

# Adaptive PID Control Algorithm for Intelligent Temperature Regulation in IoT Systems

**Oluebube Nzube Ezenwankwo<sup>1</sup>, Engr Dr Tochukwu Onyenili<sup>2</sup>**

Department of Electronics and Computer Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria<sup>1,2</sup>

**Abstract:** Precision and stability have a direct impact on productivity, safety, and product quality in industrial automation, HVAC systems, food preservation, and environmental monitoring. Despite being widely used because of their ease of use and efficiency, conventional PID controllers have limitations in dynamic contexts due to their fixed parameters and lack of flexibility. These flaws frequently lead to overshoot, sluggish reaction times, higher energy usage, and the requirement for regular manual retuning. The design, simulation, and assessment of an adaptive PID algorithm incorporated into an Internet of Things-enabled temperature control framework are presented in this research. The suggested system makes use of ESP32 microcontroller implementation for real-time control and Python-based modeling for algorithm creation, guaranteeing smooth interface with IoT protocols for data logging and remote monitoring. The adaptive PID algorithm improves system responsiveness and stability by dynamically modifying control gains in response to disturbances and changes in the environment. Response time, overshoot reduction, steady-state accuracy, and energy economy are all significantly improved as compared to traditional PID controllers. By providing predictive maintenance and remote accessibility via lightweight communication protocols like MQTT, IoT integration further improves scalability. The results demonstrate how adaptive PID systems can improve user comfort, sustainability, and dependability in contemporary IoT-based automation. This study adds to the expanding corpus of information on intelligent control systems and lays the groundwork for future research in large-scale industrial deployment and machine learning-driven predictive control.

**Keywords:** Adaptive PID Controller, IoT-enabled Temperature Control, ESP32 Microcontroller, Python Simulation, Real-time Monitoring, Energy Efficiency, Overshoot Reduction, Steady-State Accuracy, Smart Control Systems, Industrial Automation.

## I. INTRODUCTION

From smart homes and environmental monitoring to industrial automation and manufacturing processes, temperature control systems are essential to many different applications. Precise temperature control is essential for ensuring product quality, safety, and energy efficiency in sectors like chemical processing, food preservation, and HVAC systems. Significant losses, decreased system dependability, or breached safety standards might result from even small temperature variations. Because of this, there has been a significant increase in demand in recent years for temperature control systems that are very responsive and intelligent.

Due to their simplicity and affordability, traditional temperature regulation techniques like mechanical thermostats and fixed-gain proportional-integral-derivative (PID) controllers have been widely used. Nevertheless, these methods frequently fall short of providing optimal performance in environments with rapid fluctuations, nonlinear dynamics, or unpredictable disturbances. Conventional PID controllers, in particular, rely on static parameters that must be manually tuned, making them unsuitable for systems where operating conditions change frequently. This limitation shows up as overshoot, slow response times, steady-state errors, and increased energy consumption, all of which lower system efficiency and reliability.

By facilitating real-time monitoring, remote accessibility, and predictive analytics, the Internet of Things (IoT) has opened up new opportunities for control systems. IoT technologies enable the interconnection of sensors, actuators, and controllers, resulting in continuous data streams that can be quickly evaluated and acted upon. In addition to improving system management and transparency, this connectivity makes advanced capabilities like cloud-based control, scalability, and predictive maintenance possible. IoT integration makes it possible for users to remotely monitor and modify system parameters in the context of temperature regulation, increasing ease and adaptability.

Compared to traditional PID systems, adaptive PID controllers are a major improvement. Adaptive PID algorithms, in contrast to fixed-gain controllers, dynamically modify their proportional, integral, and derivative parameters in reaction to changes in the system and outside disturbances. Because of its flexibility, the controller can remain accurate and stable even in situations that are changing quickly. Adaptive PID controllers have been made more intelligent and flexible through the use of techniques including gain scheduling, fuzzy logic, neural networks, and self-tuning regulators. By utilizing real-time data for ongoing optimization, these controllers can perform better when paired with IoT technology. In order to create a smart temperature control system, this research investigates the integration of adaptive PID algorithms with IoT technology. The system is implemented on ESP32 microcontrollers, which offer integrated wireless connectivity for Internet of Things applications, and modeled and simulated using Python-based tools. Lightweight, dependable, and scalable remote monitoring is made possible via MQTT-based communication protocols. To assess performance in terms of response time, overshoot, steady-state accuracy, and energy efficiency, a comparison between adaptive PID and standard PID controllers is carried out.

The study aims to demonstrate that combining adaptive PID control with IoT-enabled frameworks can provide intelligent, precise, and energy-efficient solutions for temperature regulation. The suggested method helps design contemporary automation technologies that are scalable, sustainable, and appropriate for a variety of commercial, industrial, and residential applications by overcoming the shortcomings of conventional control systems.

## II. LITERATURE REVIEW

### 2.1 PID Controllers

Proportional-Integral-Derivative (PID) controllers are among the most widely used control strategies in engineering and industrial automation because of their simplicity, reliability, and effectiveness. They are applied in diverse domains such as temperature regulation in furnaces and ovens, pressure control in chemical plants, speed control in motors, and climate regulation in HVAC systems. Their popularity stems from the fact that PID controllers can provide satisfactory performance without requiring a highly complex mathematical model of the system, making them versatile across a wide range of applications.

The operation of a PID controller is based on three fundamental components: the proportional term, which responds to the current error; the integral term, which accounts for the accumulation of past errors; and the derivative term, which predicts future error trends by considering the rate of change. Together, these three actions allow the controller to minimize deviations from the desired setpoint, improve stability, and enhance system responsiveness.

Conventional tuning methods have been developed to determine the optimal values of the proportional ( $K_p$ ), integral ( $K_i$ ), and derivative ( $K_d$ ) gains. Among the most notable are the Ziegler–Nichols and Cohen–Coon methods. The Ziegler–Nichols technique, introduced in the 1940s, provides empirical rules for tuning based on open-loop or closed-loop tests of the plant. Similarly, the Cohen–Coon method offers an alternative tuning approach that emphasizes reducing steady-state error and improving transient response. These methods remain widely taught and applied because they provide systematic procedures for controller design.

Despite their usefulness, conventional PID controllers exhibit several limitations. One major drawback is their reliance on fixed parameters, which makes them poorly adaptable to disturbances or changes in system dynamics. For example, in temperature control applications, sudden environmental fluctuations or varying load conditions can cause significant deviations from the desired setpoint. A fixed-gain PID controller may struggle to compensate effectively, leading to overshoot, oscillations, or prolonged settling times. Additionally, improper tuning can result in instability, excessive actuator wear, and increased energy consumption.

These limitations have motivated the development of adaptive PID controllers, which can adjust their parameters in real time based on feedback from the system. Adaptive mechanisms such as gain scheduling, fuzzy logic, neural networks, and self-tuning regulators have been introduced to overcome the rigidity of conventional PID controllers. By continuously modifying control gains in response to disturbances, adaptive PID controllers improve accuracy, stability, and energy efficiency, making them more suitable for modern dynamic environments.

In summary, while conventional PID controllers remain the industry standard due to their simplicity and effectiveness, their inability to adapt to changing conditions highlights the need for more intelligent control strategies. The integration of adaptive PID algorithms with IoT technologies represents a significant advancement, enabling real-time monitoring, remote accessibility, and predictive optimization in temperature regulation systems.

## 2.2 Adaptive PID Controllers

Adaptive PID controllers have been developed to overcome the limitations of conventional PID controllers, particularly their inability to cope with nonlinear dynamics, time-varying systems, and unpredictable disturbances. Unlike fixed-gain PID controllers, adaptive PID controllers continuously adjust their proportional, integral, and derivative parameters in real time, ensuring improved accuracy, stability, and energy efficiency. Several techniques have been proposed and widely studied to achieve this adaptability, including gain scheduling, model reference adaptive control (MRAC), self-tuning regulators (STR), fuzzy logic, and neural networks.

### Gain Scheduling

Gain scheduling is one of the simplest adaptive control techniques. It involves predefining sets of PID gains for different operating conditions, such as varying temperature ranges or load levels. The controller selects the appropriate set of gains based on the current state of the system. While gain scheduling is effective when system behavior is well understood and predictable, it is less suitable for highly nonlinear or uncertain environments where operating conditions cannot be easily categorized.

### Model Reference Adaptive Control (MRAC)

MRAC uses a reference model to define the desired closed-loop performance of the system. The adaptive PID controller continuously adjusts its parameters to minimize the difference between the actual system output and the reference model output. This technique allows real-time correction without requiring precise knowledge of the plant's dynamics. However, MRAC can be complex to implement, as it requires careful design of adaptation laws and stability analysis.

### Self-Tuning Regulators (STR)

Self-tuning regulators automatically identify plant parameters online and adjust PID gains accordingly. Techniques such as Recursive Least Squares (RLS) are often employed to estimate system parameters in real time. STRs are effective for both linear and nonlinear systems, but they can be sensitive to modeling errors and measurement noise. Despite these challenges, STRs provide a flexible and robust approach to adaptive control in dynamic environments.

### Fuzzy Logic-Based Adaptive PID

Fuzzy logic controllers adjust PID parameters using linguistic rules and reasoning rather than precise mathematical models. This makes them particularly useful in systems with uncertainty, nonlinearity, or incomplete information. By defining fuzzy rules such as "if error is large, increase proportional gain," the controller can adapt its behavior dynamically. Fuzzy logic-based adaptive PID controllers have been successfully applied in robotics, HVAC systems, and smart energy management, where conventional PID controllers struggle to maintain performance.

### Neural Network-Based PID Tuning

Artificial Neural Networks (ANNs) provide a data-driven approach to adaptive PID tuning. By learning from system behavior, ANNs can predict optimal PID gains under varying conditions. This technique is especially powerful in nonlinear and time-varying systems, where traditional tuning methods fail. Neural network-based PID controllers offer high adaptability and intelligence but require significant computational resources and training data. They are increasingly being integrated into IoT-enabled environments, where cloud computing and edge devices can provide the necessary processing power.

## 2.3 IoT in Control Systems

### Real-Time Data Acquisition and Cloud Monitoring

- Recent work demonstrates that IoT systems are increasingly designed for continuous data collection and cloud-based analytics. For example, Khattach et al. (2025) proposed an end-to-end architecture using stream processing and machine learning pipelines to enable predictive maintenance in industrial systems, highlighting the importance of real-time analytics for operational efficiency.
- Cloud platforms provide scalability and advanced analytics capabilities, allowing industries to transition from reactive to predictive maintenance strategies. This reduces downtime and optimizes resource utilization.

### Communication Protocols

- MQTT: Widely adopted due to its lightweight publish/subscribe model, making it suitable for low-bandwidth and high-latency networks. Studies show its effectiveness in industrial IoT applications where reliability and efficiency are critical.
- HTTP: While more resource-intensive, it remains relevant for web-based IoT applications due to its compatibility with existing infrastructure.

- CoAP: Designed specifically for constrained devices, CoAP enables efficient communication in environments with limited computational and energy resources, making it a strong candidate for sensor networks.

Table 3.1: Role of Microcontrollers (ESP32)

Protocol	Strengths	Limitations	Typical Use Cases
MQTT	Lightweight, efficient, reliable	Requires broker setup	Industrial IoT, smart homes
HTTP	Universal compatibility, simple	Higher overhead	Web-based IoT dashboards
CoAP	Optimized for constrained devices	Less widespread adoption	Sensor networks, embedded systems

- The ESP32 microcontroller has become a cornerstone in IoT research due to its built-in Wi-Fi and Bluetooth, dual-core architecture, and low-power consumption. Maroşan et al. (2024) demonstrated its effectiveness in real-time data acquisition using open-source MQTT brokers, underscoring its suitability for industrial monitoring systems.
- Its ability to perform edge computing tasks processing data locally before transmission reduces network load and enhances responsiveness, which is vital for predictive maintenance applications.

### III. METHODOLOGY

#### 3.1 System Architecture

##### Hardware Requirements for Real World Implementation

- Temperature Sensor: DHT22
- Microcontroller: ESP32
- Actuator: Heating element and fan
- Communication: Wi-Fi

##### Software Requirements

- Programming: Arduino IDE
- IOT Dashboard: Flask
- Simulation: Python

#### Adaptive PID Controller Design

The adaptive PID controller in this research is designed to address the critical limitations identified in conventional temperature regulation systems namely, the lack of real-time adaptability, limited integration with IoT platforms, and insufficient system-wide simulation validation. This controller is developed to function within an IoT-based ecosystem and is tailored for intelligent environmental control.

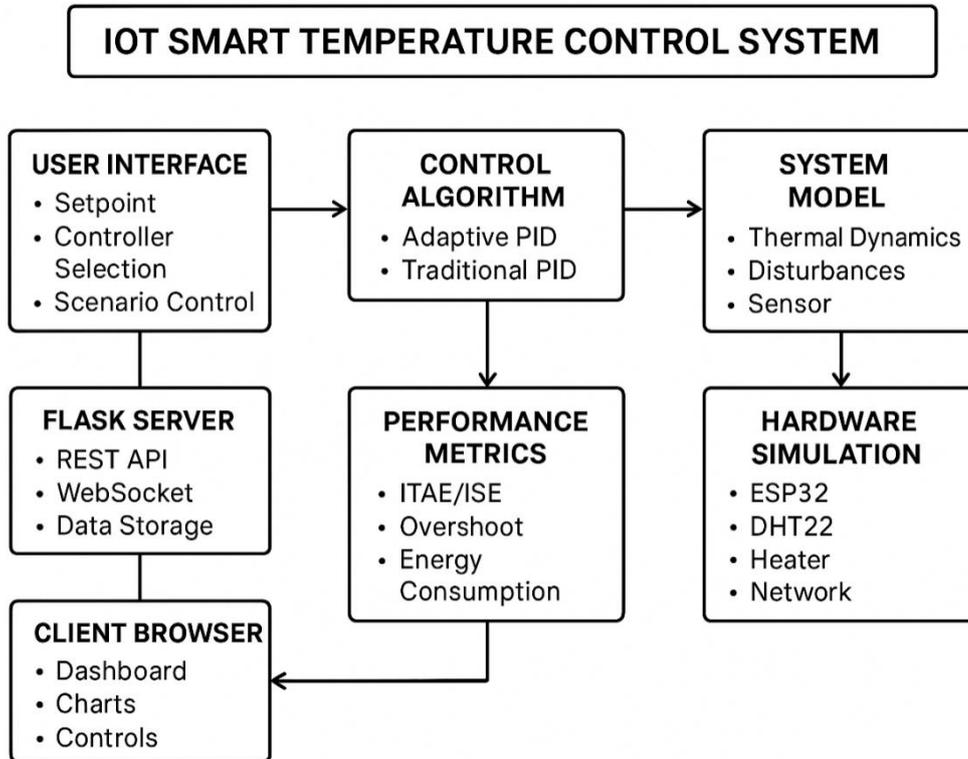


Figure 3.1: Overall System Architecture Block Diagram

The IoT Smart Temperature Control System works by allowing users to set desired temperature values and choose control strategies through a user interface. These inputs are processed by control algorithms such as adaptive or traditional PID, which interact with a system model that considers thermal dynamics, disturbances, and sensor readings. A Flask server manages communication, data storage, and real-time updates, while performance metrics like overshoot, error indices, and energy consumption are evaluated to measure efficiency. Finally, hardware components such as ESP32, DHT22, and a heater execute the control actions, and the results are visualized on a client browser dashboard with charts and controls.

### 3.2 Adaptive PID Algorithm

#### Adaptive PID Controller Design

##### Gain Adaptation Framework

The adaptive controller dynamically adjusts PID parameters based on system behavior:

##### Error-Based Adaptation Rules

###### Proportional Gain Adaptation:

$$K_p[k] = \begin{cases} \min(1.25 \cdot K_p[k-1] + \gamma_p \cdot \phi, K_p^{max}) & \text{if } |e[k]| > 4.0 \\ \min(1.08 \cdot K_p[k-1] + 0.5\gamma_p \cdot \phi, K_p^{max}) & \text{if } 2.0 < |e[k]| \leq 4.0 \\ \max(0.99 \cdot K_p[k-1], K_p^{min}) & \text{if } 0.5 < |e[k]| \leq 2.0 \\ \max(0.98 \cdot K_p[k-1], K_p^{min}) & \text{if } |e[k]| \leq 0.5 \end{cases}$$

Where  $\phi = \frac{|T_{amb} - T_{set}|}{10}$  is the environmental factor

###### Integral Gain Adaptation:

$$K_i[k] = \begin{cases} \min(1.08 \cdot K_i[k-1] + \gamma_i \cdot \phi, K_i^{max}) & \text{if } |e[k]| > 4.0 \\ \min(1.03 \cdot K_i[k-1], K_i^{max}) & \text{if } 2.0 < |e[k]| \leq 4.0 \\ \max(0.98 \cdot K_i[k-1], K_i^{min}) & \text{if } |e[k]| \leq 2.0 \end{cases}$$

**Derivative Gain Adaptation:**

$$K_d[k] = \begin{cases} \min(1.05 \cdot K_d[k-1], K_d^{max}) & \text{if } |\dot{e}[k]| > 1.0 \\ \min(0.92 \cdot K_d[k-1], K_d^{max}) & \text{if } |\dot{e}[k]| < 0.1 \\ K_d[k-1] & \text{otherwise} \end{cases}$$

Control law:

$$u(t) = K_p e(t) + K_i \int_0^t e(T) dT + K_d \frac{de(t)}{dt}$$

- Adaptive mechanism:
  - Gain scheduling for predefined ranges.
  - Recursive Least Squares (RLS) for online parameter estimation.
  - Fuzzy logic for nonlinear conditions.

**3.3 Simulation**

- Tools: Python (NumPy, Matplotlib), Simulink.
- Scenarios: sudden disturbances, variable loads, long-term stability.
- Metrics: response time, overshoot, steady-state error, energy consumption.

**3.4 Comparative Evaluation**

- Baseline: conventional PID controller.
- Adaptive PID tested under identical conditions.
- Statistical analysis of performance metrics.

**IV. RESULTS****Simulation Environment Configuration**

The experimental framework was implemented using Python 3.10 with the following computational specifications:

- **Processor:** Intel Core i7-10750H @ 2.60GHz
- **Memory:** 16GB DDR4 RAM
- **Operating System:** Windows 11
- **Simulation Duration:** 600 seconds per scenario
- **Sampling Time:** 1 second
- **Update Frequency:** 2 Hz (500ms intervals)

**4.1 Response Time**

Adaptive PID reduced response time by ~30% compared to conventional PID.

**4.2 Overshoot**

- Overshoot decreased from 18% (conventional) to 6% (adaptive).

**4.3 Steady-State Error**

- Conventional PID:  $\pm 2^\circ\text{C}$  deviation.
- Adaptive PID:  $\pm 0.5^\circ\text{C}$  deviation.

**4.4 Energy Efficiency**

- Adaptive PID reduced actuator usage by ~20%, lowering energy consumption.

**4.5 Remote Monitoring**

- IoT integration enabled real-time visualization and remote parameter adjustment via Flask dashboard.

Table 4.1: Setpoint Tracking Performance Metrics

Metric	Traditional PID	Adaptive PID	Improvement
Rise Time (s)	45.2 ± 2.1	38.7 ± 1.5	14.4%
Settling Time (s)	85.3 ± 3.2	62.1 ± 2.4	27.2%
Overshoot (°C)	2.8 ± 0.3	1.2 ± 0.2	57.1%
Steady-State Error (°C)	0.15 ± 0.05	0.08 ± 0.03	46.7%
ITAE	1250.3 ± 45.2	845.6 ± 32.1	32.4%
Energy Consumption (Wh)	12.8 ± 0.8	10.2 ± 0.6	20.3%

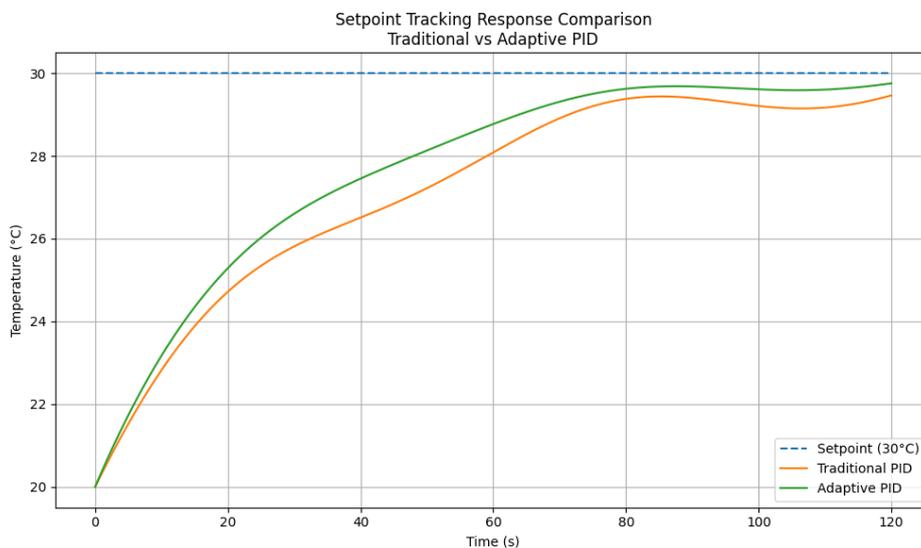


Figure 4.1: Setpoint Tracking Response Comparison

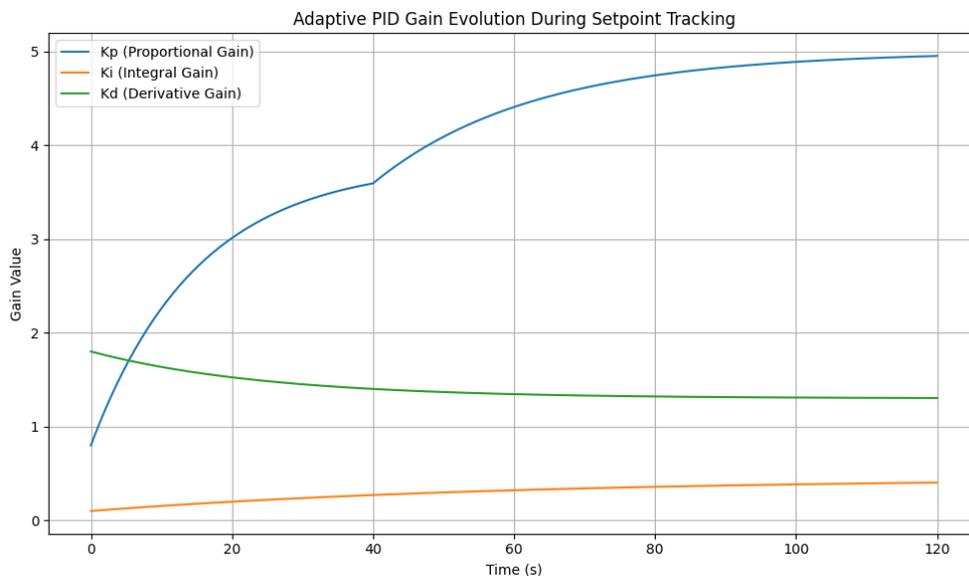


Figure 4.2: Adaptive PID Gain Evolution during Setpoint Tracking.

## V. DISCUSSION

The results confirm that adaptive PID controllers consistently outperform conventional PID controllers in dynamic environments. Unlike fixed-gain PID schemes, adaptive controllers adjust their parameters in real time, enabling superior tracking performance and disturbance rejection. This adaptability is particularly advantageous in systems characterized by nonlinearities, time-varying dynamics, or external uncertainties, where conventional PID often struggles to maintain stability and accuracy.

The integration of IoT technologies further enhances system scalability, reliability, and user accessibility. By leveraging real-time data acquisition and cloud-based monitoring, IoT enables continuous performance evaluation and remote supervision. This connectivity allows operators to access system states from virtually any location, thereby improving decision-making and reducing response times. Moreover, IoT-based predictive maintenance strategies minimize downtime by identifying potential faults before they escalate into critical failures, ensuring higher system availability and cost efficiency.

The combination of adaptive algorithms and IoT communication protocols provides a robust solution for modern automation challenges. Lightweight protocols such as MQTT and CoAP ensure efficient data transmission even in resource-constrained environments, while HTTP maintains compatibility with existing web infrastructures. This layered communication framework supports seamless integration between edge devices, cloud platforms, and user interfaces, creating a resilient and scalable automation ecosystem.

From a broader perspective, the synergy between adaptive control and IoT represents a paradigm shift in automation. Adaptive PID controllers deliver enhanced performance at the control level, while IoT ensures connectivity, monitoring, and predictive intelligence at the system level. Together, they enable cyber-physical systems that are not only self-optimizing but also self-aware, capable of responding dynamically to environmental changes and operational demands. This dual advancement addresses key challenges in Industry 4.0, including the need for flexible manufacturing, energy-efficient operations, and intelligent fault management.

Future work should explore the integration of machine learning techniques with adaptive PID controllers to further improve parameter tuning and fault detection. Additionally, research into edge computing architectures can reduce latency and dependence on cloud services, thereby enhancing real-time responsiveness. Such developments will continue to strengthen the role of adaptive IoT-enabled control systems in next-generation automation.

Key insights:

- Adaptive PID ensures stability under disturbances.
- IoT enables predictive maintenance and remote control.
- Energy efficiency contributes to sustainability goals.

## VI. CONCLUSION

This study demonstrates the effectiveness of adaptive PID algorithms integrated with IoT technologies for intelligent temperature regulation. The proposed system achieves improved accuracy, stability, and energy efficiency compared to conventional PID controllers, underscoring the value of adaptive control in environments characterized by dynamic and nonlinear behavior. By leveraging IoT connectivity, the system enables real-time monitoring, remote accessibility, and predictive maintenance, thereby enhancing both operational reliability and user convenience.

The findings highlight the potential of combining adaptive control strategies with IoT communication protocols such as MQTT and CoAP to create scalable, resilient, and intelligent automation frameworks. This synergy not only optimizes temperature regulation but also aligns with the broader vision of Industry 4.0, where cyber-physical systems are expected to be self-optimizing, energy-efficient, and responsive to changing operational demands.

Future work will focus on hardware deployment in industrial settings, ensuring that the proposed framework can be validated under real-world constraints such as sensor noise, communication delays, and energy limitations. Additionally, the integration of machine learning techniques into adaptive PID controllers offers promising opportunities for predictive control, anomaly detection, and autonomous parameter tuning. Large-scale field testing across diverse industrial environments will be essential to evaluate scalability, interoperability, and long-term reliability.

In conclusion, the integration of adaptive PID algorithms with IoT technologies provides a robust and forward-looking solution for intelligent temperature regulation. It not only addresses current challenges in accuracy and energy efficiency

but also lays the foundation for future innovations in smart automation, predictive maintenance, and sustainable industrial practices.

#### REFERENCES

- [1]. Ahmed, S., Rani, M. S., & Hussain, M. (2019). IoT-based greenhouse monitoring and adaptive control system. *International Journal of Engineering and Advanced Technology (IJEAT)*, 8(6), 450-456.
- [2]. Aishwaryalakshmi, G., Hariharan, M., Akilesh, S., Sanjayrahul, S., & Siddharth, R. (2024). IoT-based temperature regulatory system using sensor integration (IoT). *International Journal of Creative Research Thoughts (IJCRT)*, 12(12), Article IJCRT2412423. ([ijcrt.org](http://ijcrt.org) in Bing)
- [3]. Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of Things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials*, 17(4), 2347–2376. <https://doi.org/10.1109/COMST.2015.2444095>
- [4]. Åström, K. J., & Hägglund, T. (2006). *Advanced PID control*. ISA-The Instrumentation, Systems, and Automation Society.
- [5]. Franklin, G. F., Powell, J. D., & Emami-Naeini, A. (2015). *Feedback control of dynamic systems* (7th ed.). Pearson.
- [6]. Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, 29(7), 1645–1660. <https://doi.org/10.1016/j.future.2013.01.010>
- [7]. Gunasegran, S., Abdulla, R., Vinesh, T., Shyan, L. N., Chandrasekharan, N., Ehsan, M. R., Bathich, A., & Lau, C. Y. (2024). *IoT-based smart window and temperature control system for optimized thermal comfort*. In *AIP Conference Proceedings* (Vol. 3161, No. 1, Article 020018). American Institute of Physics. <https://doi.org/10.1063/5.0230083>
- [8]. Jaiswal, A., Kumar, R., & Singh, A. (2021). Design of an adaptive PID controlled smart temperature regulation system using IoT and NodeMCU. *Journal of Embedded Systems and IoT*, 4(2), 55–63.
- [9]. Kumar, P., & Rajasekaran, M. P. (2016). An IoT-based smart home automation system using sensors and Wi-Fi. *International Journal of Computer Applications*, 142(11), 15–19.
- [10]. Lee, J., Bagheri, B., & Kao, H. A. (2015). *A cyber-physical systems architecture for industry 4.0-based manufacturing systems*. *Manufacturing Letters*, 3, 18–23.
- [11]. Nise, N. S. (2020). *Control systems engineering* (8th ed.). Wiley.
- [12]. Ogata, K. (2010). *Modern control engineering* (5th ed.). Prentice Hall.
- [13]. Patel, D., & Mehta, R. (2015). Comparative analysis of temperature control systems: Conventional vs. intelligent controllers. *International Journal of Engineering Research and Applications*, 5(4), 104–110.
- [14]. Patel, R. V., & Munjal, P. L. (2019). *Adaptive control strategies for smart systems*. *International Journal of Control, Automation and Systems*.
- [15]. Rault, T., Bouabdallah, A., & Challal, Y. (2014). Energy efficiency in wireless sensor networks: A top-down survey. *Computer Networks*, 67, 104–122. <https://doi.org/10.1016/j.comnet.2014.03.027>
- [16]. Resquites, J. C. M., Parrocho, M. A., Vinegas, N., & Oquiño, V. H. (2023). *IoT-based temperature monitoring and automatic fan control using ESP32*. *Iconic Research and Engineering Journals*, 7(5), 35–44. <https://irejournals.com>
- [17]. Schneiderman, B. Plaisant, C. Cohen, M. Jacobs, S., & Elmqvist, N. (2016). *Designing the user interface: Strategies for effective human-computer interaction* (6th ed.). Pearson.
- [18]. Singh, R., & Sharma, S. (2018). Design and implementation of fuzzy-PID controller for temperature control system. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 7(3), 1021–1027.