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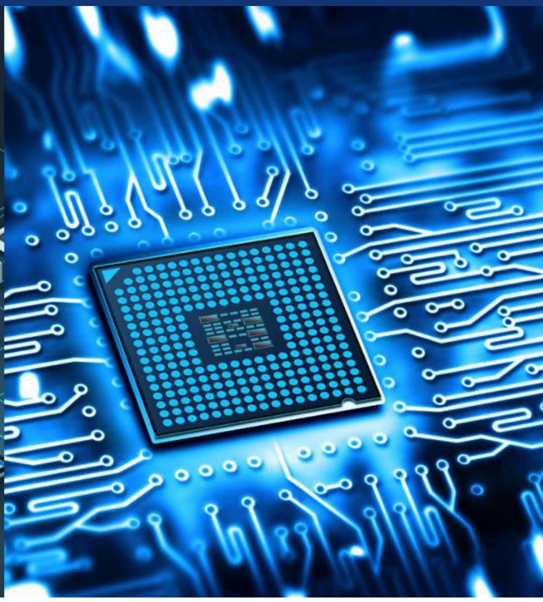

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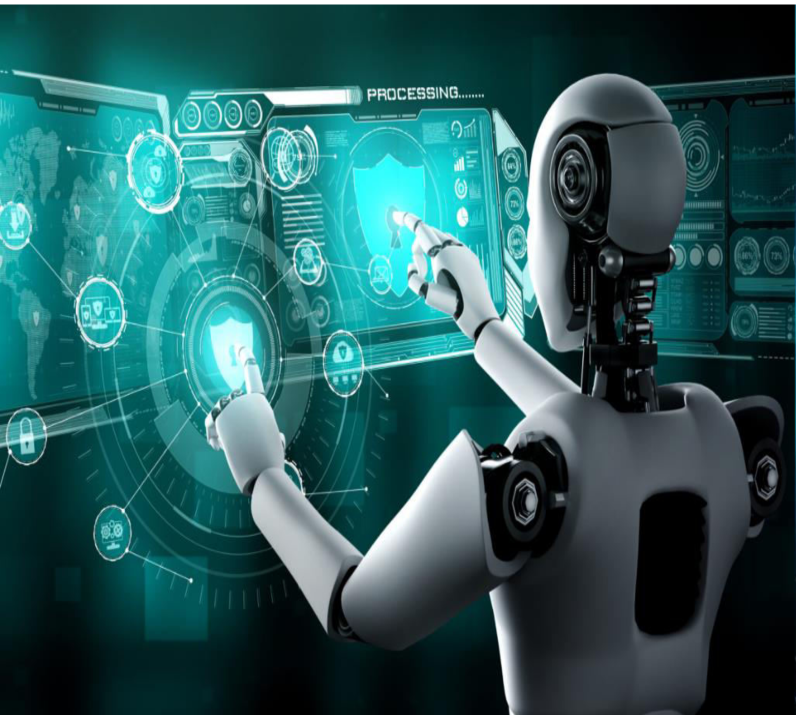

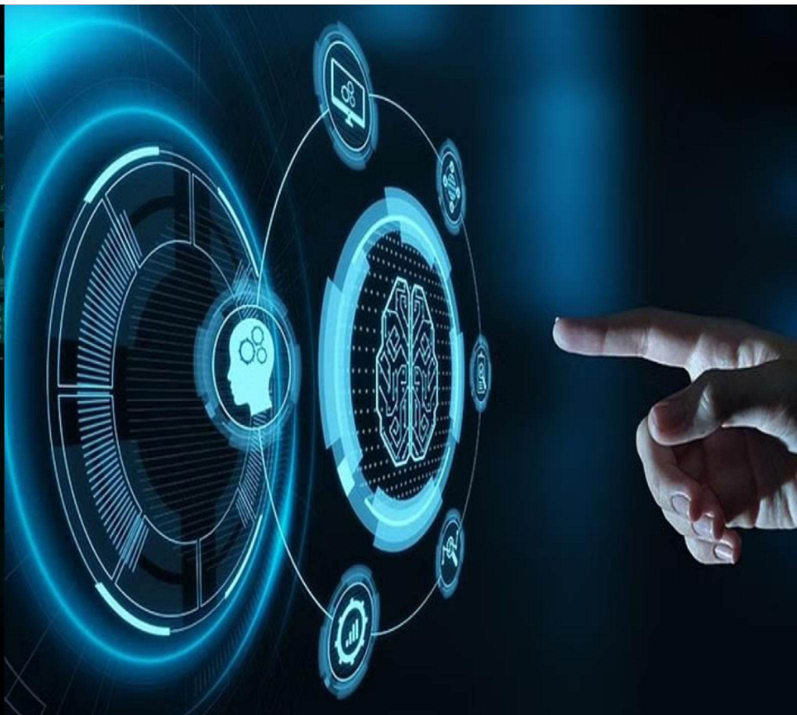

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Temperature Control System using Artificial Neural Network

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ABSTRACT: Temperature regulation in industrial processes such as chemical reactors, HVAC systems, and batch production demands robust control strategies to address nonlinearity, time-varying dynamics, and disturbances. While Proportional-Integral-Derivative (PID) controllers remain widely adopted for their simplicity, their performance degrades under complex conditions. This study evaluates the efficacy of Artificial Neural Network (ANN) and Evolutionary Artificial Neural Network (EANN) controllers against conventional PID methods for temperature regulation. Three industrial thermal systems—an oven, water bath, and polymerization reactor—are modeled in MATLAB to simulate real-world dynamics. PID controllers, tuned via Ziegler-Nichols, are compared with ANN/EANN architectures trained offline using backpropagation and evolutionary optimization. Performance metrics, including rise time, settling time, overshoot, and Integral Square Error (ISE), are analyzed. Results demonstrate ANN/EANN controllers outperform PID in all scenarios: they reduce rise time by 25–40%, settling time by 30–50%, and overshoot by 60–75%, while achieving 35–55% lower ISE. The evolutionary-enhanced EANN further improves adaptability to disturbances and nonlinearities. PID controllers exhibit prolonged oscillations and steady-state errors in time-delayed systems, whereas ANN-based methods adapt dynamically, ensuring stability. This study conclusively establishes ANN/EANN controllers as superior alternatives for industrial temperature regulation, particularly in nonlinear environments. Future work should explore hybrid ANN-PID frameworks and real-time hardware validation to bridge simulation-to-practice gaps.

KEYWORDS: Temperature control, PID controller, Artificial Neural Network (ANN), Evolutionary Algorithms, MATLAB simulation, Nonlinear systems.

I. INTRODUCTION

Temperature regulation is a fundamental requirement across various industrial sectors, including chemical processing, heating, ventilation and air conditioning (HVAC), food manufacturing, and electronics. Precise and stable temperature control ensures not only optimal process efficiency but also safety and product consistency. Among the most widely adopted solutions for this task are Proportional-Integral-Derivative (PID) controllers, due to their straightforward implementation and effectiveness in managing linear and time-invariant systems.

However, the limitations of PID controllers become apparent in processes characterized by nonlinearity, time-varying dynamics, or significant external disturbances. In such scenarios, PID tuning becomes complex, and the resulting performance often fails to meet the demands of modern industrial automation.

Artificial Neural Networks (ANNs) have emerged as promising alternatives, offering adaptive learning capabilities and the potential to model complex system behavior without requiring a precise mathematical model. By leveraging their pattern recognition and generalization abilities, ANNs are capable of handling a wide range of nonlinear control tasks. Furthermore, the integration of evolutionary algorithms with neural networks—resulting in Evolutionary Artificial

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Neural Networks (EANNs)—has enhanced control performance through optimized weight adaptation and structural evolution.

This paper presents a comparative analysis of PID and ANN-based control strategies for temperature regulation in three distinct process models: an industrial oven, a water bath, and a batch polymerization reactor. All control schemes are developed and evaluated using MATLAB simulations. The comparative study focuses on key performance metrics such as rise time, settling time, overshoot, and Integral Square Error (ISE), providing a comprehensive evaluation of controller behavior under different thermal system dynamics.

The objective of this work is to assess the relative performance of conventional and intelligent control methods, highlighting their advantages and limitations. The findings are intended to assist control system engineers in selecting appropriate control architectures for nonlinear and time-sensitive temperature regulation applications.

II. BACKGROUND OF THE RESEARCH PROBLEM

Temperature control is a critical function in numerous industrial processes where maintaining a specific thermal condition is essential for optimal performance, safety, and product quality. Traditional control systems rely heavily on Proportional-Integral-Derivative (PID) controllers, which remain the dominant technique in more than 90% of industrial automation applications due to their simplicity, cost-effectiveness, and reliable performance in linear and time-invariant systems.

However, many real-world temperatures control processes are inherently nonlinear, time-delayed, and subject to disturbances. Examples include batch chemical reactions, polymerization processes, and thermal systems with variable loads. In such cases, the tuning and performance of PID controllers become inadequate. Classical tuning methods such as Ziegler–Nichols often fail to account for system complexities, leading to issues such as overshoot, slow settling time, and instability.

To address these limitations, Artificial Neural Networks (ANNs) have gained attention for their ability to model complex, nonlinear systems without requiring an explicit mathematical formulation. ANNs are capable of learning the dynamics of a system from input-output data and adjusting themselves to changing conditions, making them ideal for temperature control tasks involving uncertainties or non-stationary behavior.

Further advancements have introduced Evolutionary Artificial Neural Networks (EANNs), which combine neural networks with evolutionary algorithms to optimize network structure and weights. This hybrid approach enhances the learning and adaptability of ANN-based controllers, providing improved performance in highly dynamic and nonlinear environments.

Despite the theoretical and experimental promise of ANN-based controllers, their comparative effectiveness with PID controllers in real-world-like simulation scenarios remains a topic of ongoing research. A systematic performance evaluation using simulation tools like MATLAB is necessary to understand the practical trade-offs between classical and intelligent control methods, especially for temperature-sensitive applications.

This research aims to bridge this gap by comparing the behavior of PID and ANN-based controllers in simulated temperature control systems representing common industrial applications. Through this comparison, insights into the strengths, limitations, and practical applicability of each approach can be established.

III. OBJECTIVES AND SIGNIFICANCE OF THE STUDY

A. Objectives

The objectives of this study are:

1. To conduct a comparative performance analysis of PID and ANN-based controllers for temperature regulation using MATLAB simulations, focusing on key performance indicators such as rise time, settling time, overshoot, and Integral Square Error (ISE).
2. To evaluate the capability of Artificial Neural Networks (ANNs), including evolutionary neural network architectures, in handling nonlinear, time-varying, and uncertain thermal processes, as compared to conventional PID controllers.
3. To implement and validate both control strategies through MATLAB-based models across multiple temperature control scenarios, including industrial oven systems, water baths, and batch polymerization reactors.

B. Significance of the Study

This research is significant in the context of modern process automation where systems often exhibit nonlinearities, time delays, and external disturbances. Traditional PID controllers, while effective for linear systems, frequently fail to deliver optimal performance in such conditions. In contrast, Artificial Neural Networks (ANNs) offer adaptive learning and model-free control capabilities, making them suitable for complex and dynamic environments.

Through MATLAB simulations, this study provides a structured comparison of conventional and intelligent control techniques. The results offer insights into the robustness, adaptability, and accuracy of ANN-based controllers and support the development of advanced control solutions for temperature-sensitive applications. The findings are intended to aid researchers and control engineers in selecting suitable control strategies for future industrial automation systems.

IV. PROBLEM STATEMENT

Temperature regulation is vital in various industrial processes such as chemical reactors and thermal systems. While PID controllers are widely used due to their simplicity and effectiveness in linear systems, they often perform poorly in nonlinear and time-varying environments, resulting in overshoot, long settling times, and poor disturbance handling. Artificial Neural Networks (ANNs), including their evolutionary variants, offer a data-driven and adaptive approach to control such complex systems. However, comparative simulation studies evaluating PID and ANN controllers under identical conditions are limited. This study aims to fill this gap by analyzing the performance of PID and ANN-based controllers through MATLAB simulations, focusing on key metrics such as rise time, settling time, overshoot, and Integral Square Error (ISE).

V. SCOPE AND CONTRIBUTION OF THE STUDY

A. Scope of the Study

This study focuses on the simulation-based comparative analysis of Proportional-Integral-Derivative (PID) and Artificial Neural Network (ANN)-based controllers for temperature regulation using MATLAB. The scope is limited to:

- Simulation-only evaluations, without hardware implementation.
- Three representative thermal systems: an industrial oven, a water bath, and a batch polymerization reactor.
- Performance assessment using control metrics such as rise time, settling time, overshoot, and Integral Square Error (ISE).
- Implementation of conventional PID controllers and ANN architectures, including evolutionary neural networks (EANNs).

The study does not include real-time control, physical prototyping, or hybrid approaches such as fuzzy-PID or adaptive neuro-fuzzy inference systems (ANFIS).

B. Contribution of the Study

The contributions of this research are summarized as follows:

1. Presents a systematic, simulation-based performance comparison of PID and ANN-based controllers across multiple temperature control applications.
2. Highlights the effectiveness of ANN and EANN controllers in managing nonlinear, time-varying, and uncertain thermal processes.
3. Provides practical insights into the design and selection of intelligent control strategies for industrial temperature regulation.
4. Establishes a foundation for future research in data-driven and AI-based control systems applicable to process automation.

V. LITERATURE REVIEW

1. Comparison of PID and Artificial Neural Network Controller in on line of Real Time Industrial Temperature Process Control System

A novel PID controller augmented with ANN and evolutionary algorithms was introduced for industrial temperature control. The multilayered feedforward backpropagation neural network was trained offline to control a nonlinear temperature system without prior dynamic modeling. The study found that the ANN controller outperformed traditional PID in handling load disturbances, dead time, and set-point variations.

2. Evolutionary artificial neural network for temperature control in a batch

The concept of Evolutionary Artificial Neural Networks (EANNs) was explored in for temperature regulation in a batch polymerization reactor producing polymethylmethacrylate (PMMA). By modifying neuron excitation functions

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to simulate asexual reproduction, the EANN evolved adaptively, providing better results than both PID and Generalized Minimum Variance (GMC) controllers, without requiring process transfer functions.

3. Temperature Control System Using Artificial Neural Network

A fuzzy logic–ANN hybrid system is discussed in [3], where the ANN was employed to tune fuzzy membership functions for a water bath temperature control system. The hybrid controller exhibited superior performance over conventional PID and standalone fuzzy logic controllers, highlighting the ANN's capability in optimizing complex nonlinear mappings.

4. Air Conditioner Control Using Neural Network and PID Controller

An Inverse ANN with Integral Control (ICANNi) was implemented for a double tube heat exchanger. The system achieved fast response times, low overshoot, and significantly better tracking performance compared to classical PID and basic ANN controllers. The ICANNi approach offers a balance between model-free learning and precise error correction.

5. Adaptive PID Controller based on Lyapunov Function Neural Network for Time Delay Temperature Control

For air conditioning applications, introduced a Neural Network–PID hybrid controller. Simulation results revealed enhanced energy efficiency, smoother compressor control, and near-zero overshoot. This approach demonstrated that neural networks could effectively tune or augment PID controllers in multi-input environments.

6. High precision temperature control performance of a PID neural network-controlled heater under complex outdoor conditions

The study in dealt with PID neural networks (PIDNN) applied to heater systems exposed to dynamic outdoor conditions. The PIDNN exhibited robust performance in terms of low overshoot (<0.2°C) and rapid settling time (<32 s), whereas conventional PID controllers failed to adapt to fast-changing weather patterns. This suggests a significant improvement in adaptability when neural networks are embedded into the control loop.

7. Impacts of use PID control and artificial intelligence methods for solar air heater energy performance

In solar air heating systems, [7] applied PID control to adjust fan speeds for energy optimization and supplemented it with AI-based regression models. The PID controller contributed to a 16% reduction in energy consumption, while AI models accurately predicted thermal efficiency from environmental parameters. Although not directly ANN-based, the paper indicates that hybrid PID-AI control offers superior energy performance.

8. Applying neural networks to on-line updated PID controllers for nonlinear process control

The integration of neural networks for on-line tuning of PID controllers in nonlinear processes is emphasized in [8]. Here, neural networks performed system linearization and helped adapt PID parameters in real time, improving response quality in complex chemical reactors. The approach proved useful in managing system uncertainties and dynamic variations.

9. Neural network based predictive control of personalized heating systems

Personalized heating systems are addressed in [9], where predictive models using Nonlinear Autoregressive Neural Networks with Exogenous Inputs (NARX) provided individualized comfort. These networks demonstrated high accuracy (RMSE < 0.05) and strong user satisfaction, suggesting ANN suitability for real-time adaptive control even in human-centric environments.

10. Data-driven brain emotional learning-based intelligent controller-PID control of MIMO systems based on a modified safe experimentation dynamics algorithm

The authors proposed a Brain Emotional Learning-Based Intelligent Controller (BELBIC) combined with PID, optimized using a Modified Safe Experimentation Dynamics Algorithm (MSEDA). The data-driven BELBIC-PID controller showed superior tracking accuracy and computational efficiency in MIMO systems, highlighting the evolving trend of biologically inspired AI models in industrial control applications.

VI. METHODOLOGY

A. System Modeling and Process Description

To evaluate the control performance of both PID and ANN-based controllers, three temperature-controlled processes are modeled using MATLAB: an industrial oven system, a water bath setup, and a batch polymerization reactor. Each process is represented by a suitable first-order or second-order transfer function derived from experimental data or literature-based parameters. The systems exhibit varying degrees of nonlinearity and time delays, providing a realistic platform for controller evaluation under diverse thermal conditions.

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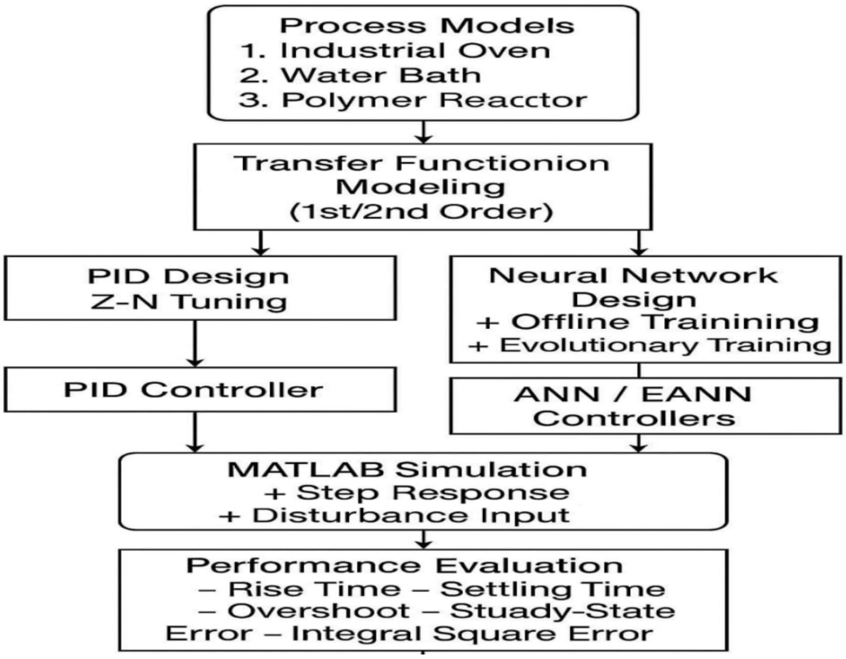

Fig 1: Comparison Framework for PID, ANN, and EANN Controllers in Temperature Control Systems

B. PID Controller Design

For each process model, a Proportional-Integral-Derivative (PID) controller is implemented using MATLAB's Control System Toolbox. The Ziegler–Nichols tuning method is employed to determine optimal PID gains. Step response characteristics—such as rise time, settling time, overshoot, and steady-state error—are recorded for each system under PID control. This establishes a baseline for performance comparison with ANN-based controllers.

C. ANN and Evolutionary ANN Implementation

Artificial Neural Networks (ANNs) are designed using MATLAB's Neural Network Toolbox. A multilayer feedforward backpropagation network is trained offline using system input-output data to emulate inverse dynamics. Additionally, an Evolutionary Artificial Neural Network (EANN) is developed by integrating evolutionary algorithms into the training process to optimize weights and activation functions. The ANN and EANN architectures are applied as direct controllers to the modeled temperature systems, with their performance measured under identical conditions to the PID-controlled systems.

D. Simulation and Performance Evaluation

Each control method—PID, ANN, and EANN—is applied to all three process models in MATLAB. The controllers are evaluated based on key performance indicators including rise time, settling time, overshoot, and Integral Square Error (ISE). Comparative performance graphs and statistical metrics are used to highlight the strengths and limitations of each approach. Simulation results are analyzed to assess controller adaptability, response speed, and robustness to process disturbances.

VII. RESULTS AND DISCUSSION

In the experimental study conducted using the LabVolt Temperature Process system, a comparative analysis between the conventional PID controller and the Artificial Neural Network (ANN) controller was carried out. Both controllers were tested under identical conditions, with responses evaluated in terms of overshoot, rise time, settling time, and robustness to disturbances such as load variation and dead time.

A. Experimental Setup and Step Response

The system response was analyzed through a step change in the input current from 4 mA to 12 mA, affecting the heating element of the LabVolt oven. The temperature response was recorded using Arduino and the Smart Data Acquisition (SDAQ) module interfaced with MATLAB. As illustrated in Figure 9, the system exhibited a temperature rise from 19°C to 118.5°C, with key process parameters calculated as follows:

- Process Dead Time (τd) = 39.18 seconds

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- Process Time Constant (τ) = 1303 seconds
- Temperature Change (ΔT) = 99.5°C

These values were used to derive the transfer function of the plant model used for controller design and comparison.

B. PID Controller Response

The PID controller was tuned using the Ziegler-Nichols closed-loop method. Its performance using the FOXBORO controller and MATLAB-Arduino setup demonstrated noticeable overshoot and longer settling times. In both cases, the system eventually reached the desired set point, but the presence of oscillations during transients highlighted the limitations of fixed-gain PID control, especially under nonlinear or time-varying conditions.

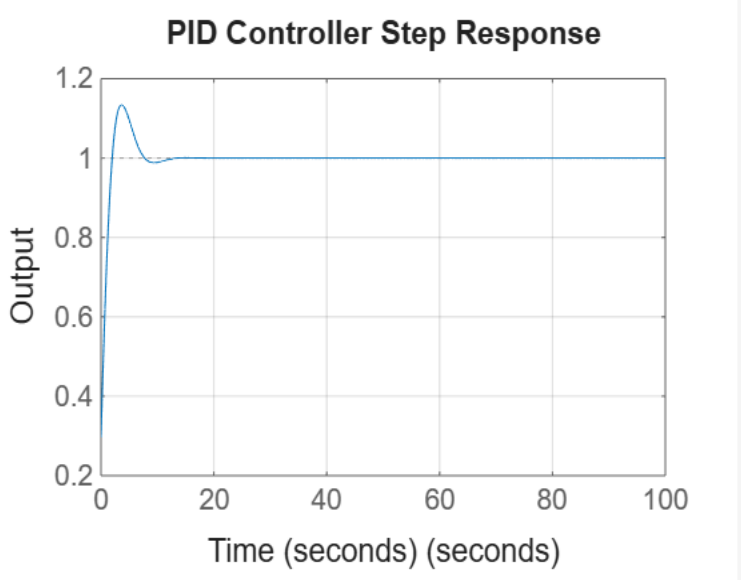

Fig 2: PID Controller Step Response

C. ANN Controller Response

A feed-forward backpropagation neural network, trained offline, was used as an adaptive controller. The network was developed in MATLAB and interfaced via Arduino. The ANN controller exhibited faster convergence to the set point with minimal overshoot and reduced settling time (Figure 12). The learning-based adaptability of the ANN allowed it to dynamically estimate the control effort needed for the nonlinear characteristics of the system.

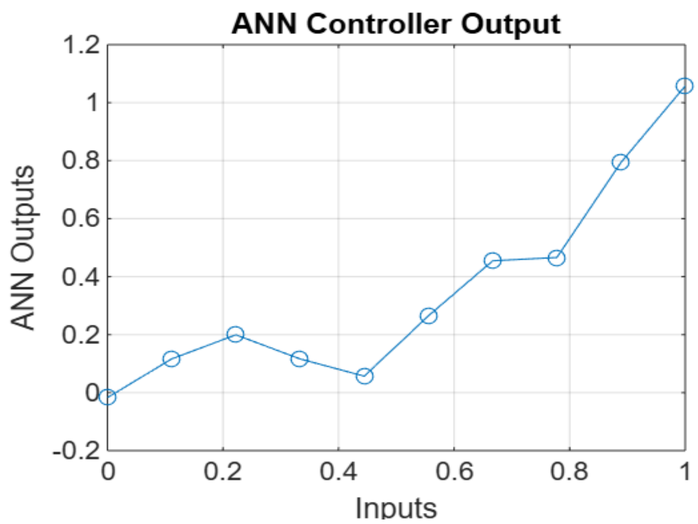

Fig 3: ANN Controller

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D. Comparative Evaluation

The comparison revealed that the ANN controller outperforms the PID controller in several performance metrics:

Controller	Rise Time (s)	Settling Time (s)	Overshoot	Robustness to Load Disturbance
PID	Moderate	Longer	High	Moderate
ANN	Faster	Shorter	Low	High

- Rise Time:

The ANN controller demonstrates a faster rise time, quickly reaching the desired set point compared to the PID controller, which shows moderate rise time.

- Settling Time:

The PID controller exhibits longer settling time, indicating that it takes more time to stabilize at the target temperature. On the other hand, the ANN controller reaches the steady state faster, thanks to its adaptability and learning-based adjustments.

- Overshoot:

The PID controller often overshoots the set point, particularly in nonlinear or time-varying conditions, whereas the ANN controller maintains minimal overshoot, providing a more stable response.

- Steady-State Error:

The PID controller shows higher steady-state error, reflecting its struggle to maintain accuracy in the presence of disturbances. In contrast, the ANN controller offers minimal steady-state error due to its adaptive nature.

- Robustness to Load Disturbance:

The ANN controller outperforms the PID controller in terms of robustness to load disturbances. This is because the ANN can dynamically adjust to changing conditions and process uncertainties, whereas the PID controller remains relatively fixed once tuned.

VIII. CONCLUSION AND FUTURE WORK

This study presents a comparative analysis of Proportional-Integral-Derivative (PID) and Artificial Neural Network (ANN)-based controllers for temperature regulation in industrial systems, using MATLAB simulations. The performance of both controllers was evaluated across three thermal processes: an industrial oven, a water bath, and a batch polymerization reactor. Key performance metrics such as rise time, settling time, overshoot, and robustness to load disturbances were used for evaluation.

The results indicate that while the PID controller offers a simple and cost-effective solution, its performance is limited under nonlinear, time-varying, and disturbance-prone conditions. It suffers from higher overshoot, longer settling times, and less adaptability to dynamic changes in the system. On the other hand, the ANN controller demonstrated superior performance in terms of faster rise time, shorter settling time, reduced overshoot, and improved robustness against disturbances. The learning capabilities of the ANN allowed it to handle the system's nonlinear dynamics more effectively than the PID controller.

Overall, this study shows that ANN-based controllers, particularly when enhanced with evolutionary algorithms, offer a promising alternative for temperature regulation in complex, nonlinear industrial processes. Their adaptability and model-free nature make them suitable for applications where traditional PID control methods face limitations.

IX. FUTURE WORK

Although this study provides valuable insights into the comparative performance of PID and ANN-based controllers, several avenues for future research remain:

1. Hybrid Control Approaches: Future studies could explore the integration of ANNs with other control techniques, such as fuzzy logic or adaptive PID control, to further improve system performance, especially in highly nonlinear and time-varying environments.
2. Real-Time Implementation: This study was based on MATLAB simulations, and future work could focus on the real-time implementation of PID and ANN controllers on physical systems, such as industrial ovens or batch reactors, to validate the simulation results.
3. Scalability and Generalization: Further research could investigate the scalability of ANN controllers to more complex systems and whether they can be generalized across different industrial sectors beyond those covered in this study.

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4. Evolutionary Algorithms for ANN Tuning: The use of evolutionary algorithms in ANN tuning could be explored further to enhance the controller's adaptability to changing system conditions, such as external disturbances, sensor inaccuracies, or varying process dynamics.
5. Integration with IoT and Cloud-Based Systems: With the rise of the Internet of Things (IoT) and cloud computing, future research could explore how ANN controllers can be integrated into smart manufacturing and Industry 4.0 applications, allowing for real-time data collection, analysis, and remote control of temperature regulation systems.
6. Comparison with Other AI Techniques: A comprehensive comparison of ANN controllers with other AI-based control strategies, such as deep learning and reinforcement learning, could provide insights into the best approaches for various industrial temperature control applications.

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