Modular Heating Instrument

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Product Documentation

Revision: 1.0

Abstract

The Modular Heating Instrument is a dual-zone, PID-controlled heating system designed for laboratory applications. It provides precise thermal regulation using thermistor feedback, MOSFET-based switching, and user interfaces via OLED display and serial commands. The system is modular, allowing heaters and microcontrollers to be swapped easily for flexible experimentation. The goal of this device is to enable homogeneous gas and sensor heating with controllable temperatures. From May 2025 – August 2025, I learned the necessary hardware, software, design, and engineering skills required to design, model, and source a working PID-controlled heating system from scratch.

System Overview

The Modular Heating Instrument supports up to two independent heating channels. Each channel uses an NTC thermistor for temperature sensing, a MOSFET for power switching, and a PID algorithm running on a microcontroller (Arduino Nano Every, ATmega4809, or ESP32). An OLED display provides real-time status of temperature and setpoint, and setpoints can be adjusted via serial input or encoder button. The system operates from a 12V DC 5A supply and features modular design with terminal blocks and switches for easy integration. This system is also meant to be used along with the LabVIEW UI I created to create multiple gas flow rates and easily monitor the flow-rates and status of the lab's mass flow controllers.

Desired Constraints

• Max gaseous flow rate of 5L/min

• Gases: CO_2, O_2, N_2

• Temperature: 25 C – 50 C (increments of 5 C)

Technical Specifications

• Input Voltage: 12V DC

• Heater Power: Up to 60W per channel

• Microcontroller: Arduino Nano Every (default), ATmega4809, ESP32 (supported)

• Temperature Sensor: 10kΩ NTC Thermistor (B=3950)

• Display: 128x64 OLED (I2C interface)

• Control Method: PID with tunable parameters

• User Input: Serial commands, optional encoder

• Outputs: PWM control via logic-level MOSFETs

Bill of Materials (BOM)

A detailed BOM including part numbers and vendors is maintained separately. Key components include a 12V DC power supply, silicone heating pads, MOSFETs (IRLZ44N), NTC thermistors, a 128x64 OLED, and modular terminal blocks. See accompanying BOM.xlsx for sourcing information.

Circuit Design

The circuit consists of a 12V DC supply powering two heater channels. Each heater is switched on the low-side via an N-channel MOSFET, with a flyback diode protecting the MOSFET. Each heater also has a SPST switch to allow power to only flow through a singular heater and protect the further circuit from surges. Thermistors are configured in voltage divider circuits with fixed 10kΩ resistors, and their voltages are read by the MCU's ADC pins. An I2C OLED shares the SDA and SCL lines with pull-up resistors. Separate SPST switches are used for the heater supply and the microcontroller supply. Buck converters provide regulated 5V rails as required. See accompanying KiCAD files for schematic.

Firmware / Software

The firmware implements two independent PID control loops using the Arduino PID_v1 library. Temperature is calculated using the Steinhart–Hart approximation for thermistors. Outputs are driven using PWM via the analogWrite function. Users can adjust setpoints via serial commands (e.g., 'S1:50') or via encoder input if implemented (software currently not written for analog inputs). The OLED displays real-time temperature and setpoints for both channels. There is additionally Arduino and Python software used to produce heating curves to test both heaters and sensors. After uploading "Heating_curve.ino" onto the MCU, run the serialLog.py file to continuously record temperature data to a csv. Note that any serial monitor other than the one running “serialLog.py” must not be opened to establish a connection between the device and Python script. Set point commands must directly be inputted into the terminal running the Python program. See accompanying code files for working software.

Assembly & Integration

1. Connect heaters to terminal blocks.
2. Wire thermistors in a voltage divider with 10kΩ resistors to analog inputs.
3. Attach thermistors to desired sensing zone (inline tube : gas; beaker : sensor)
4. Connect MOSFET gates to PWM-capable pins through resistors.
5. Provide 12V DC input via barrel jack or terminal block.
6. Mount OLED display on I2C pins (SDA/SCL).
7. Place SPST switches for heater and MCU power control.
8. Use buck converters for regulated 5V and 3.3V rails.

Safety Notes

• Use an inline fuse (7–10A) on the heater supply line.
• Ensure MOSFETs are mounted with heatsinks if driving >2A.
• Do not touch heaters during operation (if set point exceeds 100°C).
• Insulate all terminals to prevent accidental shorting.
• Verify correct voltage rails before connecting sensitive microcontrollers.

Testing & Validation

• Validate thermistor readings against a calibrated thermometer.
• Tune PID values using step response testing (Ziegler–Nichols or manual method).
• Confirm OLED correctly displays setpoint and temperature.
• Test both channels under load and verify stable regulation.
• Check power supply stability under maximum heater load.

Conclusion & Future Improvements

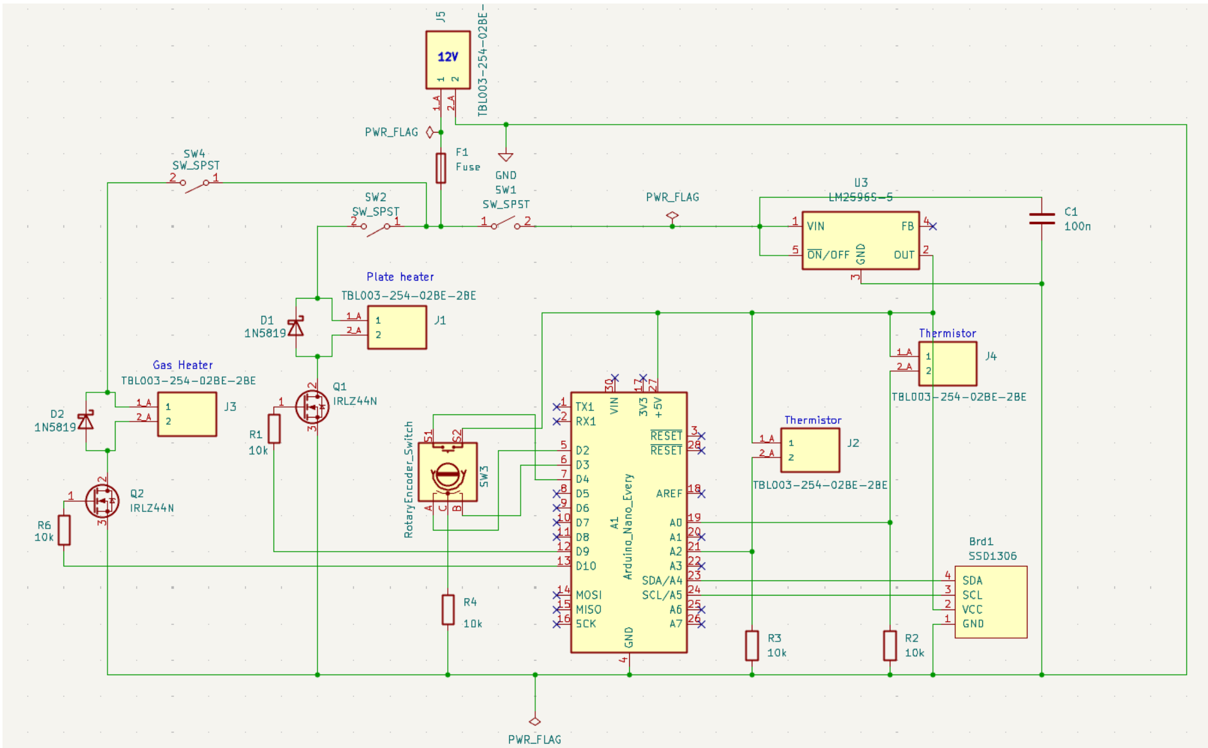
The Modular Heating Instrument provides reliable dual-zone PID heating control in a modular, lab-ready package. Future improvements may include wireless logging via ESP32, improved enclosure design, automated calibration routines and temperature reading filtering, and the software implementation of the rotary encoder. These will both optimize the PID algorithm and facilitate the set-up and usage of the device.

Appendix

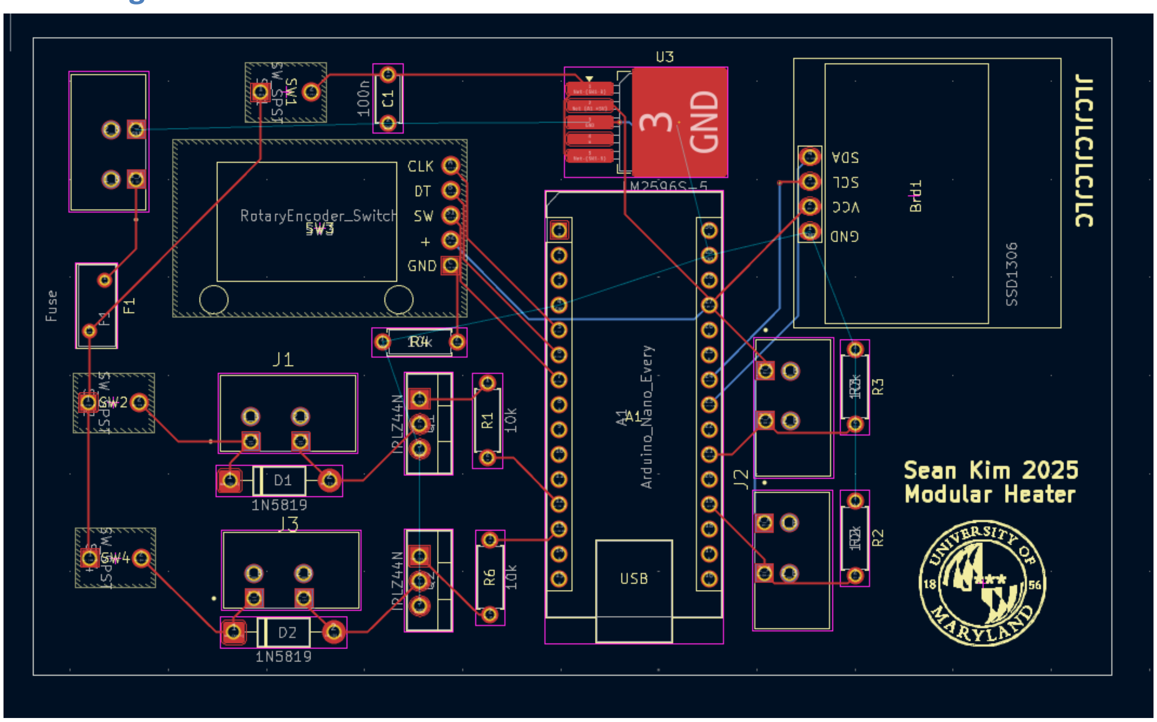
Bill of Materials

Category	Part	Notes	Link Example
Power Supply	12V 5A DC	Powers both heater and Microcontroller	12V 5A Power Source
Heating Element	12V 60W Silicone Pad	Draws ~5A at 12V. Good surface coverage	Adafruit Silicone Heater
Microcontroller	Arduino Nano Every	Reads thermistor via analog pin and outputs PWM to heater	Arduino Nano Every in lab
MOSFET	IRLZ44N	Logic-level N-channel; >20A	IRLZ44NPBF
Flyback Diode	1N5819	Protect from voltage spikes	1N5819
Thermistor	10kΩ NTC (3950 B-value)	Widely supported below 150°C	10k NTC 3950 Thermistor
Voltage Divider Resistor	10kΩ 1% metal film	Matches thermistor	10kΩ Resistor
LCD Display	I2C 16x2 LCD	Output display	I2C LCD Module
Switches	SPST Toggle or Rocker	One each for MCU & load	Mini Toggle Switch
Capacitor	100nF Ceramic	Reduce EMI	100nF Capacitor
Terminal Blocks	2/3-pin scr	Allows interchangeability	In Lab
Buck Converter	LM2596	Steps down input voltage	3.3V Buck Converter
Buck Converter	LM2596	Steps down input voltage	5V Buck Converter
Rotary Encoder	WayinTop	Allows analog control	Rotary Encoder
Breadboard & Wires		Prototyping	Breadboard and Wires
Wirestrippers		Prototyping	Wirestrippers
Fuse		Safety	Fuse

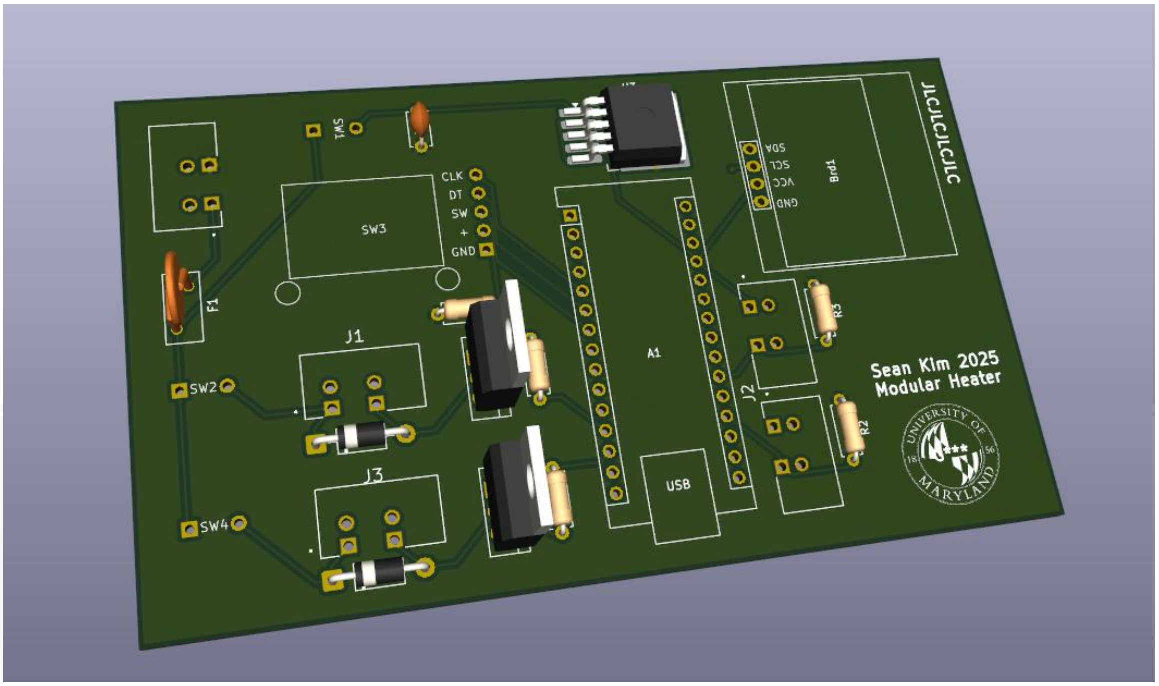
Circuit Schematic



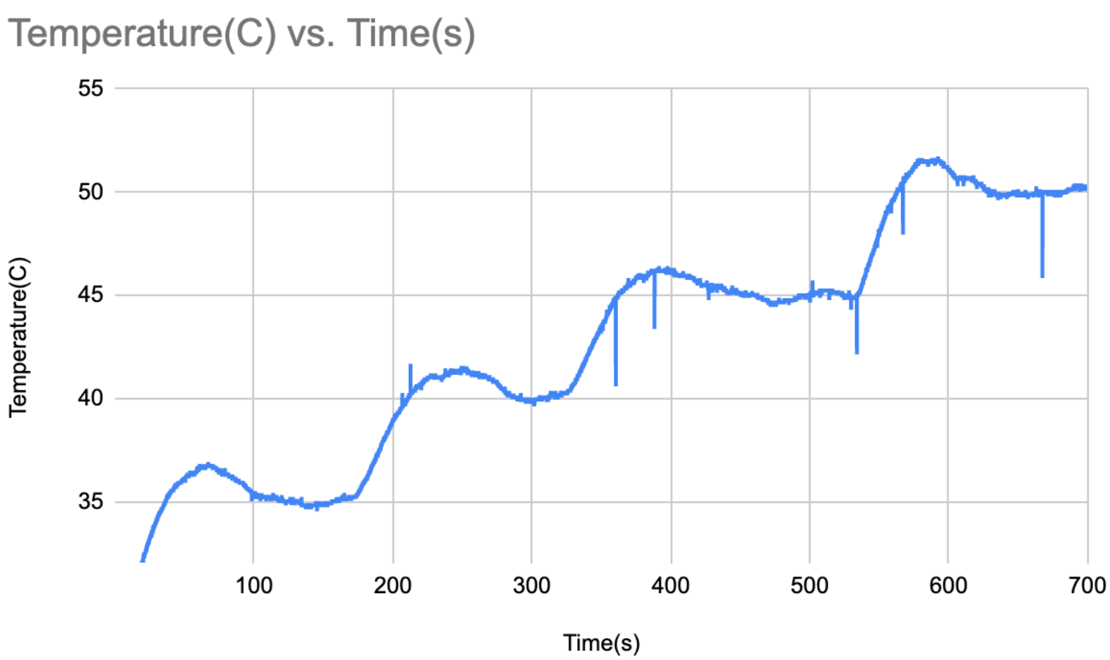
PCB Design



PCB 3D Model



Heating Curve Testing



Software:

Double_Heater_no_
encoder.ino

Heating_curve.ino

serialLog.py