UNIVERSITI TEKNOLOGI MARA

PERFORMANCE ANALYSIS OF MODEL REFERENCE ADAPTIVE CONTROL VERSUS CONVENTIONAL AND FUZZY PID FOR PRECISE TEMPERATURE REGULATION IN HEATING SYSTEM

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Thesis submitted in fulfilment
of the requirements for the degree of
Master of Science
(Electrical Engineering)

Faculty of Electrical Engineering

January 2026

ABSTRACT

This study investigates the effectiveness of Model Reference Adaptive Controller (MRAC) utilizing MIT and Lyapunov methods, alongside conventional PID, Fuzzy PID, and Fuzzy PID with Model Reference (FPID+MR) controllers for temperature regulation in the PT326 Process Trainer heating system. The controllers were implemented and tuned to evaluate their ability to achieve optimal temperature control under operational conditions. The study first focused on designing, implementing, and tuning each controller using the ARX223 model derived through system identification in MATLAB/Simulink, addressing the first objective. Performance evaluation was conducted based on rise time, settling time, overshoot and root mean square error (RMSE). To fulfil the second objective, the study assessed the enhancement provided by fuzzy logic and model reference integration. Results showed that FPID improved the PID rise time from 27.22 seconds to 20.12 seconds and settling time from 49.86 seconds to 38.29 seconds, while FPID+MR further reduces them to 12.33 seconds and 23.61 seconds, with RMSE decreasing from 10.72 (PID) to 8.508 (FPID+MR). The results, which addressed the third objective, validated through simulations indicate that MRAC methods, particularly MIT-based approach, outperform conventional PID, Fuzzy PID, and FPID+MR controllers across all key metrics. The MIT rule exhibited the fastest response, minimal steady-state error, reduced overshoot, more accurate temperature tracking through RMSE. MRAC MIT achieved a rise time of 3.12 seconds and settling time of 8.10 seconds. The Lyapunov-based MRAC also demonstrated strong performance, especially in robustness and stability with a rise time of 3.93 seconds, settling time of 8.00 seconds, and the lowest RMSE of 6.202, though it was slightly less efficient than the MIT method. The FPID+MR controller showed improved adaptability compared to conventional PID and standalone Fuzzy PID controllers. It offered better response times and robustness, yet it still fell short of the MRAC methods. While Fuzzy PID improved upon conventional PID controllers, it remained inferior to both MRAC and FPID+MR approaches. MRAC-based controllers demonstrated the most significant enhancements, with MRAC MIT achieving the fastest rise time and MRAC-Lyapunov delivering the best balance of speed, stability, and tracking accuracy. The findings suggest that MRAC-Lyapunov is the most suitable control method for achieving fast, stable, and accurate temperature regulation in the PT326 heating system.

ACKNOWLEDGEMENT

First and foremost, would like to express my deepest gratitude to Allah SWT for granting me the strength, perseverance, and guidance throughout the course of this research and the completion of this thesis. Without His blessings, this work would not have been possible.

I wish to extend my sincere appreciation to my supervisor, Dr. Norlela binti Ishak, for her invaluable guidance, constructive feedback, and unwavering support during the development of this research. Her expertise and encouragement have been crucial in shaping the direction of this work and in helping me overcome the challenges I encountered.

My heartfelt thanks also go to the faculty members and laboratory staff of Universiti Teknologi MARA who provided access to resources, facilities, and technical support, particularly in the use of the PT326 heating system and MATLAB/Simulink software. Their assistance played a key role in ensuring that the research was conducted successfully.

I am also grateful to my friends and colleagues for their encouragement, thoughtful discussions, and moral support, which kept me motivated throughout the research journey. Their companionship made the process more manageable and enjoyable.

Finally, I dedicate this thesis to my beloved family especially my parents, siblings, and loved ones for their endless love, prayers, and encouragement. Their patience and belief in me have been my greatest source of strength and inspiration. This piece of victory is dedicated to both of you. Alhamdulilah.

To all who contributed, directly or indirectly, to the completion of this thesis, I offer my heartfelt appreciation.

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CHAPTER 1
INTRODUCTION

1.1 Research Background

Temperature regulation plays a central role in many engineering and industrial processes, including chemical production, power generation, food processing, and HVAC (Heating, Ventilation, and Air Conditioning) systems. In such applications, maintaining a stable temperature is not only important for energy efficiency but also critical for safety, product quality, and equipment longevity. Traditionally, the Proportional–Integral–Derivative (PID) controller has been the most widely adopted solution for temperature control due to its relatively simple design and reliable performance. PID controllers continue to be used extensively in both academic training and industry because they are easy to tune and well understood.

However, the nonlinear behavior of heating systems introduces challenges that limit the performance of conventional PID. Thermal systems often exhibit time delays, variable process gains, and dynamic disturbances, which make fixed-gain PID tuning less effective. These limitations have motivated the exploration of more advanced strategies such as Fuzzy Logic Controllers (FLCs), which can handle uncertainties by mimicking human reasoning, and Model Reference Control (MRC), which improves tracking by using a predefined reference model as guidance. More recently, Model Reference Adaptive Control (MRAC) methods, particularly those based on the MIT rule and Lyapunov stability theory, have emerged as powerful tools capable of adapting controller parameters in real-time to achieve both fast response and robustness under varying operating conditions.

The PT326 heating system is a well-established laboratory platform that provides a controlled environment for testing such controllers. It is widely used in academic settings because it realistically models the dynamics of industrial heating processes while remaining manageable for experimentation and simulation. Thus, evaluating and comparing PID, FPID, FPID+MR, MRAC MIT, and MRAC Lyapunov controllers on the PT326 system provides valuable insights into the practical strengths and limitations of conventional, intelligent, and adaptive control strategies.