OVEN TEMPERATURE CONTROL USING PID WITH SMARTPHONE MONITORING VIA FIREBASE

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ABSTRACT

This paper presents the development and implementation of an effective temperature control system for an oven using a PID (Proportional-Integral-Derivative) controller. The primary objectives are to achieve precise temperature regulation, reduce rise time (RT), minimize overshoot (OV) and settling time (ST), and eliminate steady-state error (SSE). System identification experiments were conducted to obtain an empirical model of the oven system, facilitating the tuning of the PID controller parameters. Various tuning techniques, including Ziegler-Nichols 1 (Z-N 1), Ziegler-Nichols 2 (Z-N 2), Cohen-Coon (C-C), Direct Synthesis (D-S), Internal Model Control (IMC), and Chien-Hrones-Reswick (C-H-R) methods, were investigated and evaluated. The PID controller parameters were determined to meet the desired performance criteria. Additionally, an IoT-based real-time data logging system was developed using Google Firebase, enabling smartphone monitoring of the oven temperature.

Keyword : - *Temperature control, PID controller, System identification, Tuning techniques, Google Firebase integration, Smartphone monitoring*

1. INTRODUCTION

Maintaining precise temperature control is essential in various industrial applications, including ovens, furnaces, and heat treatment systems. Accurate regulation of temperature is key to ensuring product quality, enhancing energy efficiency, and guaranteeing process safety. This study aims to develop a reliable temperature control system for an oven, utilizing an RTD sensor and a PID controller to establish optimal controller parameters for achieving the desired performance criteria.

The RTD sensor delivers precise and dependable temperature readings, and the PID controller modulates the heating element's power to keep the temperature at the desired setpoint. The PID controller algorithm determines an error value by comparing the setpoint with the temperature measured by the RTD sensor. Using this error value, the controller calculates the required control action to reduce the error and align the process variable (temperature) with the desired setpoint.

1.1 Objectives

- Developing an effective temperature control system for an oven utilizing an RTD sensor and a PID controller.
- Conducting system identification experiments to obtain an empirical model of the oven system for PID tuning.
- Investigating and evaluating various tuning methods for the PID controller.
- Determining the PID controller parameters to minimize overshoot, reduce rise time, eliminate steady-state error, and minimize settling time for oven temperature control.

- Identifying the most effective PID tuning method that yields optimal performance for the oven temperature control application.
- Developing an IoT-based real-time data logging system on a smartphone using Google Firebase for remote monitoring and data analysis.

2. SYSTEM IMPLEMENTATION AND INTEGRATION

The implementation of the RTD-PID oven control system with IoT-based monitoring involved the integration of various hardware and software components, including the oven and heating element, RTD sensor, communication interfaces, PID control algorithm implementation, IoT platform integration, mobile application development, and user interface and data visualization tools.

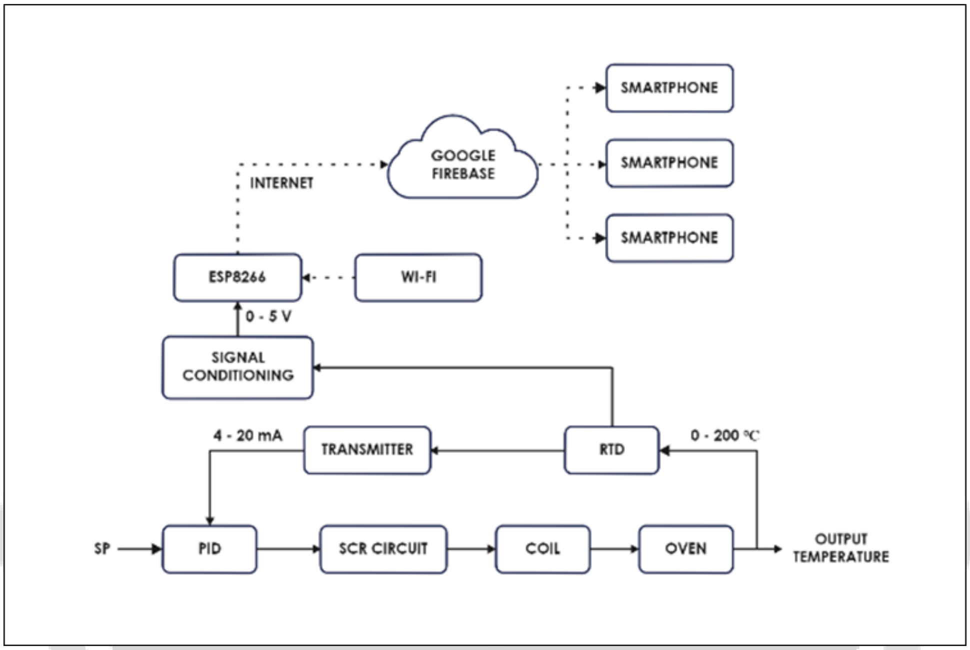

Fig-1: System block diagram

Comprehensive system tests were conducted to assess the overall performance, stability, and reliability of the integrated system, subjecting it to various operating conditions, temperature setpoints, and simulated scenarios to validate its robustness and ability to meet the desired performance criteria.

3. SYSTEM IDENTIFICATION

To conduct this research, we set up an enclosure containing a 600W coil. The tip of an RTD (Resistance Temperature Detector) is inserted at the center of the enclosure. The output of the RTD is fed into a PID controller, and with the help of signal conditioning, the PID controller regulates the voltage supplied to the coil.

The empirical model of the system was determined by applying a 20% step input from the PID controller. Based on the system's response to this input, the model was identified as a first-order plus time delay (FOPTD) model, represented by the following transfer function:

$$G_p = \frac{K_p}{\tau_p s + 1} * e^{-\theta s}$$

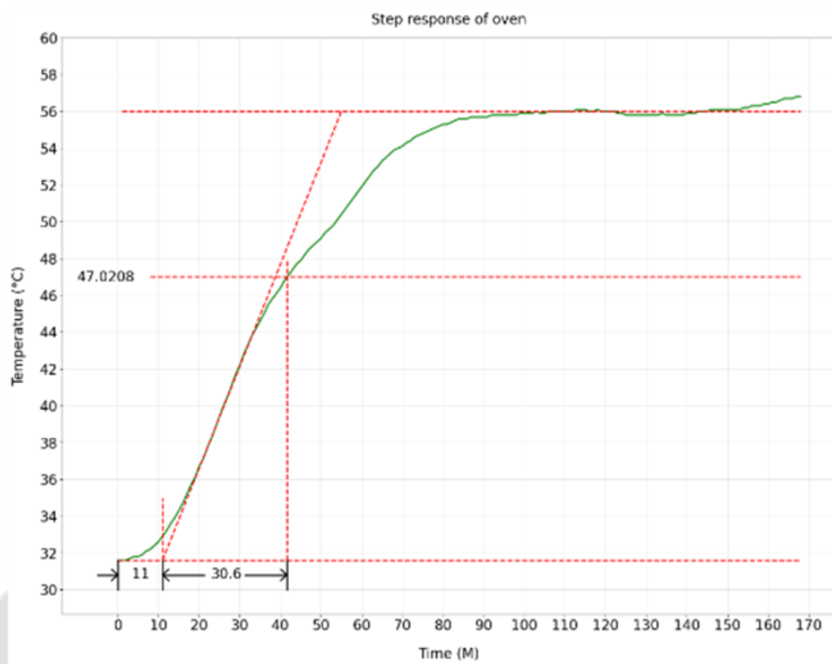

Fig-2: Step response of oven

The specific parameters of the empirical model were determined to be

$$G_p = \frac{1.22}{30.6s + 1} * e^{-11s}$$

Where,

Kp = 1.22 (process gain)
τp = 30.6 (time constant)
θ = 11 (time delay)

Obtaining an accurate empirical model is crucial for effective PID tuning, as it captures the inherent dynamics and characteristics of the oven system, enabling the selection of appropriate controller parameters.

3. PID TUNING METHODS

Various tuning techniques were employed to determine the PID controller parameters (Kp, Ki, and Kd) for different configurations: PID, PI, and P-only. The tuning methods investigated include Ziegler-Nichols 1, Ziegler-Nichols 2, Cohen-Coon, Direct Synthesis, Internal Model Control, and Chien-Hrones-Reswick. The tuned PID parameters for each configuration and tuning method are presented in the following table:

Table -1: Tuning parameters for P-only, PI and PID configurations

	P-only	**PI Config**		**PID Configurations**		
Method	KP	KP	KI	KP	KI	KD
Ziegler-Nichols 1	0.0745	0.0670	0.0018	0.0894	0.0040	0.4918
Ziegler-Nichols 2	2.2801	2.0521	0.0565	2.7362	0.1243	15.049
Cohen-Coon	2.5534	2.1204	0.0602	3.2451	0.1371	0.8643

Direct-Synthesis	NA	1.9293	0.0630	NA	NA	NA
Internal Model Control	NA	14.795	0.4098	3.9453	0.1092	18.393
Chien-Hrones-Reswick	0.6840	0.7980	0.0217	1.3681	0.0447	7.5245

5. Performance Evaluation and Optiml Tuning Method

The tuned PID controllers were implemented in the oven temperature control system, and their performance was evaluated based on various metrics, including overshoot, rise time, settling time, and steady-state error. The performance metrics for each tuning method and configuration are presented in the following tables:

A. P-only configuration

Table-2: Performance evaluation of P-only configuration

Method	**OV**	**RT**	**ST**	**SSE**
Z-N 1	0	1806.5	3552.8	9.1667
Z-N 2	44.7114	225.7872	3186.5	2.6442
C-C	54.1693	204.8210	3761.9	2.4300
D-S	NA	NA	NA	NA
IMC	NA	NA	NA	NA
C-H-R	0.0838	696.5471	1431.9	5.4509

B. PI configuration

Table-3: Performance evaluation of PI configuration

Method	**OV**	**RT**	**ST**	**SSE**
Z-N 1	0	29050	51971	0
Z-N 2	33.0069	307.9216	3554.7	0
C-C	37.1337	291.7638	3615.4	0
D-S	34.6844	318.8818	3081.3	0
IMC	0	119.7475	45273	Inf
C-H-R	≅ 0	1710.9	4354.3	0

C. PID configuration

Table-4: Performance evaluation of PID configuration

Method	**OV**	**RT**	**ST**	**SSE**
Z-N 1	0	12132	21787	0

Z-N 2	69.3121	101.7902	2821.8	0.0007
C-C	103.1612	182.2856	25337	0
D-S	NA	NA	NA	NA
IMC	119.7449	42.0328	18980	-0.0019
C-H-R	2.2025	838.4806	2762.1	0

The responses of the different tuning techniques for P-only, PI, and PID control modes are shown in Figures 3, 4, and 5, respectively.

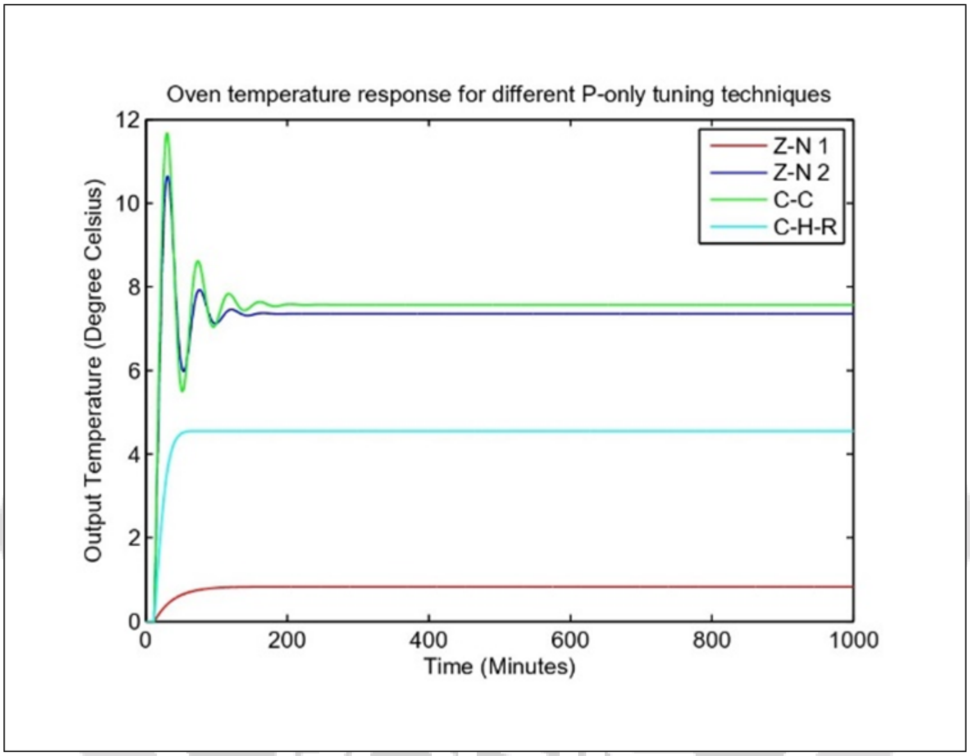

Fig-3: Oven temperature responses for different P-only tuning techniques

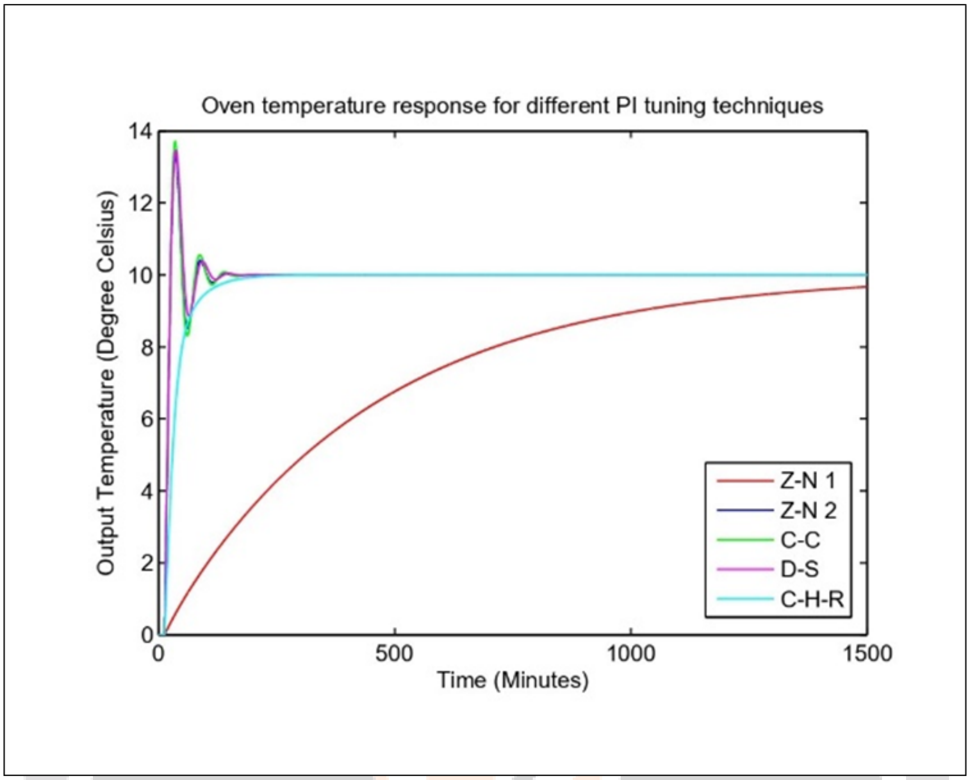

Fig-4: Oven temperature responses for different PI tuning techniques

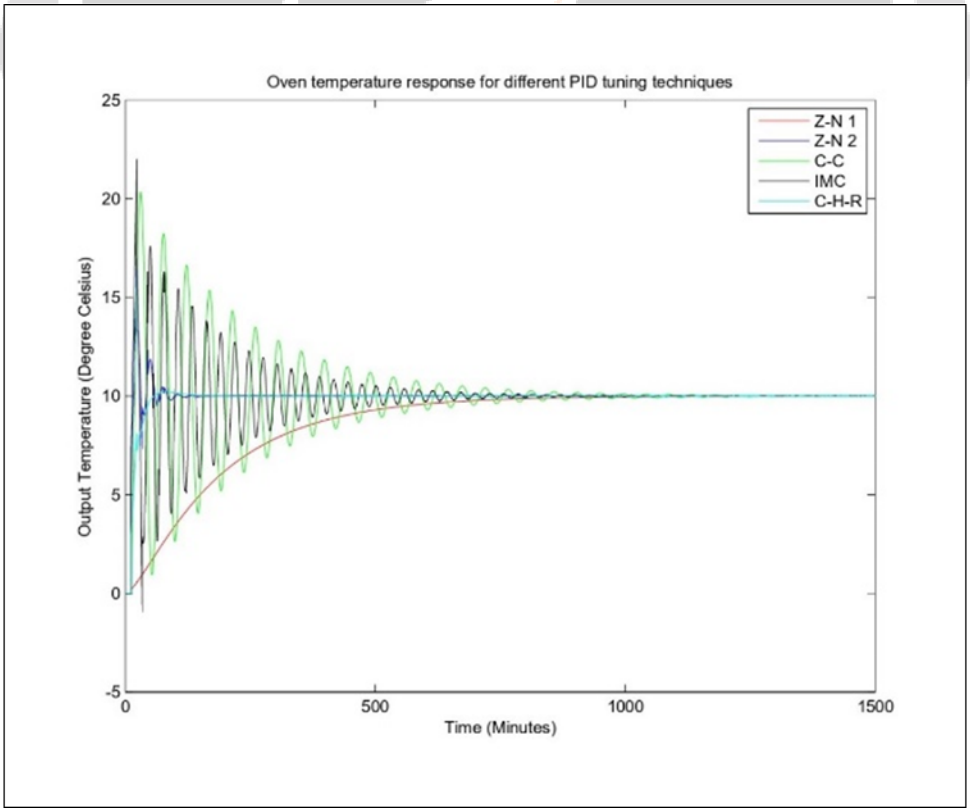

Fig-5: Oven temperature responses for different PID tuning techniques

Based on the analysis of the temperature responses and performance metrics, the Chien-Hrones-Reswick tuning method for the PID configuration was identified as the most effective, yielding optimal performance for the oven temperature control application. It provided a balanced trade-off between the various performance criteria, minimizing overshoot while maintaining a reasonable rise time and settling time, and effectively eliminating steady-state error.

6. IoT-based Real-time Data Logging with Smartphone Monitoring

To enable remote monitoring and data logging capabilities, an Internet of Things (IoT)-based system was developed using the Google Firebase platform. The oven temperature data was transmitted from the control system to the Firebase Realtime Database using a secure communication protocol, allowing for real-time monitoring of the oven temperature from any device with an internet connection, including smartphones, tablets, and computers.

The temperature measurement was performed using an RTD sensor connected to a Wheatstone bridge circuit and an operational amplifier (op-amp) configuration. The Wheatstone bridge converted the resistance changes of the RTD into a voltage signal proportional to the temperature, while the op-amp amplified and scaled this voltage signal to a range compatible with the analog-to-digital converter (ADC) of an ESP8266 microcontroller.

The ESP8266 microcontroller was programmed to read the analog voltage signal from the op-amp, convert it into a digital value, and then transmit the temperature data to the Firebase Realtime Database. This process was repeated at regular intervals, ensuring continuous monitoring and data logging of the oven temperature.

A dedicated mobile application was developed for Android platform, leveraging the Firebase Realtime Database integration. The app provided a user-friendly interface for monitoring the current oven temperature in real-time, as well as visualizing historical temperature data in the form of charts and graphs.

The key features of the IoT-based data logging and monitoring system include:

A. Real-time Temperature Monitoring: The mobile app displays the current oven temperature in real-time, allowing users to monitor the process from anywhere, as long as they have an internet connection.

B. Historical Data Visualization: The app provides graphical representations of the oven temperature over time, enabling users to analyze trends, identify anomalies, and gain insights into the process behavior.

C. Data Logging and Reporting: The Firebase Realtime Database serves as a centralized repository for temperature data, enabling users to export data for further analysis, generate reports, or integrate with other systems for data processing or archiving.

The integration of the IoT-based data logging and monitoring system with the oven temperature control system provided several benefits, including remote monitoring and accessibility, data-driven decision making, improved process visibility and traceability, and scalability and integration potential.

7. RESULTS AND DISCUSSIONS

The implementation of the PID oven control system with IoT-based monitoring yielded promising results, demonstrating the effectiveness of the integrated approach in achieving precise temperature control and remote monitoring capabilities.

The optimally tuned PID controller achieved a smooth and well-damped temperature response, with minimal overshoot and a reasonable rise time. The steady-state error was effectively eliminated, ensuring precise temperature regulation at the desired setpoint.

The integration of the Google Firebase platform and the development of the dedicated mobile application enabled seamless remote monitoring and data logging capabilities. Users could access real-time oven temperature data from their smartphones, as well as visualize historical temperature trends through intuitive charts and graphs.

Fig-6: Oven System

The availability of comprehensive temperature data logged in the Firebase Realtime Database facilitated data-driven decision making and process optimization. By analyzing the historical temperature trends and correlating them with process parameters or product quality data, users could identify areas for improvement, optimize process settings, and implement preventive maintenance strategies. Furthermore, the temperature data stored in the database provided a detailed record of the process, enhancing traceability and enabling root cause analysis in case of deviations or quality issues.

8. CONCLUSIONS

This work successfully developed an effective oven temperature control system using PID controller with various tuning techniques. Among these techniques, Chien-Hrones-Reswick (CHR) tuning stood out as the best for our process. The IoT-based monitoring system integrated with Google Firebase allowed real-time data logging and visualization through a mobile app. This combination significantly improved process efficiency, product quality, and compliance.

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