3D Bioprinter Temperature Control

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Mechanical Engineering

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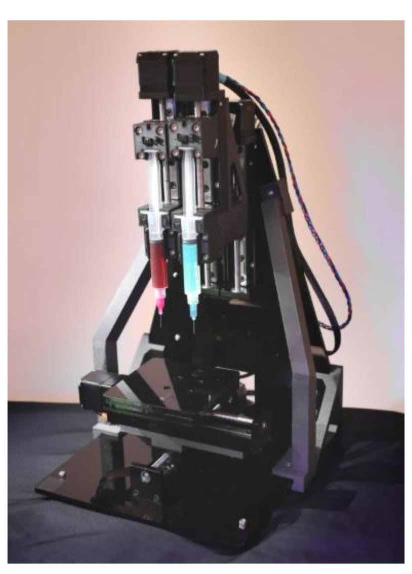
BIOMAKERS

Existing 3D bioprinters are expensive technology with larger prices ranging from $10,000 to $300,000. These machines are closed source and use proprietary hardware, software, and materials, making the additive manufacturing method unavailable to the average person. The Printess is an affordable 3D bioprinter developed with this in mind, providing high modularity and a simplistic user interface within a compact design. Our team's project aimed to develop an inexpensive temperature control loop add-on that could monitor and maintain the extrusion temperatures of printed "bioink" material within a temperature range of 4 to 40°C for the Printess bioprinter. The team achieved this goal by incorporating thermoelectric devices to either heat or cool the bioink via a recirculating water loop with thermocouples incorporated to provide live feedback and monitor the system's temperature.

The Printess Bioprinter

The Printess is a low-cost, open-source 3D bioprinter developed in 2024 by the Skylar-Scott Laboratory at Stanford University. Designed to provide greater access to bioprinting, it enables direct ink writing of bioinks and biomaterials using a combination of polymer 3D-printed parts and commercially available components, with a total build cost of roughly $250 for the base model.

Thermal Limitations



The Printess Bioprinter

Bioprinting involves the extrusion of diverse biomaterials, each with specific thermal requirements that directly affect viscosity, print fidelity, and cellular viability. Commonly used bioinks, such as PDMS and Pluronic F-127, may require extrusion temperatures ranging from refrigerated conditions (~4°C) to elevated temperatures (~40°C). However, the Printess bioprinter can only operate effectively at room temperature or with limited external cooling, and it lacks an integrated system capable of maintaining temperatures across this range of values and beyond. This creates a clear need for improved thermal management methods that ensure consistent, reliable biomaterial extrusion under varying temperature conditions.

Project Goal

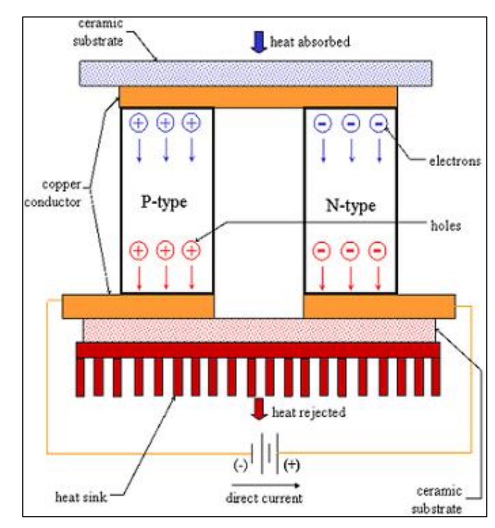
To design and develop an affordable temperature control system add-on for the Printess bioprinter that enables reliable thermal regulation of biomaterials during extrusion.

System Specifications

$	Cost	< $200
🌡	Temp. Range	4 - 40°C
±	Temp. Precision	± 1°C
💉	Multiple Bioink Compatibility	
🧼	Clean/Sterile Environment	

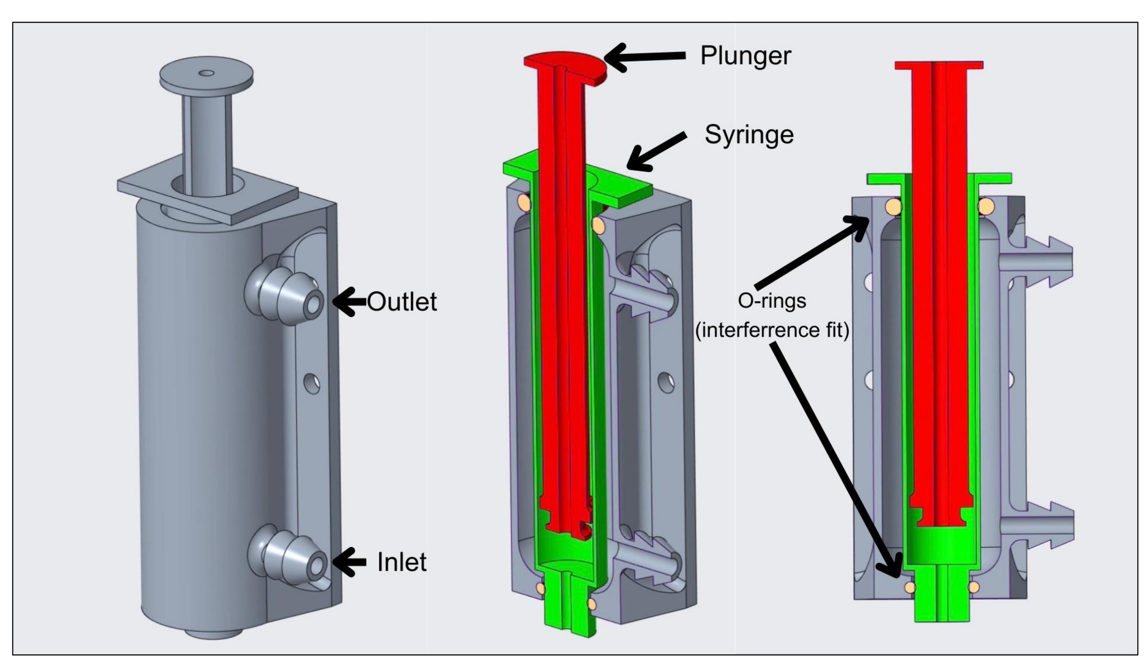
The Peltier Effect

- Electron energy transport across semiconductor junctions.
- One side of the module absorbs heat (cooling) while the other releases heat (heating).
- Reversing current flow alters the hot and cold module sides.
- Used to heat or cool a circulating fluid loop reservoir to regulate bioink extrusion temperatures.



Peltier Effect Schematic

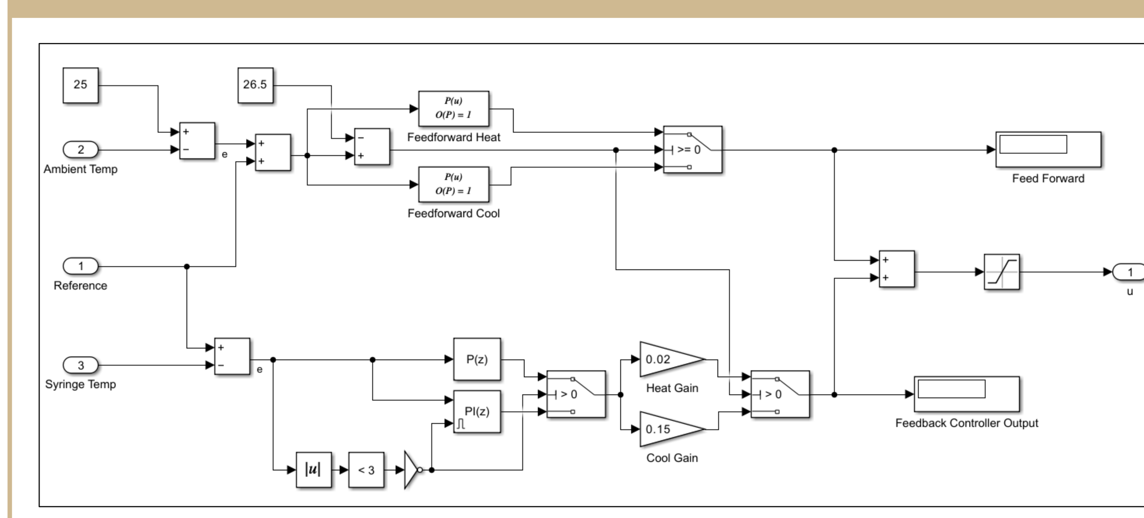
Syringe Sleeve Design



Custom Syringe Sleeve for Convective-Conductive Energy Transfer

The syringe sleeve allows circulating fluid to directly contact the syringe barrel for efficient heat transfer and uses interference-fit O-rings to prevent leakage during operation. A centrally aligned channel within the plunger houses a thermocouple probe, enabling continuous monitoring of the bioink temperature during extrusion.

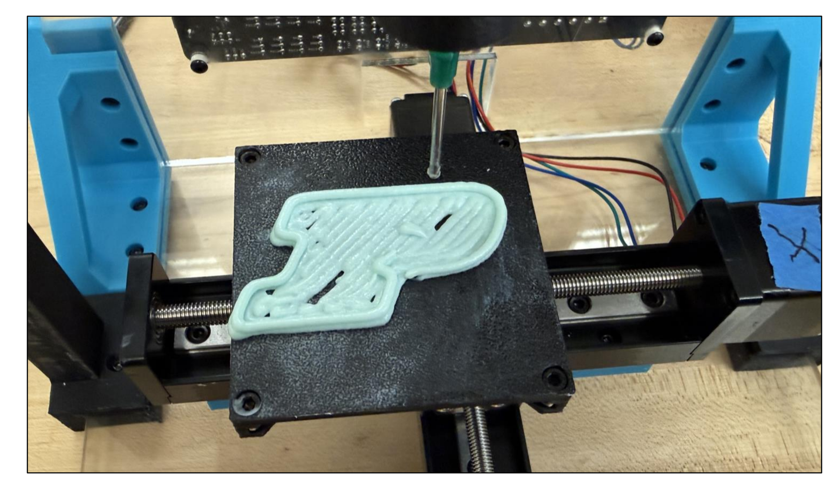
Temperature Controller



MATLAB Simulink Custom Temperature Controller

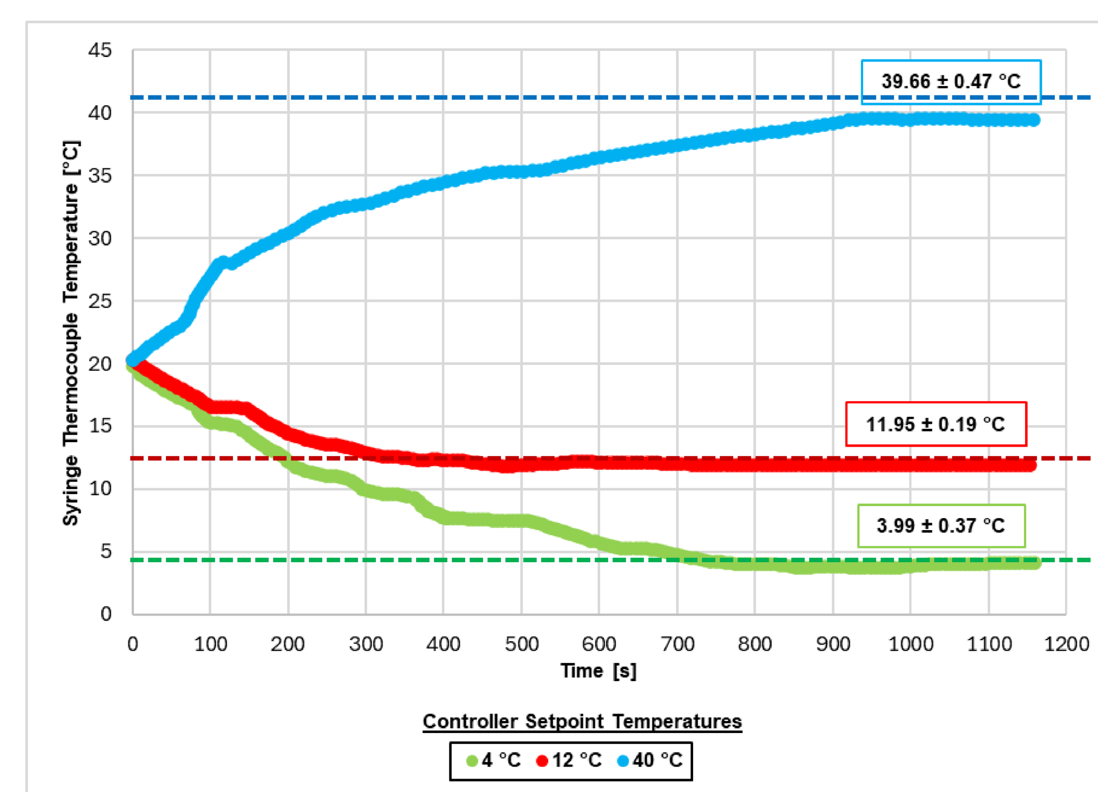
The temperature control loop uses a user-specified reference temperature and continuously compares it to real-time thermocouple readings from the syringe plunger. A combined feedforward and PI-based feedback controller adjusts the heating or cooling power delivered to the Peltier module to minimize error and maintain stable syringe bioink temperature. This ensures responsive, energy-efficient thermal regulation across varying ambient and printing conditions.

System Testing & Validation



Printess Test Printing with Toothpaste

To verify functionality of the Printess G-code interface, test prints were performed using toothpaste as a low-cost surrogate ink and successfully produced a Purdue "P," confirming reliable extrusion and motion control.



Temperature Controller Steady State Response and Precision

The thermal control loop was validated by running the system at three representative setpoints of 4°C, 12°C, and 40°C while monitoring the syringe temperature via thermocouple feedback. The Simulink controller consistently reached and maintained steady-state temperatures within approximately ±1°C of each targeted input, demonstrating stable performance across both desired cooling and heating extremes as well as intermediate temperatures.

Project Conclusions

- Successful integration of closed-loop thermal control enabling syringe temperature regulation **between 4°C to 40°C**.
- Development of a custom syringe sleeve and plunger to accurately monitor print temperature readings of extruded bioink material.
- Validated testing of steady-state temperature control **within ±1°C** across low, intermediate, and elevated setpoints.
- Total commercial part investment cost of **$160.40** for the add-on.

Future Improvements

- Integration of the temperature controller and the printer interface.
- Mobile app development to notify users of printer progress.
- Improved mounting and dismounting of the extrusion syringes.
- Further emphasis on product packaging to improve user experience.

Closed Loop Temperature Control Add-on for Biomaterial Extrusion in a Printess 3D Bioprinter