An Enhanced Auto-tuning approach for PID Controllers

Hindol Paul, Saswata Paul, Romit Chatterjee, Amit Sanyal and Indrajit Pandey

***Abstract*--The PID controller is a particularly easy but effective commercial manipulating tool presenting fast and sturdy responses. Due to its simplicity, it is nevertheless used in lots of commercial applications. Ziegler-Nichols (ZN) tuning is the most famous tuning technique used for PID controllers. However, ZN tuning affords excessively massive overshoot for better order and non-linear processes and isn't tolerable in a maximum of situations. The layout of the PID controller is a trouble of substantial theoretical and realistic importance. The ZN technique affords a very massive overshoot for excessive-order and nonlinear processes. There are many unique strategies to be had for tuning PID controllers which include analytical, direct search, and heuristic strategies. Among the numerous heuristic strategies, the maximum broadly used heuristic strategies are Ziegler-Nichols (ZN) and Cohen-Coon (CC) strategies. The ZN and CC strategies are appropriate for linear processes. Many strategies had been proposed to enhance the overall performance of ZN-tuned PID controllers in beyond few years. The proposed augmented ZNPID (AZNPID) guarantees high-quality closed-looped reactions on numerous excessive order linear and non-linear dead-time processes. This report presents results for four systems using the Ziegler-Nichols (ZN) tuning method in the MATLAB simulation environment. We then revisit the four example systems and perform the proposed Augmented Ziegler-Nichols (AZN) PID tuning procedure. It shows satisfactory closed-loop responses to a variety of higher-order linear and nonlinear dead-time processes.**

***Index Terms*--Auto tuning, Ziegler-Nichols, PID Controller, Augmented Ziegler-Nichols (AZN), PID tuning.**

Hindol Paul is with the Department of Applied Electronics and Instrumentation Engineering, Techno International New Town, Kolkata, India.
Saswata Paul is with the Department of Applied Electronics and Instrumentation Engineering, Techno International New Town, Kolkata, India.
Romit Chatterjee is with the department of Applied Electronics and Instrumentation Engineering, Techno International New Town, Kolkata, India.
Amit Sanyal is with the department of Applied Electronics and Instrumentation Engineering, Techno International New Town, Kolkata, India.
Indrajit Pandey is with the department of Applied Electronics and Instrumentation Engineering, Techno International New Town, Kolkata, India. (email:Indrajit.pandey@tict.edu.in).

I .INTRODUCTION

The Zigler-Nichols (ZN) tuning approach is a famous heuristic approach for PID controller tuning that changed into brought with inside the 1940s. The approach is primarily based totally on step reaction experiments, which contain making use of a step entry to the machine and gazing at its reaction. The ZN approach includes locating the last gain (ku) and the last period (Tu) of the machine, which are used to calculate the proportional, integral, and spinoff profits of the PID controller. [2]
The ZN tuning approach is straightforward and clean to implement, that's why it's extensively utilized in practice. However, it's acknowledged to bring about overshoot and gradual reaction instances for a few systems that could result in bad performance. Therefore, the ZN approach is regularly used as a start line for similar tuning, in preference to as a very last tuning approach. [4]
Many different tuning strategies have evolved over the years, which include analytical strategies, direct seek strategies and heuristic strategies. These strategies can offer greater correct tuning parameters than the ZN approach, however, they also can be more complicated and time-eating to implement. Some examples of those strategies consist of the Cohen-Coon approach, the Tyreus-Luyben approach, and the particle swarm optimization approach. [5]
In summary, whilst the ZN tuning approach stays famous because of its simplicity and simplicity of use, it's essential to notice that it can now no longer usually bring about the most efficient performance. Engineers ought to not forget the use of different tuning strategies if they require greater correct tuning parameters or higher performance.
Another method is the benefit schedule, which entails the use of a couple of PID controllers with unique tuning parameters to manipulate the device at unique running points. This technique may be powerful for nonlinear strategies in which the conduct of the device modifications extensively over its running range. [6]
There also are many different tuning techniques that have been proposed for high-order and nonlinear strategies, which includes techniques primarily based totally on frequency reaction analysis, adaptive management, and fuzzy logic. [9] [10]

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In summary, whilst the Ziegler-Nichols and Cohen-Coon tuning techniques won't be appropriate for all strategies, there are numerous different strategies to be had which can offer higher overall performance for high-order and nonlinear systems. It is vital for engineers to cautiously not forget the traits in their method and pick out a tuning approach that is suitable for their unique application.

The proposed control scheme helps to provide efficient set point tracking and load disturbance rejection for higher-order linear and non-linear processes with dead time. [8]

In Ziegler–Nichols tuning, the derivative and integral gains are set to zero. The proportional gain is then increased until a sustained oscillation is obtained as the process response. This gain is called the ultimate gain (K_u) and the period of oscillation is called the ultimate period (T_u). [1]

The Zigler-Nichols tuning scheme based on ku and Tu is given below.

The proportional and integral gains are then set to a particular fraction of the derivative gain. In the Tyreus-Luyben tuning, the loop is first tuned for integral action by setting the derivative gain to zero. The integral gain is then increased until the system oscillates with a particular amplitude and period. The derivative gain is then set to a particular fraction of the integral gain and the proportional gain is set to a particular fraction of the derivative gain. The Cohen-Coon tuning is a modification of the Ziegler–Nichols tuning in which the proportional and integral gains are set to zero. The derivative gain is then increased until the system oscillates with a particular amplitude and period. The integral gain is then set to a particular fraction of the derivative gain and the proportional gain is set to a particular fraction of the integral gain. [5]

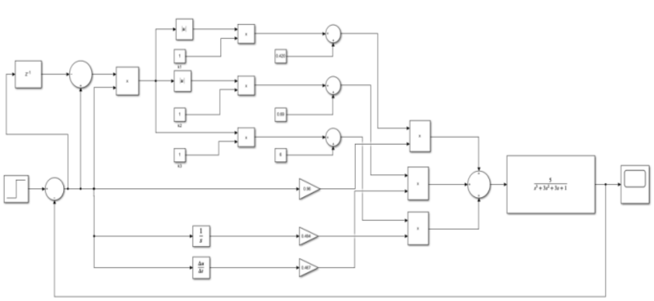

Fig. 1.0 The proposed AZNPID MATLAB Block

II. Proposed Control Scheme

The proposed AZNPID controller consists of two main modules: PID control and gain correction. A PID control module is responsible for generating a control signal u as a function of the control error e and its integral and derivative values. A gain change module is responsible for adjusting her PID gains according to current process trends. The Gain Modification module is further split into two sub-modules: Gain Update (GU) and Gain Manipulation (GM). The GU submodule is responsible for updating the PID gains according to the current control error. The GM submodule is responsible for manipulating the PID gains according to current process trends. Here we detail the behavior of his proposed AZNPID controller. The purpose of the gain update is to adjust the PID gains according to the current control error. Control deviation e is defined as the difference between the setpoint reference and the actual process variable. The control deviation e is fed to the GU submodule and normalized to the control deviation e. Then use the normalized error e to update the PID gains, as shown in Figure 1.

III. Design of Augmented ZNPID

Figure 1 illustrates an block diagram(abridged) for the suggested PID (Proportional-Integral-Derivative) controller that shows how the gain updating factor which is denoted by α, function of the process error which is denoted by e, and change in error which is denoted by △e constantly alter the settings of Ziegler-Nichols (ZN) PID. The beginning point of the Augmented Ziegler-Nichols (AZN)PID for a specific process is illustrated in Figure 1 by its corresponding Ziegler-Nichols (ZN) PID, signifying that the projected PID autotuner's early settings are based on Ziegler-Nichols (ZN) tuning parameters. Every single modifying factor updates each of these ZN tuning parameters of Augmented Ziegler-Nichols (AZN) PID gets updated by each individual regulating factor α is mediated by some fundamental relationships.

The discrete form for conventional Ziegler-Nichols (ZN) PID is given as follows:

$$u^c(k) = K_p\left[e(k) + \frac{\Delta t}{T_i}\sum_{i=0}^{k} e(i) + \frac{T_d}{\Delta t}\Delta e(k)\right] = K_p e(k) + K_i\sum_{i=0}^{k} e(i) + K_d \Delta e(k)$$

(1)[1]

In Equation (1), the control action at the k^{th} sampling instant is represented by $u^c(k)$, proportional gain is represented by K_p, integral gain is represented by $K_i = K_p\,(\Delta t/T_i)$, and $K_d = K_p\,(T_d/\Delta t)$ represents derivative gain, where T_i represents integral time, T_d represents derivative time, and Δt represents the sampling interval. T_d and T_i are then considered using Ziegler-Nichols (ZN) tuning rules (which is, $K_p = 0.6\,K_u$, $T_i = 0.5\,T_u$, and $T_d = 0.125\,T_u$)

(1)

Now, e(k) and Δe(k) are shown as:

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e(k)=R− Y(k), (2)

Δe(k)=e(k)−e(k−1), (3)

where R is the set point and Y(k) is the output of the process. The suggested α which is the gain updating factor, represented by

α(k)=e_n(k)×Δe_n(k). (4)

Here, are all the normalized values of e(k) and Δ e(k)

e_n(k)=e(k)/R (5)

and Δ e_n (k) = e_n (k) − e_n (k − 1) (6)

respectively.

According to Eq. (4), without sacrificing generality, the allowable variation will be between [-1, 1] for every close-loop stable process.

The gain updating factor will continually modify K_p , K_i , and K_d in our lodged AZNPID using the following basic evaluated relations:

K_p^m(k)=K_p (c$_x$+k_x|α(k)|), (7)

K_i^m(k) = K_i (c$_y$ + k_yα(k)) , (8)

K_d^m(k)=K_d (c$_z$+k_z|α(k)|) (9)

Thus, AZNPID can be demonstrated from (1) and (7)–(9), as

$$U^a(K) = K_p^m(k)e(k) + K_i^m(K)\sum_{i=0}^{k} e(i) + K_d^m(k)\,\Delta e(K) \quad (10)$$

where k_p^m (k) , k_i^m (k), and k_d^m(k) are then expressed as the modified proportional(P), modified integral (I), and modified derivative gains (D) respectively at k^{th} instant, and $u^a(k)$ is the corresponding control action. From Equations number 7 to Equations number 9, k_x, k_y, k_z as well as c$_x$, c$_y$, c$_z$ are the pairs of three constants whose values are greater than 0, which then will create essential changes in K_p^m, K_i^m, and K_d^m surrounding their respective starting points. [1]

The optimal auto-tuning strategy's aim is for the three AZNPID parameters to be reset following any set-point change or load disturbance. (i.e., K_p^m, K_i^m, and K_d^m) will be continually regulated by the non-linear updating factor as a consequence of the process's speedy recovery during both set-point change and load fluctuation in the absence of a substantial number of oscillations. This nonlinear gain fluctuation in real-time is used to improve control performance.

Unlike ZNPID, (7)-(9) show that in AZNPID, both the proportional (P) and derivative (D) gains which are denoted as K_p^m and K_d^m, are raised during the course of the operational cycle, albeit not always in the same amount (due to variations in the values of k_x and k_z), whereas Following the operational stages, the integral gain is either increased or lowered from its original configuration.

According to (7)-(9), AZNPID has a very nonlinear control surface due to nonlinear gain changes, which is unlike the linear control surface of ZNPID. Despite its nonlinear gain fluctuation, AZNPID retains the basic PID structure. As a result, by including an existing PID controller may be readily adjusted to the desired form. [1]

IV. The Tuning Strategy for proposed controller

To give proper control action in various operational stages, we are taking the following factors into mind. Throughout the AZNPID design:

(i) The process at the time, is rapidly approaching towards the set point while being far from it (i.e the 1st, 3rd, 6th points in Figure 2), which is proportional and to be reasonably large and so that it will reach set point very quickly but integral gain of the process must be minute enough to avert the large accretion of the control action of the system. This could result in a large undershoot or overshoot in time ahead. Meanwhile, the derivative gain should be raised for more damping and to reduce oscillations. In comparable transient phases, either Δe will have positive signs and e will have negative signs or vice versa.

As result, this becomes less than zero by Equation number 4, increasing the proportional gains (P) and the derivative gains (D) while decreasing the integral gain (I) compared to their previous figures (which are$K_p^m > K_p$, K_d^m>K_d , and $K_i^m <$ 0:3 K_i), as denoted by (7) to (9).

Hence, the proposed gain adaptive rules which are indicated in the Equations 7 to 9 which attempt to change the AZNPID framework to minimize undershoot or/and overshoot , as well as an oscillation which are the results of process response. [1]

(ii) As process deviates from the set point (which are the2nd, 4th and 5th points in Figure 2), increasing proportional gains (P), derivative gain (D), and integral gains (I) are anticipated to return to process variable to the target value as soon as possible. Hence, e and Δe both must have the identical sign, so it will be positive(+ve) which is according to the Equation 4, and then in return it makes every gain parameters of Augmented Ziegler-Nichols (AZN) PID which are denoted K_p^m, K_d^m, K_i^m, greater than their respective initial values which are according to the Equations 7 to 9 correspondingly. Control action of system becomes more belligerent (that is u^a>u^c according to equations 1 and 10), in an attempt to prevent the problem from worsening.

As a result, AZNPID meets the requirements for a relatively comprehensive and powerful controlling action to promote process recovery.

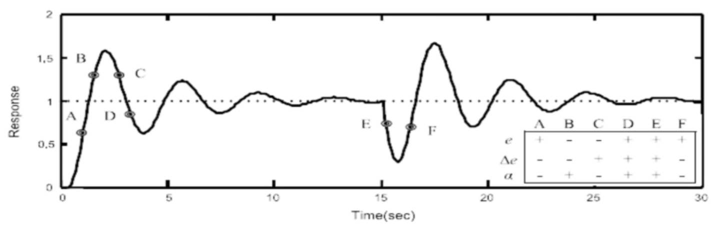


Fig. 2.0 An second-order and under-damped process's typical closed-loop response for the proposed system.

It is clear from the explanation above that the auto-tuning strategy we prefer always aims to change the AZNPID settings (proportional, integral, and derivative gains) towards obtaining the necessary control action on various transient phases to give better performances under various load disturbances and set-point changes.

Following the desired response type, appropriate values of k_x, k_y, and k_z are required for selection, either from via trial and error method or the designer's knowledge of the process which is there to be controlled . [11] [12]

V. Results

The efficiency of the preferred system is also backed up by our simulated experiments on 2nd and 3rd order processes. Our preferred tuning method which is the AZNPID method, has been tested on Matlab's Simulink environment.We also have compared the performance of the proposed Augmented Ziegler-Nichols (AZN) PID with the performance of Ziegler-Nichols (ZN) PID. For our experiment, we have considered the following processes :

- $\frac{\mathbf{10}}{s^3+20s^2+30s\ \ +60}$

Table 1.a (ZNPID)

Ultimate Period (t_u)	Ultimate Gain (k_u)	Proportional Gain (k_p)	Integral Time (t_i)	Derivative Time (t_d)	Integral Gain (k_i)	Derivative Gain (k_d)
1.155s	53.5	32.1	0.5775s	0.144375s	55.5844	4.6

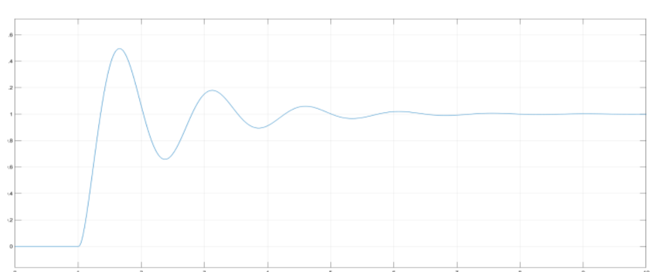
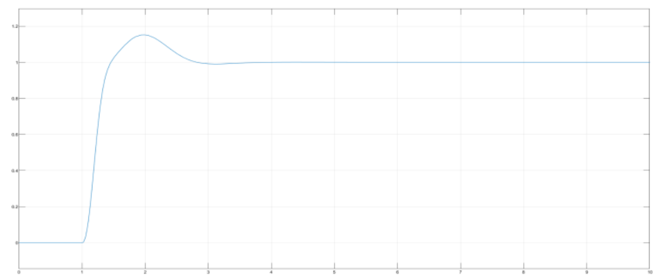


Table 1.b (AZNPID)

k_x	k_y	k_z	c_x	c_y	c_z
1.7	5	4	1	1	2



- $\frac{\mathbf{2s+10}}{s^3+3s^2+18s\ \ +9}$

Table 2.a (ZNPID)

Ultimate Period (t_u)	Ultimate Gain (k_u)	Proportional Gain (k_p)	Integral Time(t_i)	Derivative Time(t_d)	Integral Gain (k_i)	Derivative Gain (k_d)
0.964s	11	6.6	0.482s	0.1205s	13.69	0.7953

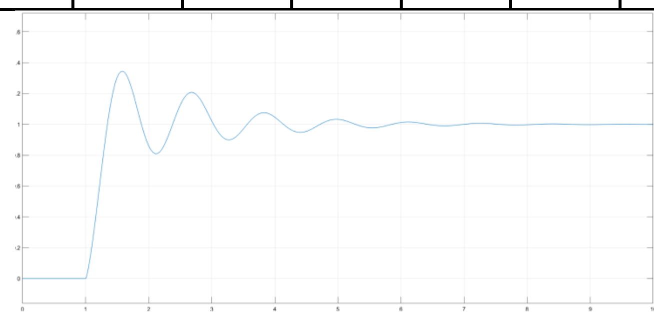
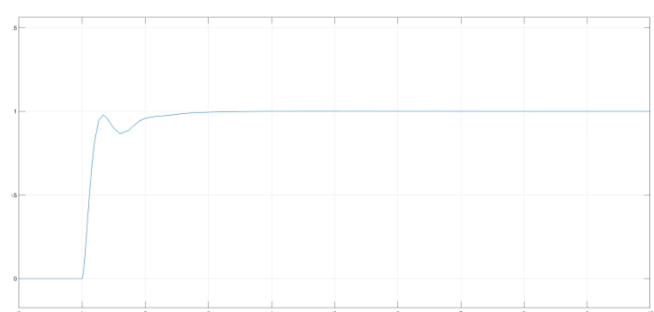


Table 2.b (AZNPID)

k_x	k_y	k_z	c_x	c_y	c_z
9	2.9	7	2.2	0.33	4.5



- $\frac{\mathbf{5}}{s^3+3s^2+3s\ \ +1}$

Table 3.a (ZNPID)

Ultimate Period (t_u)	Ultimate Gain (k_u)	Proportional Gain (k_p)	Integral Time (t_i)	Derivative Time(t_d)	Integral Gain (k_i)	Derivative Gain (k_d)
3.891s	1.6	0.96	1.9455s	0.4856s	0.494	0.467

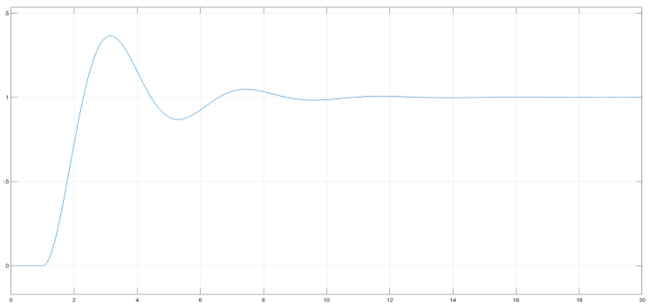
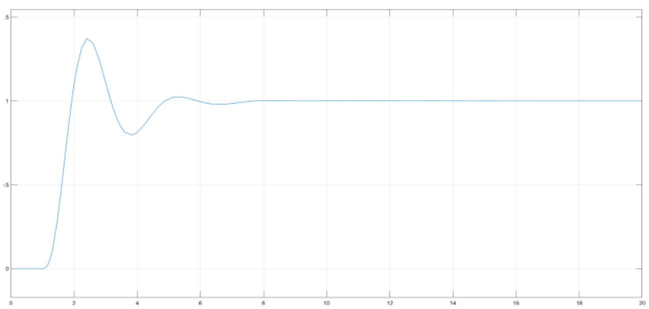


Table 3.b (AZNPID)

k_x	k_y	k_z	c_x	c_y	c_z
4	1	3	1	0.8	2



- $\frac{20}{s^3+15s^2+30s+60}$

Table 4.a (ZNPID)

Ultimate Period (t_u)	Ultimate Gain (k_u)	Proportional Gain (k_p)	Integral Time (t_i)	Derivative Time(t_d)	Integral Gain (k_i)	Derivative Gain (k_d)
1.109s	19.5	11.7	0.5955s	0.1489s	21.27	1.608

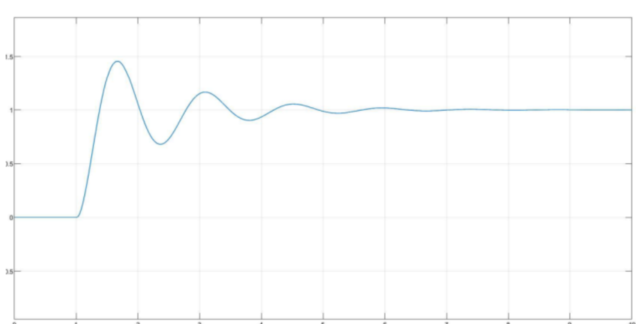
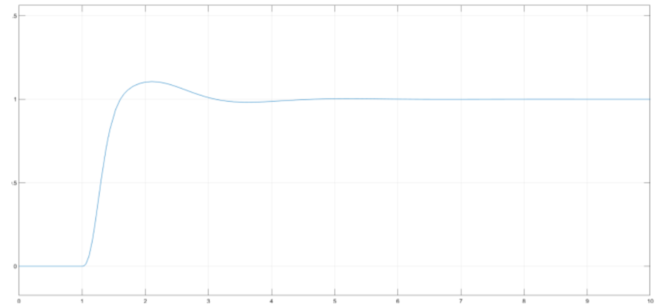


Table 4.b (AZNPID)

k_x	k_y	k_z	c_x	c_y	c_z
1	1	1	0.53	0.69	1.69



VI. Future Scope and Conclusion

Our preferred control scheme can improve the performance of the system .This is simply extendable to a preexisting controller.

Our proposed control scheme may further improve the effectiveness of the system in various nonlinear and linear higher order dead-time processes.When compared with Ziegler-Nichols (ZN) PID, it shows a consistently enhanced performance of AZNPID because of the transient and also in steady state conditions.Not only the dead-time process but also the tuning parameters k_x, k_y and k_z can be varied in order to establish robustness of performance. In future, more studies can be done in order to find more accurate values of k_x, k_y, k_z.

VII. Acknowledgment

We would like to convey our appreciation to everyone who helped us finish this project paper regarding the AZNPID controller. First and foremost, we would like to express our gratitude to our supervisor for providing us with crucial direction and assistance during the project. Your significant knowledge and skills in control systems have been important in influencing the path of our study. We are also grateful to our colleagues for their helpful criticism and intelligent talks, which helped us refine our ideas and increase the quality of our work. We'd like to express our gratitude to the organization that supplied the resources and financing for this initiative. This research would not have been possible without your help. Finally, we'd like to thank the AZNPID controller's creators for their efforts. Your breakthrough work in the field of control systems established the groundwork for our research and was critical to our grasp of the topic.

We would like to thank everyone who has helped make this initiative a success once more.

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IX . Biographies

Hindol Paul, an Applied Electronics and Instrumentation engineering scholar from Maulana Abul Kalam Azad University of Technology (MAKAUT),completed his Bachelor of Technology, showcases a strong dedication to optimizing control system performance. With a focus on PID controller optimization, Hindol's research reflects his commitment to improving efficiency and driving innovation in the field of engineering.

Saswata Paul, an engineering student from Maulana Abul Kalam Azad University of Technology (MAKAUT), focuses his research on enhancing PID controller performance. With his expertise in control systems, Saswata explores novel approaches for optimizing control systems and improving efficiency.

Romit Chatterjee is currently completing Bachelor of Technology in Applied Electronics & Instrumentation Engineering at Techno International New Town affiliated to Maulana Abul Kalam University of Technology. He completed his Higher Secondary Education from Pathfinder Higher Secondary Public School and Secondary Education from Nava Nalanda High School. He is interested in control systems and data structures & algorithms. With a solid foundation in engineering and computer science, Romit Chatterjee has made significant contributions to the field of control systems, focusing on designing, analyzing, and implementing control algorithms for various applications.

Amit Sanyal is currently completing Bachelor of Technology in Applied Electronics & Instrumentation Engineering at Techno International New Town affiliated to Maulana Abul Kalam University of Technology. The understanding and passion for the control system led his recherch to the improvement of tuning approach for PID controllers .

Indrajit Pandey, Assistant Professor at Techno International New Town in Kolkata, West Bengal, India, is a highly regarded educator. He earned his postgraduate degree from the University of Calcutta and completed his bachelor's education at Murshidabad College of Engineering and Technology. With a passion for teaching, he brings a wealth of knowledge to the classroom, inspiring and guiding his students on their academic journey with valuable insights and expertise.