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Application of PID control

Joshua Sang

Flintridge Preparatory School

Abstract:

Proportional-Integral-Derivative (PID) control is a foundational technique in engineering, widely used to regulate systems and processes with precision and efficiency. This paper explores diverse applications of PID control, ranging from temperature regulation in power generation and household appliances to motion control in robotics and vibration damping in flexible structures. It also examines advanced innovations, such as adaptive PID mechanisms and AI-optimized controllers, which enhance performance in dynamic and complex environments like unmanned aerial vehicles (UAVs) and DC motor speed regulation. By analyzing examples that highlight the versatility and adaptability of PID control, the paper underscores its significance in addressing modern engineering challenges. The insights provided demonstrate how the continuous evolution of PID techniques ensures its relevance and efficacy in a variety of industrial and technological domains.

Keywords: PID control; engineering; Proportional-Integral-Derivative; automated and dynamic systems; artificial intelligence (AI) techniques

Proportional-Integral-Derivative (PID) control is a fundamental technique used in engineering to regulate systems and processes. Its simplicity and effectiveness have made it one of the most widely used control algorithms in industrial and engineering applications, from robotics and automation to temperature control and motor speed regulation. By continuously calculating the error between a desired setpoint and the measured process variable, PID control adjusts system inputs to minimize error over time. The versatility of PID control lies in its three components: proportional, integral, and derivative, each addressing different aspects of system performance. Understanding the theory behind PID control and its practical applications is crucial for developing efficient and reliable control systems.

One practical application of PID control is in managing the temperature of superheated steam in a 500 MW boiler, which is a critical component in power generation systems. Rao, Subramanyam, and Satyaprasad(2014) in the study Study on PID Controller Design and Performance Based on Tuning Techniques, the authors investigated how different PID tuning methods impact the performance of this complex control system. Temperature control is crucial to ensure the peak efficiency of the turbine while minimizing mechanical stress on the turbine blades. The dynamic nature of the system, where factors like time delays and load changes can impact steam temperature, made it essential to explore effective tuning strategies.

The study examined several popular tuning techniques, including Ziegler-Nichols (Z-N), Cohen-Coon (C-C), Chien-Hrones-Reswick (CHR), and the Internal Model Control (IMC) method. Each method was tested and simulated in MATLAB/Simulink to evaluate performance indicators such as rise time (how quickly the system responds to changes), settling time (time taken to stabilize), peak overshoot (maximum deviation from the setpoint), and error metrics like Integral Absolute Error (IAE) and Integral Squared Error (ISE). Results from the study highlighted that IMC-PID tuning provided the best setpoint tracking and was highly flexible in adjusting controller parameters. However, it was found to be slightly less effective in disturbance rejection compared to Ziegler-Nichols. The IMC-PID method balanced performance well, with minimal rise and settling times and controlled overshoot, illustrating the trade-offs between responsiveness and stability that engineers must consider when designing PID controllers for critical industrial applications.

Another innovative application of PID control is in adaptive motion control for robotic systems, where traditional fixed-parameter PID controllers often struggle with dynamic and unpredictable environments. In the study Dynamically Adjustable PID for Adaptive Motion Control, researchers developed a novel approach called Dynamically Adjustable PID (DAPID) to address the limitations of conventional PID controllers(Arciuolo, 2020). Unlike fixed-parameter designs, the DAPID system incorporates an adaptive algorithm that continuously monitors system performance and adjusts PID gains in real time, ensuring optimal control under varying conditions.

This adaptive mechanism was tested in robotic systems, such as robotic arms performing complex tasks that involve rapid and unexpected movements. The DAPID controller showed significant improvements in stability and accuracy, effectively handling disturbances and environmental variations. By dynamically tuning control parameters, the robotic system could maintain optimal performance, demonstrating how integrating adaptive mechanisms into the PID framework enhances efficiency and reliability. This research highlights the potential for DAPID controllers to revolutionize robotic operations, enabling them to execute more sophisticated tasks with greater precision and adaptability.

PID controllers have also been effectively applied to everyday household appliances, such as refrigerators, to maintain a consistent internal temperature. The study Application of PID Controller in Controlling Refrigerator Temperature compared the performance of a PID temperature controller to a conventional on-off controller(Hamid & Kamal &Yahaya, 2009). Traditional on-off controllers operate by switching the cooling mechanism on or off based on temperature thresholds, which often leads to temperature fluctuations around the desired setpoint. This can be inefficient and result in inconsistent temperature regulation.

In contrast, the PID controller continuously adjusts the cooling input by calculating the error between the desired temperature and the actual temperature, aiming to minimize this error over time. The findings of the study indicated that the PID controller offered superior temperature stability and energy efficiency. By reducing temperature oscillations and maintaining a more consistent internal environment, the PID-controlled system enhanced food preservation and reduced energy consumption. This example demonstrates how PID control can improve the efficiency and reliability of everyday appliances, providing practical benefits for energy conservation and food storage.

PID controllers have also found applications in managing vibrations in flexible structures, such as beams and bridges, which are susceptible to oscillations that can affect their structural integrity and performance. In the study Vibration Control of Flexible Structures Using PID Controllers, the author explored the use of PID control for damping vibrations (McMillan, 2012). Vibration control is critical in engineering structures to ensure safety and stability, and the research focused on how precisely tuned PID parameters can minimize these oscillations without compromising the system’s overall stability.

Using a combination of experimental setups and simulations, the study compared the performance of PID controllers against other control strategies. The results demonstrated that the PID controller was highly effective in reducing vibration amplitudes, thereby contributing to the stability and robustness of the structure. The study highlighted the importance of optimizing PID parameters for specific applications, as improper tuning could result in reduced effectiveness. This example underscores the versatility of PID controllers in handling mechanical oscillations in various engineering fields, ensuring both safety and efficiency.

The integration of artificial intelligence (AI) techniques has further improved the performance of PID controllers in complex systems. Salman, G. A., Jafar, A. S., & Ismael, A. I. (2019), in the study Application of Artificial Intelligence Techniques for LFC and AVR Systems Using PID Controller, researchers investigated the enhancement of Load-Frequency Control (LFC) and Automatic Voltage Regulation (AVR) systems in power generation using AI-optimized PID controllers. The study applied advanced

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optimization techniques such as the Firefly Algorithm (FA), Genetic Algorithm (GA), and Particle Swarm Optimization (PSO) to tune PID controller parameters.

By using error metrics like Integral Time Absolute Error (ITAE) and Integral Time Squared Error (ITSE) as objective functions, the study aimed to minimize deviations in frequency and voltage. The simulation results revealed that the Firefly Algorithm outperformed both GA and PSO, achieving superior control performance. The optimized PID controllers provided better frequency and voltage regulation, enhancing the overall efficiency and stability of the power systems. This research illustrates the potential of AI techniques in tuning PID controllers for critical applications, offering a robust and efficient solution for power system management.

PID control plays a crucial role in regulating the speed of DC motors, which are widely used in various industrial applications. The paper Tuning PID Controller for Speed Control of DC Motor Using Soft Computing Techniques (Kushwah & Patra, 2014) reviewed multiple approaches to optimize PID parameters for better motor speed control. Traditional PID controllers often face challenges like overshoot and sluggish response to load changes, which can degrade system performance. This study explored the use of soft computing techniques, such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Fuzzy Logic, to enhance PID tuning.

The authors found that using GA and PSO significantly reduced rise time, settling time, and overshoot compared to conventional tuning methods. These techniques provided more robust and reliable speed control under varying load conditions, demonstrating the effectiveness of integrating soft computing approaches. The research emphasized that optimizing PID parameters using advanced algorithms can greatly improve the performance of DC motor systems, making them more suitable for dynamic environments.

In the field of unmanned aerial vehicles (UAVs), particularly quadrotors, maintaining stable flight is a complex challenge due to the vehicles' nonlinear dynamics and vulnerability to external disturbances. Traditional PID controllers are widely used for stabilization; however, they require precise tuning of proportional (K_p), integral (K_i), and derivative (K_d) gains, which can be labor-intensive and unsuitable for dynamic flight conditions. The study Designing of Self-Tuning PID Controller for AR Drone Quadrotor introduced a gradient descent-based approach for real-time tuning of PID parameters(Badu, Kumar, Das 2017).

This self-tuning PID controller adjusts its gains during flight, enhancing the quadrotor's ability to respond to external disturbances and maintain stability. The researchers demonstrated the effectiveness of this adaptive control method through experimental tests, showing improved performance over fixed-gain PID controllers. This advancement highlights the importance of adaptive PID strategies in UAV applications, providing a more efficient and reliable solution for navigating complex and dynamic environments.

Proportional-Integral-Derivative (PID) control remains a cornerstone of engineering, enabling precise and reliable regulation of systems across a wide array of applications. Its adaptability and simplicity have cemented its role in industries ranging from power generation and robotics to household appliances and UAVs. As demonstrated in the examples, advancements in tuning techniques, integration with artificial intelligence, and adaptive algorithms have significantly enhanced the capabilities of PID controllers. These innovations allow PID systems to address complex challenges, such as nonlinear dynamics, environmental disturbances, and the need for real-time responsiveness. Whether optimizing temperature in industrial boilers, stabilizing robotic arms, or ensuring flight stability in UAVs, PID control continues to evolve, meeting the demands of modern engineering with efficiency and precision. Looking forward, the fusion of PID control with emerging technologies promises further breakthroughs, making it a crucial tool in shaping the future of automated and dynamic systems.

References

1. Rao, P. V. G. K., Subramanyam, M. V., & Satyaprasad, K. (2014). *Study on PID Controller Design and Performance Based on Tuning Techniques*.

2. Thomas F. Arciuolo.(2020). *Dynamically Adjustable PID for Adaptive Motion Control*. IEEE Explore.

3. Noor Hayatee Abdul Hamid, Mahanijah Md Kamal, Faieza Hanum Yahaya, (2009). *Application of PID Controller in Controlling Refrigerator Temperature*. IEEE Explore.

4. Gregory K. McMillan. (2012). *Vibration Control of Flexible Structures Using PID Controllers*. Springer.

5. Salman, G. A., Jafar, A. S., & Ismael, A. I. (2019). *Application of Artificial Intelligence Techniques for LFC and AVR Systems Using PID Controller*. .

6. Kushwah, M., & Patra, A. (2014). *Tuning PID Controller for Speed Control of DC Motor Using Soft Computing Techniques*.

7. V. Madhu Babu, Kaushik Das, Swagat Kumar. *Designing of Self-Tuning PID Controller for AR Drone Quadrotor*. IEEE Explore.