LEHIGH UNIVERSITY

01 / 21 / 2026

Direct Cooling Technique

Spray Cooling

Control Strategy

Option 1: Automated cooling/heating

PID controller for both heating element / cooling element

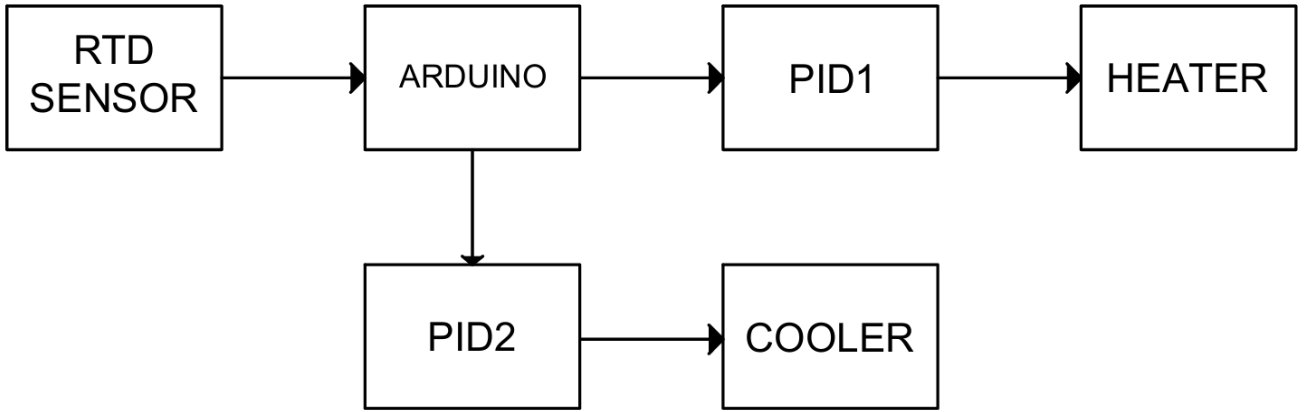

Fig. 1. Block diagram for automated heating and cooling elements

Option 2: Manual heating / Automated cooling

PID controller for cooling element / Manual open-loop for heating element

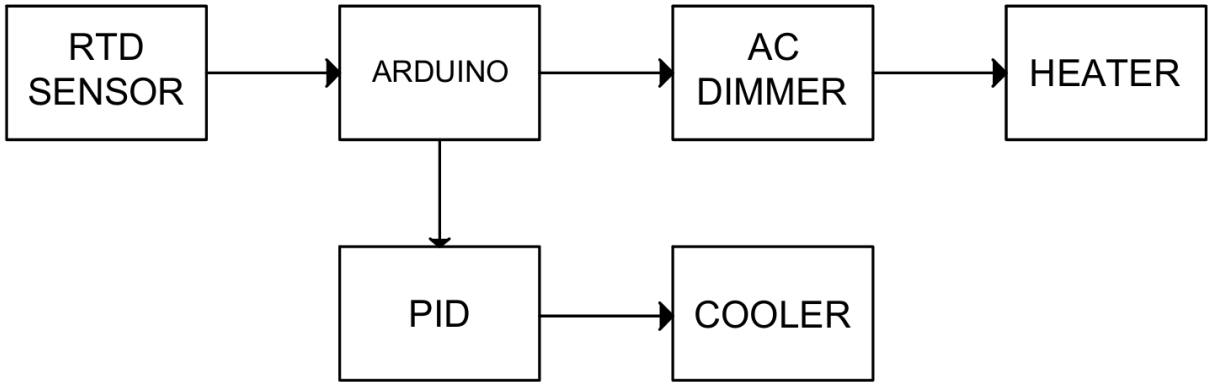

Fig. 2. Block diagram for manual heating and auto mated cooling elements

Comparision

Options	Pros	Cons
Option 1	- Precise temperature control in both directions - Faster response to setpoint change (don't need manual tuning) - Better disturbance rejection	- More complex PID tuning (2 PIDs) - Requires additional control logic to prevent simultaneous cooling/heating - Higher computational overhead - Potential for instability using 1 Arduino for both actuators
Option 2	- Simpler implementation in short-time - No heating / cooling conflict - Can easily deactivate/activate separated PID controllers if needed to further studies - Easier to troubleshoot - Lower computational requirement (less load on Arduino)	- Manual calibration of heating manual to get to set temp through power output - Less precise at elevated temperature

Table. 1. Comparison between 2 proposed options

Implementation

1) RTD set-up

No.	Parts	QTY	Price ea
1	ELEGOO MEGA R3 Board ATmega 2560	1	$22.99
2	Adafruit PT100 RTD Temperature Sensor Amplifier - MAX31865	1	$14.95
3	TE Connectivity Measurement Specialties NB-PTCO-170	1	$8.29

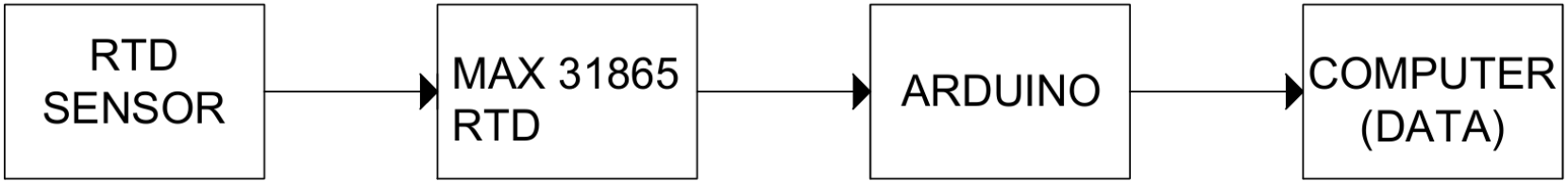

Fig. 3. Block diagram for RTD sensor w/o DAQ

w/o DAQ		With DAQ	
- Lower cost - Compact - Faster prototype - Lower power consumption - Easier data log	- Manual calibration - Scaling difficulty - Hard to diagnose	- High accuracy - Noise rejection - Automatic linearization - Easy scaling	- LABVIEW compatible - Built-in diagnostic - Higher cost

Table. 1. Comparison reading RTD sensor w/ and w/o DAQ

2) Heating Element Controller

4	120V Power Supply		
5	Zing Ear ZE-03A Dimmer Switch 120VAC 240VAC 300W MAX Repair Tools Replacement Full Range Inline Table Lamps Floor Lights Dimmable	1	$17.99
6	DERNORD Immersion Cartridge Heater 120V 200W Hot Rod Heating Element Replacement 1/2 Inch Thread	1	$19.99
7	PWM AC Programmable Light Dimmer 110V-220V	1	$24.99

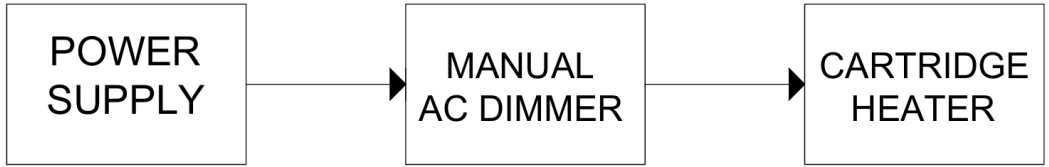

Fig. 4. Block diagram for heating element w/ manual dimmer

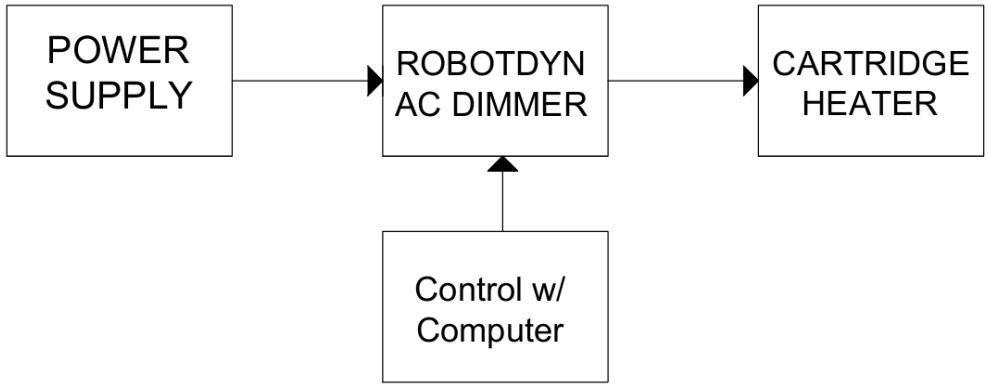

Fig. 5. Block diagram for heating element w/ digital dimmer

3) Cooling Element Controller

8	Full-Cone Spray Nozzle, Brass, 1/4 NPT Male, 1 gpm At 20 PSI, 60 Degree Angle	1	$15.17
9	HiLetgo 2pcs 5V One Channel Relay Module Relay Switch	1	$7.39
10	Water Flow Sensor flowmeter Hall Flow Sensor Water Control 1-30L/min 2.0MPa YF-S201	1	$12.99
11	FastRack 5 Gallon Hedpak with Cap | BPA-free, Food-Grade, and Leak-Proof | White Water Container	1	$23.99

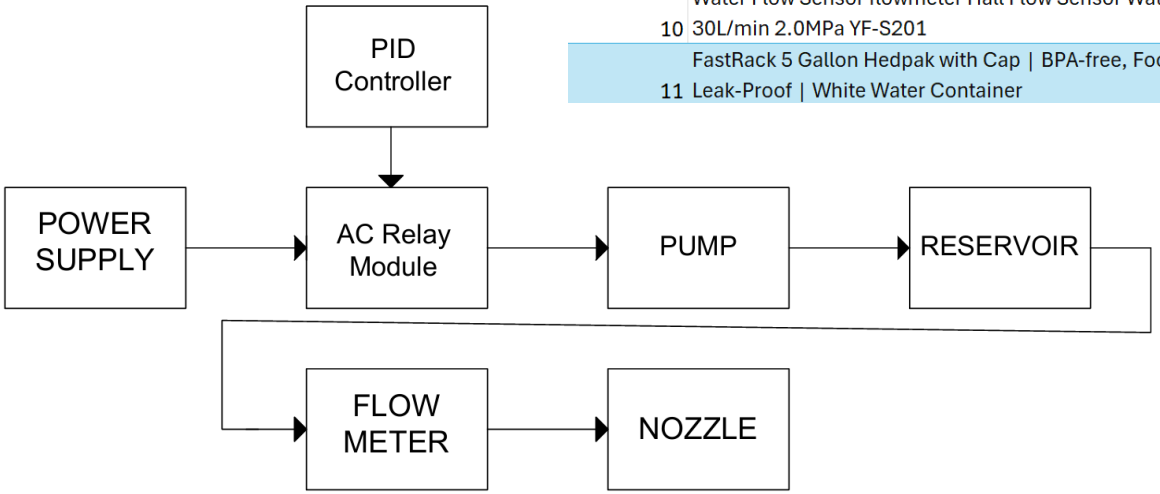

Fig. 6. Block diagram for cooling element w/ digital dimmer

Control Systems

1) Open-loop for heating element

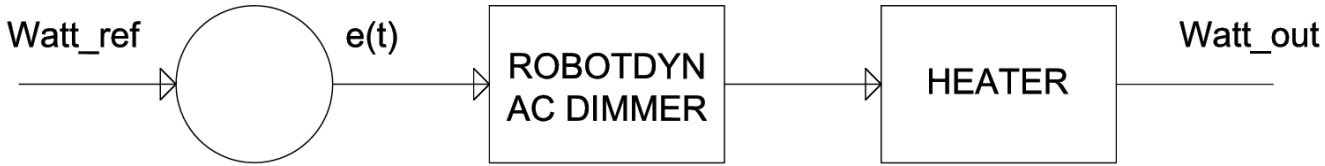

Fig. 7. Open-loop control diagram for heater

2) Close-loop for cooling element

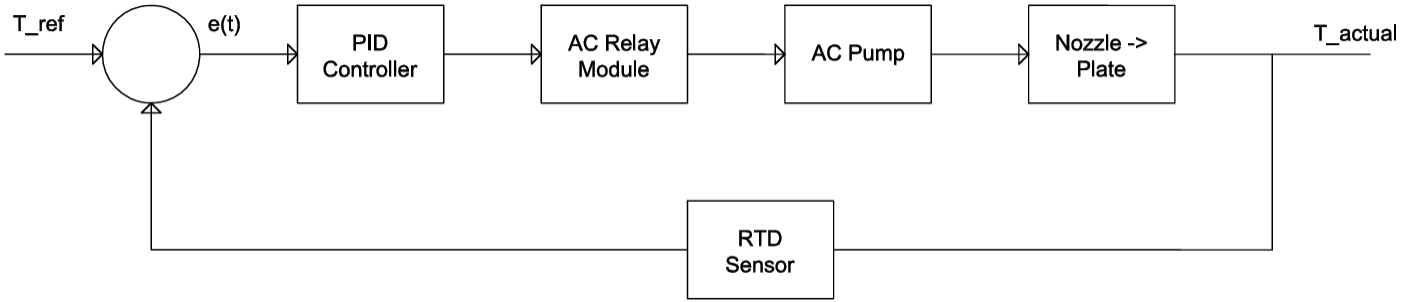

Fig. 8. Close-loop control diagram for cooling element

Next Steps

Rough Timeline

- Week (02/09-15): CAD Model for spray chamber and test rig (need additional verification from Bill Mouron or Kai, finalize BOM and start ordering (if in time)
- Week (02/16-22): Electrical schematic for hardware, hardware arrives
- Week (02/23 – 03/01): 3D prints nozzle fixture, start looking for stock to manufacture
- Week (03/02 – 03/08): Midterm deliverable
- Midterm Deliverable (03/08/2026): PPT presentation from the start (including abstract, project's vision)
- Week (03/09 – 03/15): Start assembly test rig, start construct coding for PIDs
- Week (03/16 – 03/23): Continue assembling test rig, if set up on time, tune PIDs

Rough Timeline (cont.)

- Week (03/23 – 03/29): If test rig is completed and microcontrollers are fine-tuned, setting up testing procedures
- Week (03/30 – 04/05): Run test rig under various load (plot flow rate vs temp)
- Week (04/06-04/12): Implement power meter PZEM-004T to read power consumption of pump (plot power w/ controller – without controller against temp)

- Final Presentation: Abstract, Preparation, Diagram, Part Sorting, Assembling, Tuning, Project's Vision, Future Improvements, Future Studies using the test rig (MPC & ML controller, two phases fluid, nozzle orientation [automated], neural network PID for dynamic environment, etc...)