PID + Feedforward Control for TCLab Heater for Fan Disturbance Rejection

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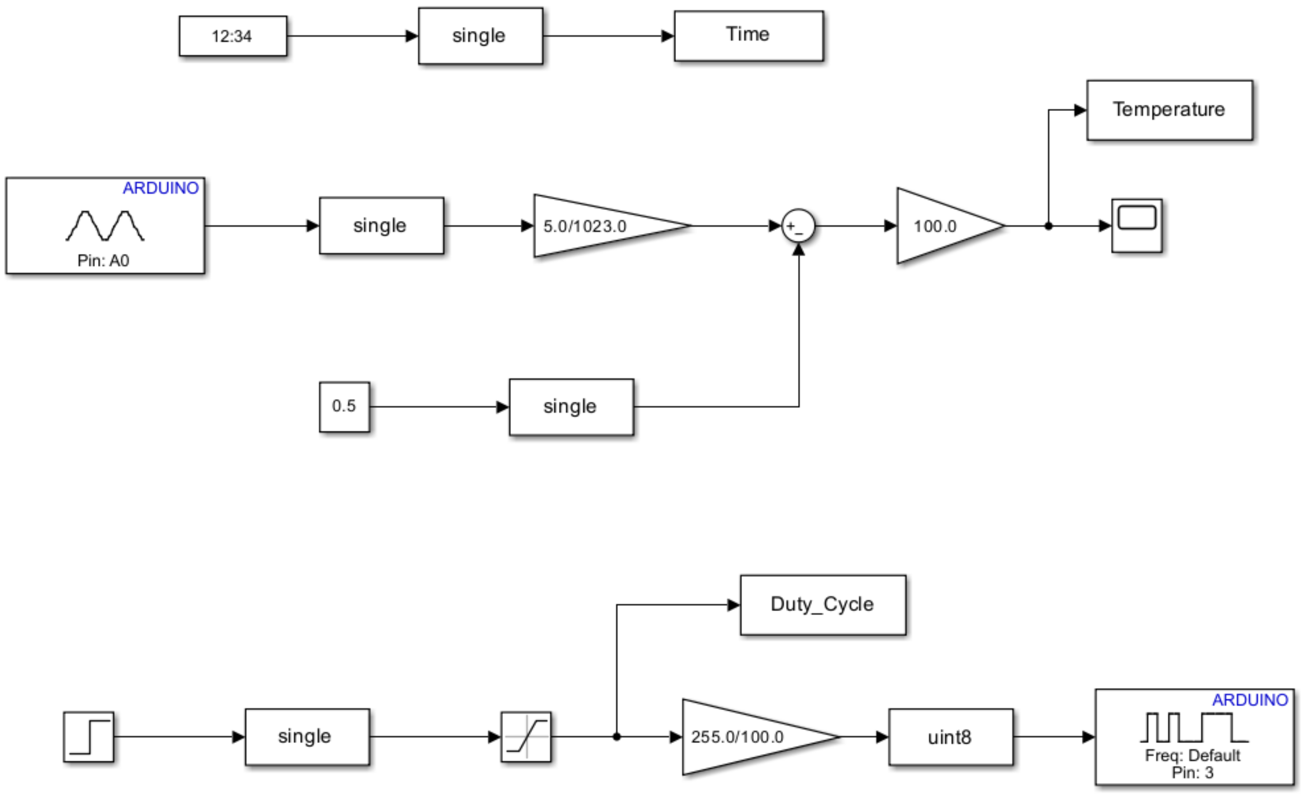
1. PROJECT OVERVIEW & MODEL DESCRIPTION

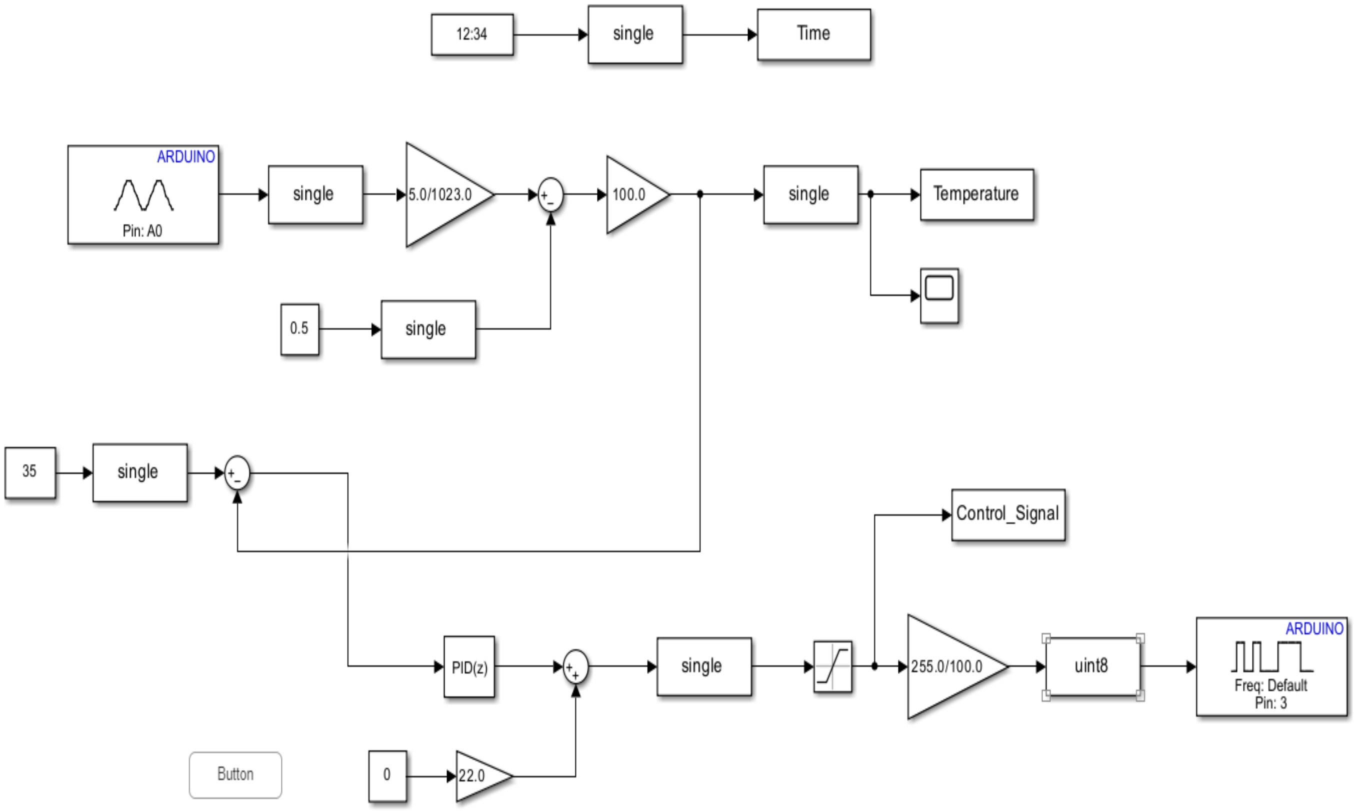
This project implements a **feedforward + feedback control system** to improve disturbance rejection in a TCLab temperature control system. A 5V DC fan acts as a measurable disturbance (cooling effect), and feedforward control compensates for this disturbance before it affects temperature. Due to hardware limitations, manual switching was used to activate both the physical fan and feedforward compensation simultaneously.

2. SIMULINK MODEL

A The following Simulink model without any controller was first used (with 40% heater Power) to calculate the process gain, cooling effect, feedforward gain required, when fan was manually turned ON.



B The following Simulink model was used to first do simple PID control (Feedforward was commented out) and then with feedforward control. During Feedforward control, press button was used to turn the feedforward gain ON at same time when fan was manually turned ON at 350 sec.



(i). Temperature Measurement & Feedback Control

Arduino Analog Input (Pin A0): Reads LM35 temperature sensor. **Signal Chain:** ADC → Gain (5.0/1023.0) → Subtract (0.5V offset) → Gain (100.0) → Temperature.

(ii). Feedforward Control path

Manual Button: Manually activated when fan turns ON (t=350s). **Feedforward Gain (Kff=22):** Pre-calculated compensation value that adds 22% heater power to counteract expected 11.73°C cooling effect from fan.

(iii). PID Control path & Actuation

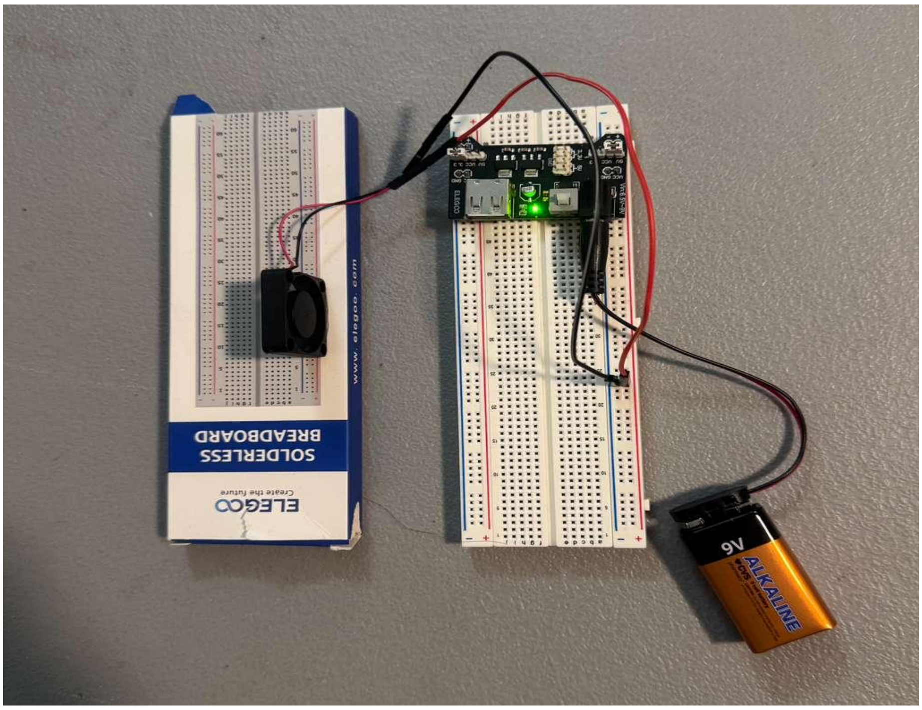
PID Controller: Processes error (Setpoint - Temperature) and generates control signal for heater.

Sum Block: Combines PID output + Feedforward output. **Saturation (0-100%):** Prevents actuator windup. **Scaling & PWM Output:** Converts to Arduino PWM (0-255) on Pin 3 for heater control.

(iv). Data Logging

Clock, Display blocks, and data export for Time, Temperature, and Control Signal visualization.

C The following separate circuit was used to switch ON or OFF the 5V DC fan. (Not connected to Arduino due to non-availability of pins as heater shield occupied all pins)



3. FEEDFORWARD GAIN CALCULATION

Experimental Parameters: Heater Power = 40%, Process Gain K = 0.45°C per 1%, Initial Temp = 24.29°C, Peak Temp (no fan) = 42.38°C, Peak Temp (with fan) = 30.65°C

Cooling Effect: 42.38°C - 30.65°C = 11.73°C temperature drop due to fan

Kff Calculation: Kff = Cooling Effect / Process Gain = 11.73°C / 0.45°C per % = 26.07% ≈ **22% (used)**. When fan turns ON, add 22% heater power to compensate.

4. EXPERIMENTAL RESULTS & ANALYSIS

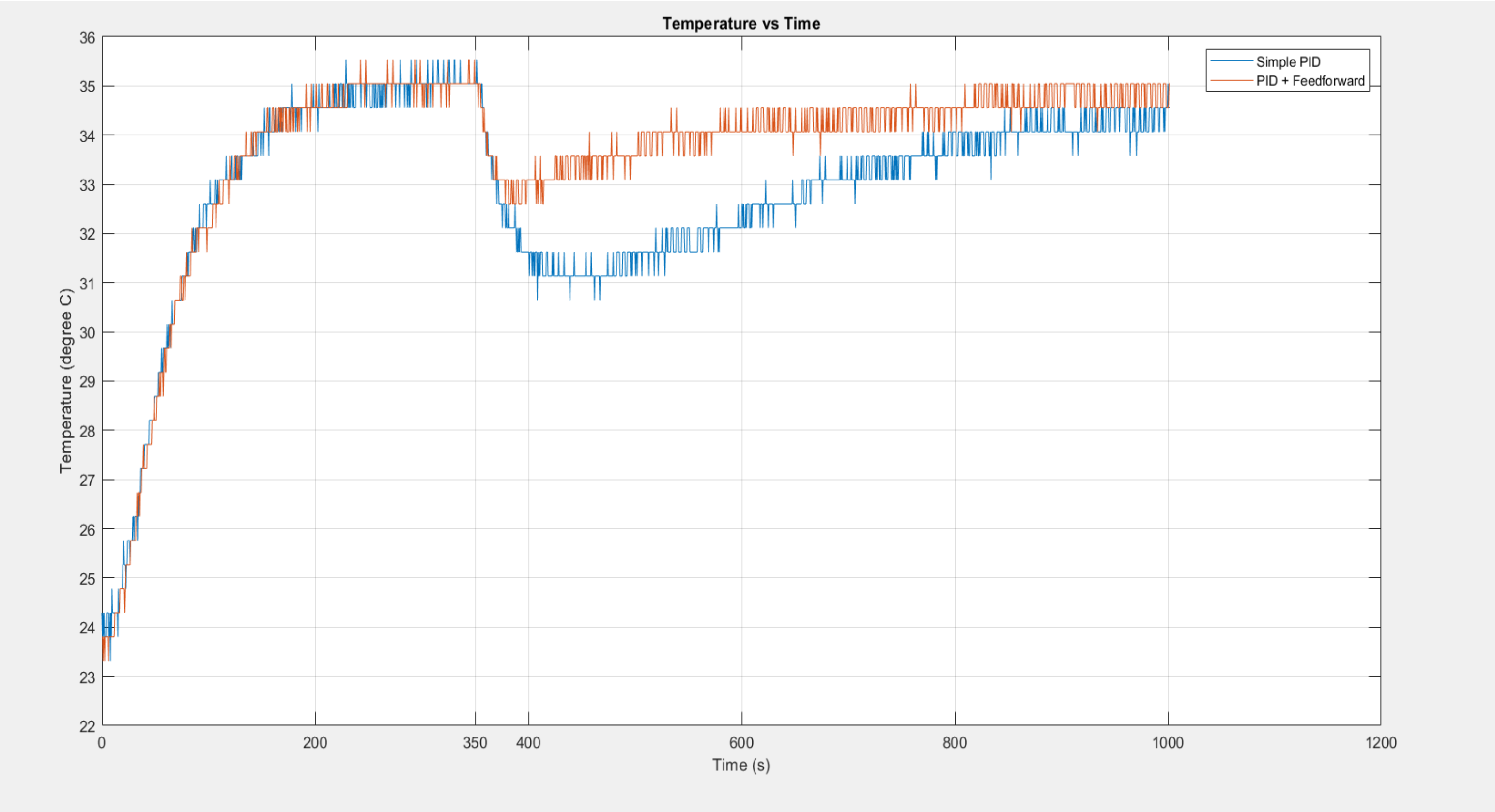
Test Procedure: Two tests of total duration 1000 secs at setpoint 35°C with fan disturbance at t=350s.

Test 1: PID only (Kff=0).

Test 2: PID + Feedforward (Kff=22, button pressed when fan ON).

Metric	Simple PID	PID + FF	Improvement
Peak Deviation	~4°C drop	~2°C drop	**50% reduction**
Recovery Time	~800 sec	~450 sec	**2× faster**

Plot: Comparison of PID vs PID + FeedForward



Key Observations: (1) *Blue line (Simple PID):* Sharp drop to ~31°C, slow recovery. (2) *Orange line (PID + FF):* Minimal drop to ~33°C, rapid recovery. Feedforward preemptively adds heater power instantly when fan turns ON, preventing most temperature deviation. PID alone only reacts after observing error.

5. CONCLUSIONS

This project successfully demonstrates **feedforward control effectiveness** for disturbance rejection: **50% reduction in peak deviation** and **2× faster recovery** compared to feedback-only control. Results validate theoretical Kff calculation through experimental data.

Educational Value: Demonstrates fundamental control principle: *feedforward anticipates disturbances while feedback reacts to them*. Combining both yields superior performance in systems with measurable disturbances (e.g., wind on aircraft, load changes in power systems, cooling in thermal processes).

Future Improvements: Automate fan control with L298N motor driver, implement dynamic feedforward with transfer function, add disturbance observer for unmeasured disturbances.