance in time and frequency domains, respectively.

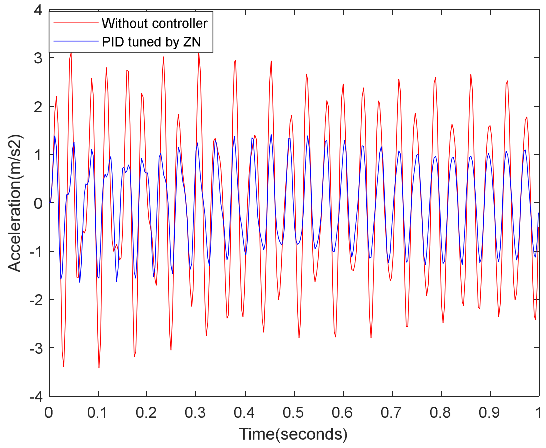

Fig. 5. PID-ZN controller under multiple sinusoidal disturbance in time domain.

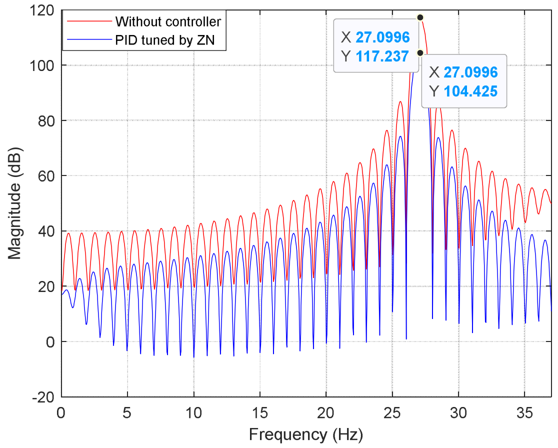

Fig. 6. PID-ZN controller under multiple sinusoidal disturbance in frequency domain.

B. *Simulation Result of PID controller Tuned by Bacterial Foraging Optimization Algorithm*

Similar to the PID-BFO controller, the performance of the controller was initially analysed by introducing a single sinusoidal disturbance onto the system. It was indicated that the PID-BFO performed well under this type of disturbance by achieving a high attenuation value at the first mode vibration with a 45.45 dB attenuation which is equivalent to 43.90 % of suppression. The magnitude of the frequency decreased from 103.48 dB to 58.03 db. In addition, the controller successfully achieved the lowest MSE value in the system as compared to PID-ZN which the value of MSE achieved was 0.0054. Table III presents the PID parameter obtained using the BFO algorithm. Figs. 7 and 8 illustrates the simulation results of PID-BFO controller under a single sinusoidal disturbance in time and frequency domains, respectively.

TABLE III. PID PARAMETERS USING BFO ALGORITHM

controller	**Parameter**			**MSE**
	K_P	***K_I***	***K_D***	
PID-BFO	8.732	21.07	0.00455	0.0054

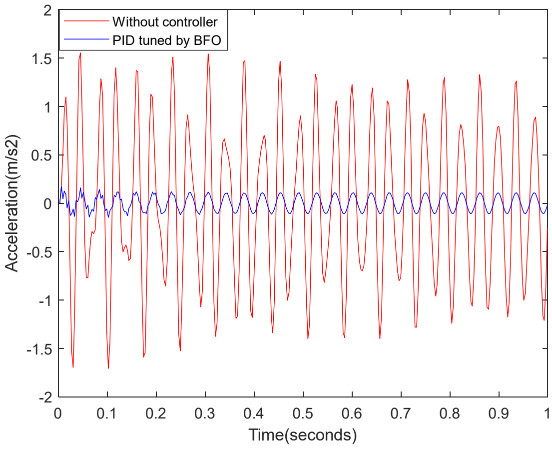

Fig. 7. PID-BFO controller under sinusoidal disturbance in time domain.

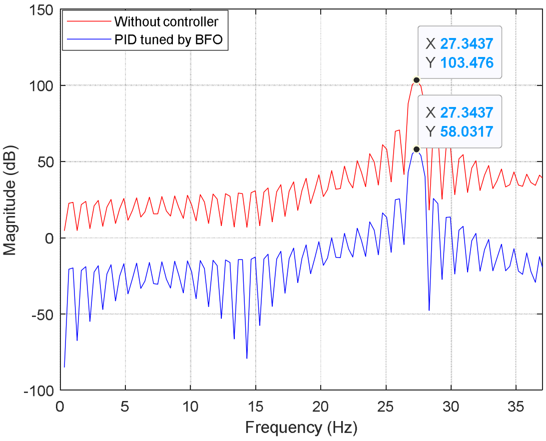

Fig. 8. PID-BFO controller under sinusoidal disturbance in frequency domain.

In order to verify the robustness of the developed PID-BFO controller, the controller was tested by introducing multiple sinusoidal disturbances in the controller block diagram with the same PID parameters used in the sinusoidal disturbance. It can be seen that the controller performed well by achieving good attenuation in suppressing the excessive vibration experienced by the system. The controller successfully attenuated 45.45 dB which is equivalent to 38.74 % of suppression. The magnitude of the frequency was diminished from 117.34 dB to 71.88 dB with the lowest MSE value achieved is 0.0054. Figs. 9 and 10 presents the simulation result of PID-BFO controller under multiple sinusoidal disturbances in time and frequency domains, respectively.

C. *Comparative assessment*

In this research, PID parameters were tuned using two different approaches, namely conventional and intelligent methods. Then, the robustness of the developed controller was validated by exerting different types of disturbances in the system. The results suggest that both proposed methods were successful in controlling the excessive vibration exerted of the horizontal flexible plate system. However, it was revealed that the PID controller tuned by BFO algorithm outperformed the PID controller tuned by the ZN method where PID-BFO controller successfully attained a high vibration reduction experienced by the horizontal flexible plate system. The algorithm parameters of the BFO algorithm were effectively tuned and this contributed to achieving the best vibration suppression in the system.

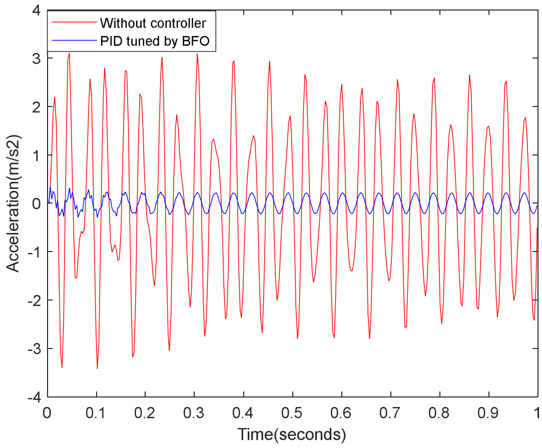

Fig. 9. PID-BFO controller under multiple sinusoidal disturbance in time domain.

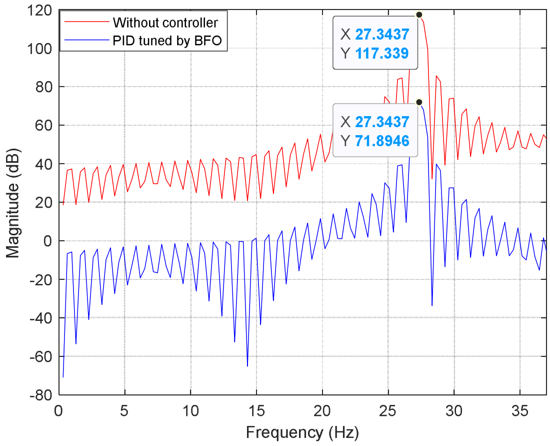

Fig. 10. PID-BFO controller under multiple sinusoidal disturbance in frequency domain.

Moreover, the PID-BFO efficiently produced 44.65 dB of vibration suppression at the primary mode compared to the PID-ZN which only produced 12.80 dB of vibration suppression. This was due to the flexibility of the intelligent controller, the proper tuning of the BFO algorithm parameter which gives more flexibility in searching the best PID parameter to attenuate the undesired vibrations experienced by the system [13]. PID-BFO also accomplished the lowest MSE in the system. The PID-BFO attained the lowest MSE of by 0.0054 compared to the PID-ZN which only achieved a MSE value of 0.1710. The BFO algorithm has the ability of dynamic tuning in order to find the best parameter for the system [14]. Thus, it is confirmed that an intelligent PID controller using BFO algorithm was successfully developed to suppress the unwanted vibration experienced by horizontal flexible plate structure.

IV. CONCLUSION

Two different methods were used, known as conventional method via Ziegler-Nichols tuning rules and intelligent method via BFO algorithm. Performance of the developed controller was validated by introducing different types of disturbances into the system. The performance of the controller was evaluated and assessed based on high attenuation at the first mode of vibration and lowest MSE value achieved in the system.

Here, the developed intelligent PID controller was successful in suppressing the unwanted vibration experienced by the horizontal flexible plate system by achieving high attenuation levels at the first mode of vibration and a lowest MSE as compared to the conventional approach. The intelligent PID controller also proved its robustness by achieving a high attenuation level at the first mode of vibration and a lowest MSE after the system was introduced with multiple sinusoidal disturbance. Thus, it is confirmed that the objective of this study to develop an intelligent controller to reduce the excessive vibration in the horizontal flexible structure was successfully achieved.

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REFERENCES

[1] M. S. Hadi, I. Z. M. Darus, M. H. Ab.Talib, H. M. Yatim, and M. O. Tokhi, “Vibration suppression of the horizontal flexible plate using proportional– integral–derivative controller tuned by particle swarm optimization,” Journal of Low Frequency Noise, Vibration and Active Control, vol. 40, no. 3, pp. 1540–1557, 2021.

[2] M. S. Hadi and I.Z.M. Mat Darus, “Modelling of horizontal flexible plate structure using artificial bee colony algorithm,” International Journal of Engineering & Technology, vol. 7, no. 4.36, pp. 415, 2018.

[3] A. Madkour, M. A. Hossain, K. P. Dahal, H. Yu, “Intelligent learning algorithms for active vibration control,” IEEE Transactions on Systems, Man and Cybernetics, Part C (Applications and Reviews), vol. 37, no. 5, pp. 1022–1033, 2021.

[4] M. S. Saad, H. Jamaluddin and I. Z. M. Darus, “Online monitoring and self-tuning control using pole placement method for active vibration control of a flexible beam,” Journal of Vibration Control, vol. 21, pp. 449-460, 2015.

[5] I. Z. M. Darus, T. A. Z. Rahman & M. Mailah, “Experimental evaluation of active force vibration control of a flexible structure using smart material,” International Review of Mechanical Engineering, vol. 5, pp. 1088-1094, 2011.

[6] S. Rodriguez, “Oscillations of velocity of sound”, Magnetic Oscillations in Metals, pp. 518–520, 1984.

[7] Z. Wang, and C. M. Mak, “Application of a movable active vibration control system on a floating raft,” Journal of Sound and Vibration, vol. 414, pp. 233–244, 2018.

[8] W. Liu, M. Zhou, Z. Wen, Z. Yao, Y. Liu, S. Wang, X. Cui, X. Li, B. Liang, and Z. Jia, “An active damping vibration control system for wind tunnel models,” Chinese Journal of Aeronautics, vol. 32, no. 9, pp. 2109–2120, 2019.

[9] D. Vale´rio and J. S. D. Costa, “Ziegler-Nichols type tuning rules for fractional PID controllers,” vol. 6: 5th International Conference on Multibody Systems, Nonlinear Dynamics, and Control, Parts A, B, and C, 2005.

[10] M. S. Hadi, H. M. Yatim, and I. Z. M. Darus, “Modelling and control of horizontal flexible plate using particle swarm optimization,” International Journal of Engineering & Technology, vol. 7, no. 2.29, pp. 13, 2018.

[11] M. S. Hadi, I. Z. M. Darus and H. Yatim, “Modeling flexible plate structure system with free-free-clamped-clamped (FFCC) edges using particle swarm optimization,” IEEE Symposium on Computers; Informatics (ISCI), 2013.

[12] Y. Liu, L. Tian, and L. Fan, “The hybrid bacterial foraging algorithm based on many-objective optimizer,” Saudi Journal of Biological Sciences, vol. 27, no. 12, pp. 3743–3752, 2020.

[13] A. A. Khan and N. Rapal, “Fuzzy PID controller: design, tuning and comparison with conventional PID controller,” IEEE International Conference on Engineering of Intelligent Systems, 2006.

[14] C. Guo, H. Tang, B. Niu, and C. Boon Patrick Lee, “A survey of bacterial foraging optimization,” Neurocomputing, vol. 452, pp. 728–746, 2021.