AI-Based MPC Controllers for Energy-Efficient HVAC Systems

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Introduction

- Motivation: Rising energy demands and environmental concerns necessitate efficient energy management in thermal systems. MPC offers predictive capabilities to optimize energy use in dynamic environments.
- Challenges: Implementation hurdles include the lack of step-by-step guidelines, the availability of suitable infrastructure, cost, and modeling accuracy.
- This work aims to reduce HVAC energy consumption by developing a smart thermostat prototype using a combination of hardware and software, employing both data-driven and AI modeling techniques to ensure precision and cost-effectiveness.
- Provide implementation steps, required equipment, and a block diagram for the MPC controller in thermal systems.

System Model:

- The system model streamlines data collection, transmission, and processing, supporting analysis and control sub-modules.
- These sub-modules initiate control signals based on predefined strategies to optimize HVAC system control.
- It is designed to represent the virtual hardware and software components necessary for data collection and processing.

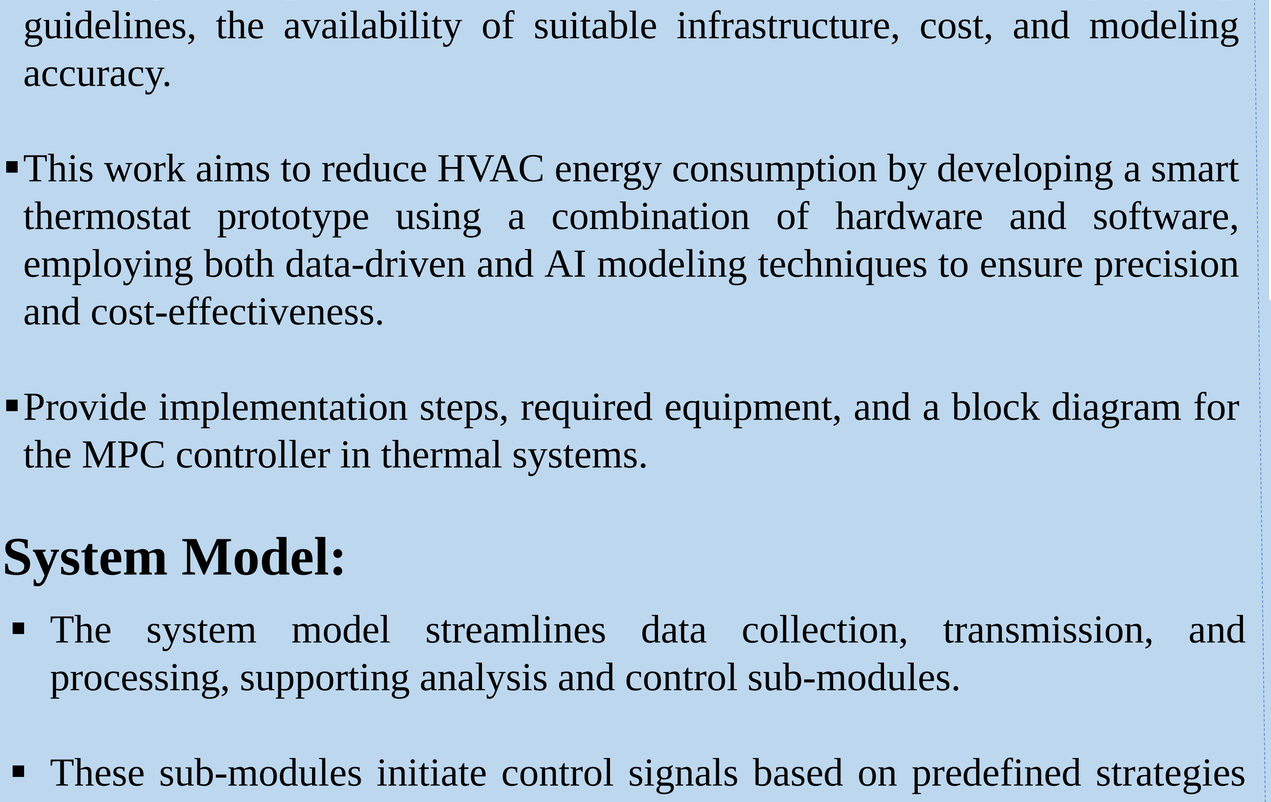

Figure 1: The Schematic Diagram of the Proposed Solution

Methodology:

- A physical testbed has been established to represent a specific zone of interest, incorporating indoor and outdoor temperature sensors and heating elements.
- A Raspberry Pi is utilized to oversee data collection and control operations.
- Two model predictive approaches will be adopted following the data collection stage.
  - First, transfer function based, as demonstrated in the presented work.
  - Second, an LSTM (Long Short Term Memory) based approach will be investigated as an ongoing efforts.
- **Data Collection with PID Controller:**
  Initial operation with a PID controller to gather baseline data on temperature and energy use.

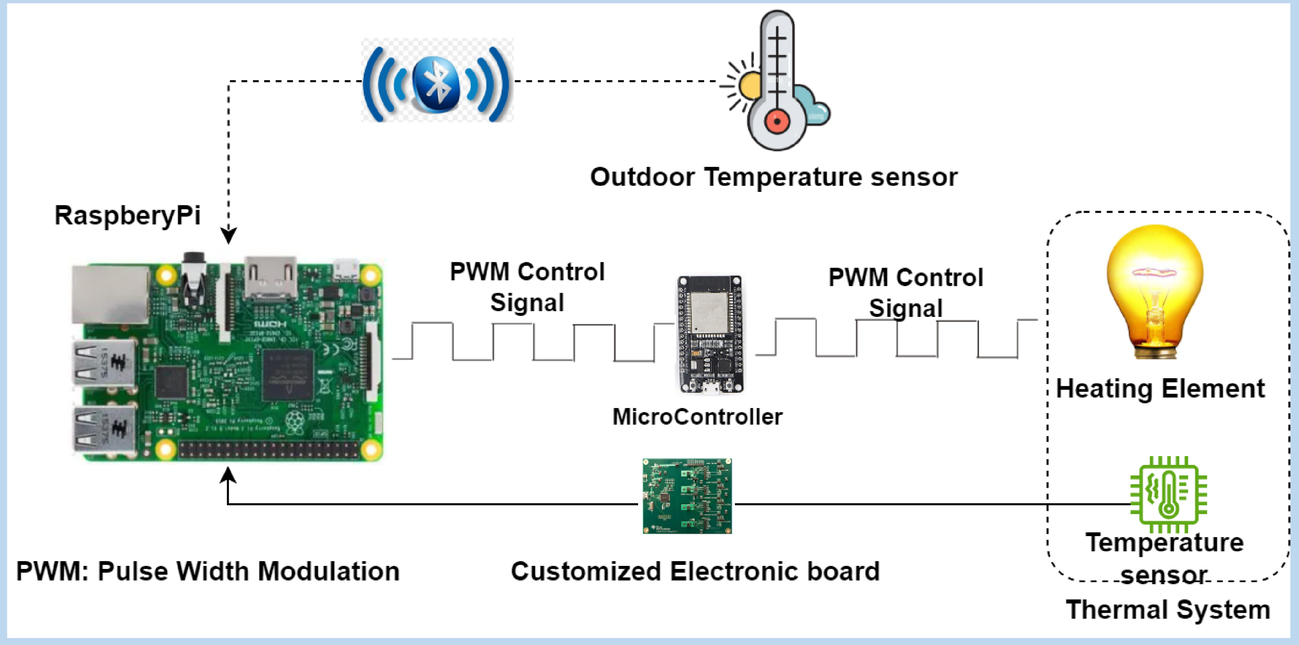

Figure 2: The Hardware components of the TestBed

- **System Identification:**

- MATLAB System Identification is used to develop the system model.
- Two transfer function (TF) models were developed from the data collected from the PID experiment.

TF1 (From Indoor Temperature to Control signal)

$$G_1(s) = \frac{0.000251}{s + 0.0029}$$

TF2 (From Outdoor Temperature to Control signal)

$$G_2(s) = \frac{0.008069}{s + 0.0029}$$

Numerical Results:

✓ Implemented the Model Predictive Control (MPC) using MATLAB/Simulink.

Figure 3: Comparison between measured data and derived model

✓ Carried out hardware implementation on the proposed test-bed
MPC achieved 25% less control signal consumption compared to PID.

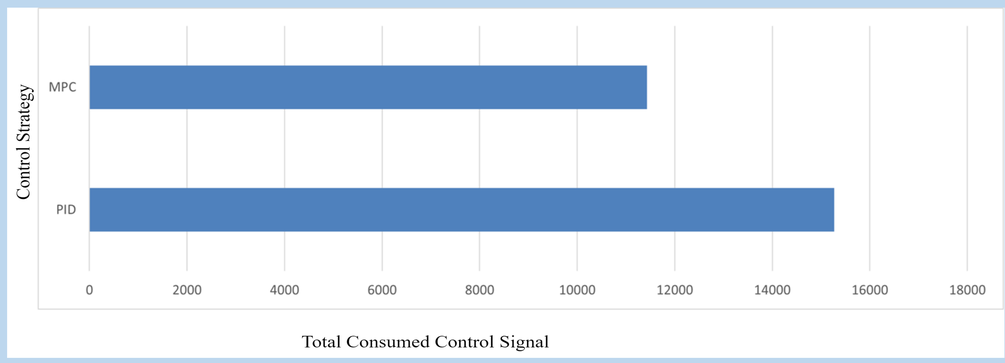

Figure 4: PID vs MPC - Total Consumed Control Signal

Conclusion:

✓ Presents a framework and comparison highlighting the benefits of MPC in energy efficiency and cost savings for thermal system applications.
✓ Findings advocate for adopting MPC over PID in energy-intensive applications.
✓ More efforts will be directed to integrate the AI in our solution including LSTM to enable proactive capabilities.

Publications:

- Abobakr, Saad, et al. "MPC-based efficient energy control and cost estimation of HVAC in buildings." *2023 IEEE Third International Conference on Signal, Control and Communication (SCC)*. IEEE, 2023.
- Alosta, Mahmud, et al. "WSN-based data-driven digital twin for energy efficient HVAC systems." *2023 IEEE Third International Conference on Signal, Control and Communication (SCC)*. IEEE, 2023.

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