ARES: Adaptive Recovery Enhancement System

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PROBLEM DEFINITION & BACKGROUND

Muscular recovery is an essential part of athletic performance, physical therapy, and everyday wellness. Methods of recovery, including heat therapy, cold therapy, and pneumatic compression, have been shown to accelerate recovery, reduce soreness, and improve circulation. Many current recovery devices are bulky, expensive, or lack a combination of these methods.

This project looks to create an affordable sleeve that integrates heating, cooling, and compression into a single wearable device. The system aims to deliver therapeutic temperature ranges and controlled pneumatic pressure while maintaining safety, comfort, and ease of use. By combining these recovery modalities in a compact and cost-effective form, the project looks to make multi-mode muscular recovery accessible to everyone, for elite athletes and everyday users seeking effective rehabilitation support.

DESIGN REQUIREMENTS

Heating: Provide a temperature in the range of 40-45°C for 10-20 minutes to the user; anything above 45°C may cause burns or skin irritation. Bare skin must never come into direct contact with heat. This criterion was considered with the IEC-60601-2-35: Basic Safety and Essential Performance of Heating Devices standard.

Cooling: 10-15°C for 10-15 minutes with adherence to ISO 13732-3:2005

Compression: Provide a pressure in the range of 30-150 mmHg for 20-30 minutes, as pain can be felt when pressure is 30 mmHg over an average systolic pressure of 120 mmHg. This criterion was considered with the ISO-80601-2-57: Safety for Pressure Limb-Compression Devices standard

Wiring Safety: All wiring must be fully insulated and protected from moisture exposure. Components must follow the IEC-60601-1 General Electrical Safety for Medical Devices standard.

Usability: All subsystems (heating, cooling, and compression) must be compatible with a centralized microcontroller. The control unit must read sensor data and give feedback. The sleeve must be comfortable for a variety of users.

Budget: Design system to be under the provided amount of $500

Time: 1 academic year

COMPONENT ALTERNATIVES

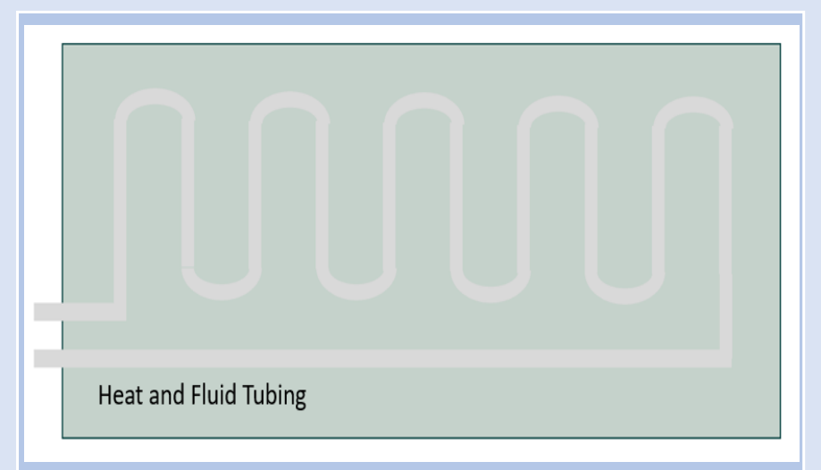
Heating:
- Chemical reusable heat packs
- Electric heating pads
- Water circulation

Cooling:
- Ice Packs & wraps
- Ice therapy machines
- Active compression and cooling devices

Compression:
- Intermittent pneumatic compression
- Compression garments (passive)

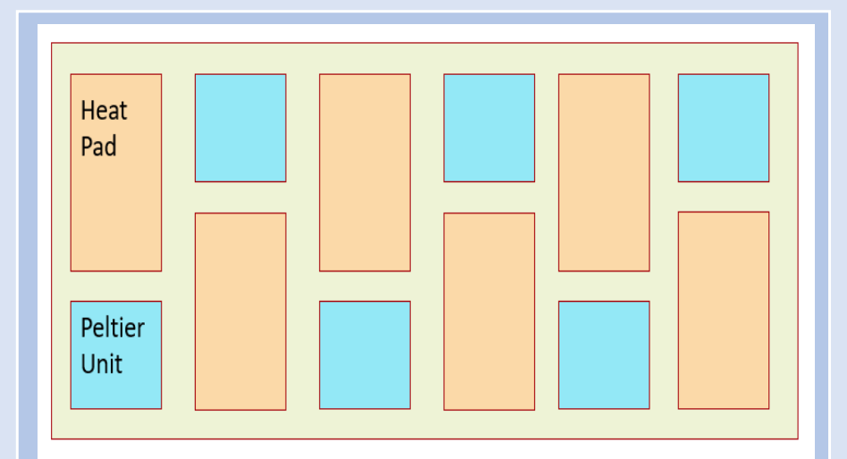
DESIGN EVALUATION & ITERATIVE PROCESS

First Design



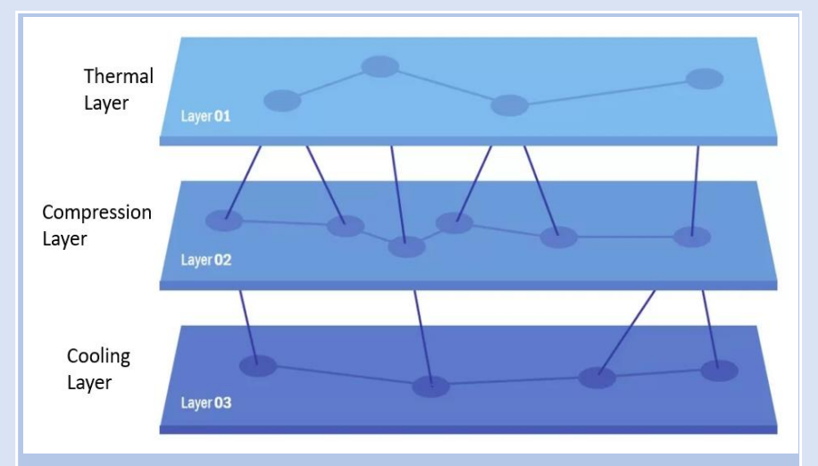
- Pros: Simple system architecture, one pump and one tubing network, efficient heat transfer with water
- Cons: Requires large water volume (poor portability), difficult to isolate hot and cold temperatures

Second Design



- Pros: No water reservoir, fast switching between heating pad and Peltier unit (a thermoelectric cooler, that functions as a hear pump), more compact and portable
- Cons: Low cooling efficiency from Peltier units as require heat dissipation systems, high power consumption

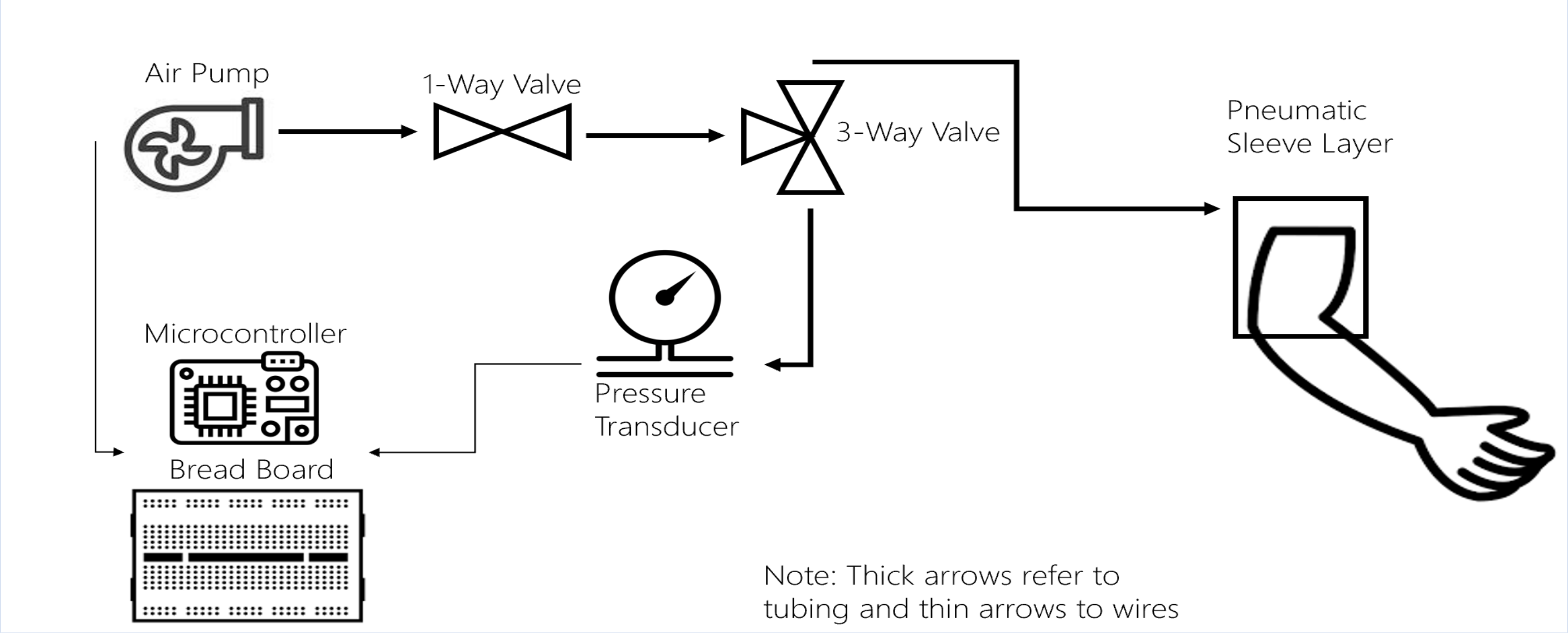
Final Design



- Pros: Combines efficient water-based cooling with simple, reliable electric heating. Eliminates need for dual water loops, reducing system complexity and water volume
- Cons: Retains some fluid system complexity and leakage risk. Requires integration of both electrical and fluid components

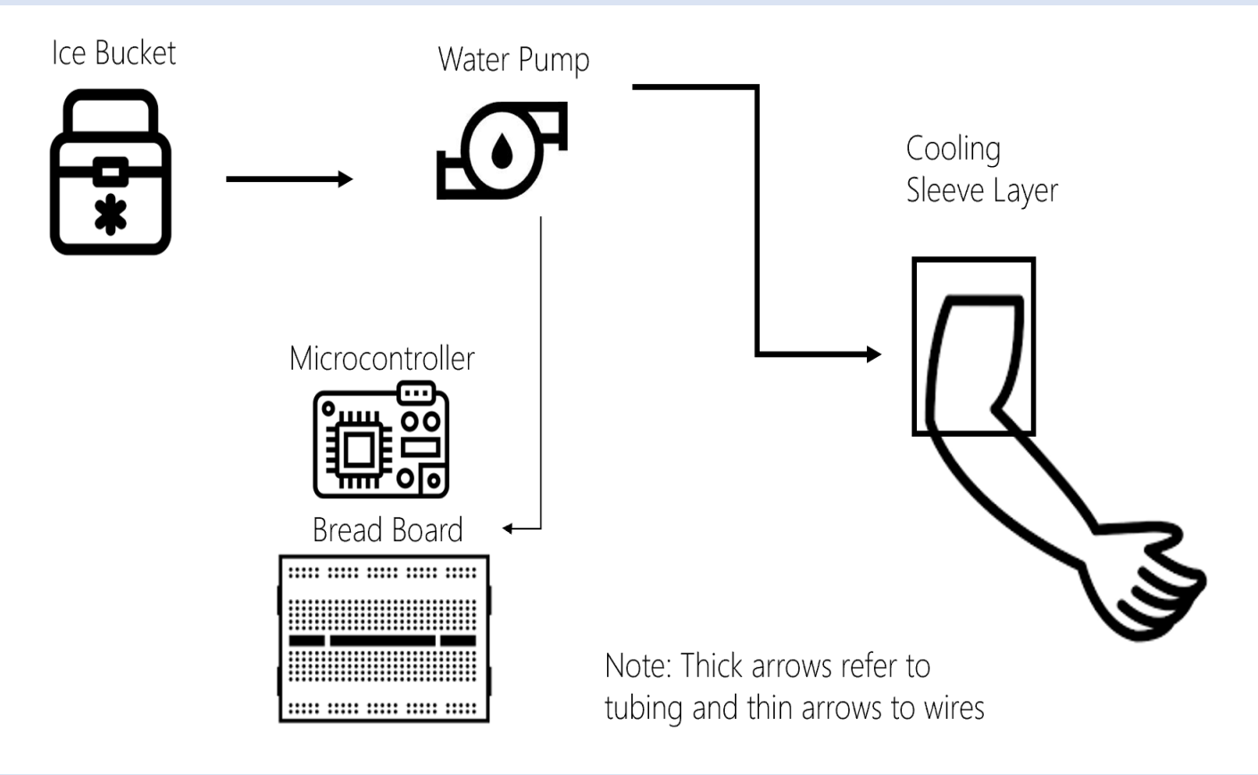
FINAL DESIGN & IMPLEMENTATION

Pneumatic Compression Sub-System



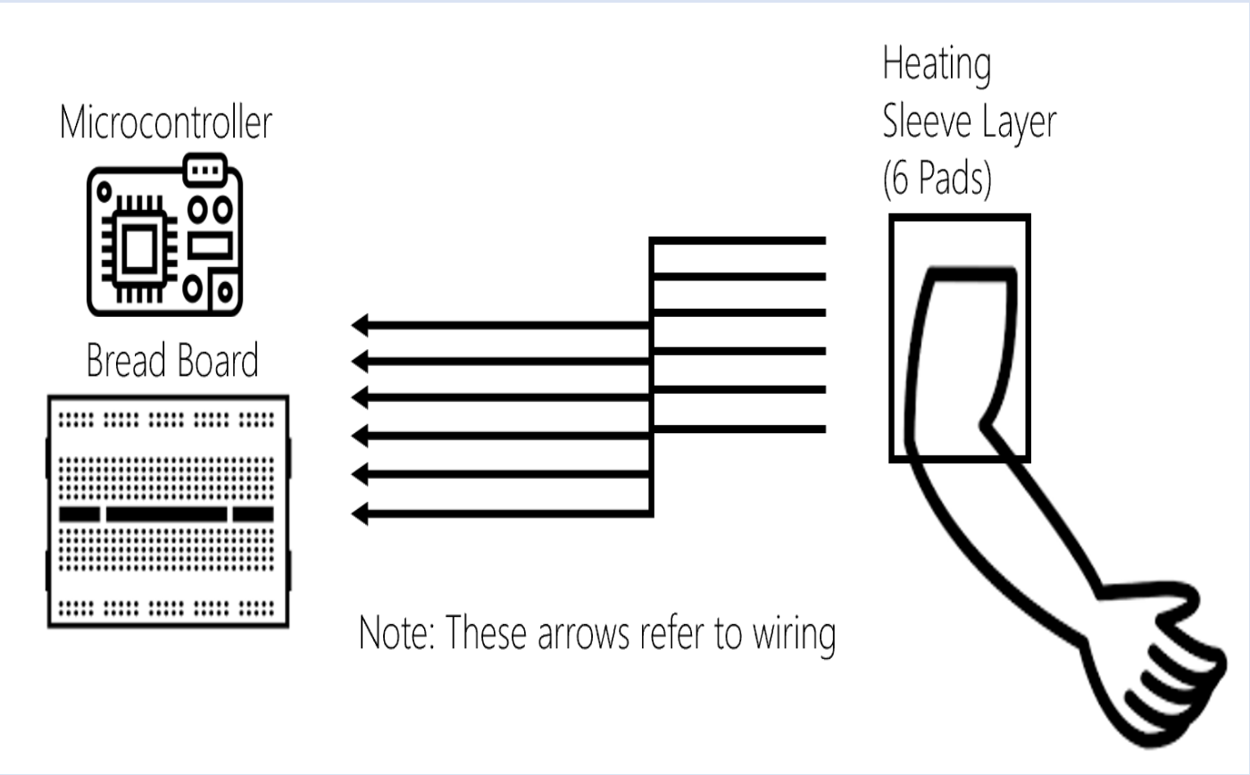
Note: Thick arrows refer to tubing and thin arrows to wires

Cooling Sub-System



Note: Thick arrows refer to tubing and thin arrows to wires

Heating Sub-System



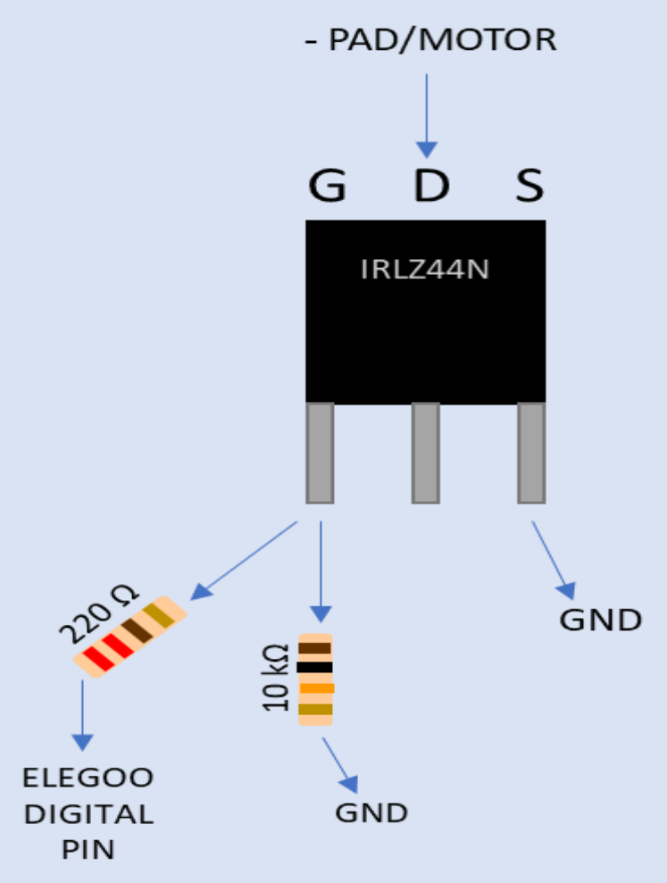
Note: These arrows refer to wiring

Methods and Iterative Design

Sleeve Specifications & User Interface: A reversible 7"×14" adjustable Velcro sleeve serves as the base, powered by dual 12V supplies for the heating pads and air pump, and a 5V supply for the pressure transducer and water pump. Four-button control panel: **S** Stop · **H** Heat · **C** Cool · **P** Compress

Leakage Control: The cooling system uses a closed-loop winding pattern with 20ft of tubing, maximizing skin surface coverage while preventing fluid from escaping. For the air bladder, initial attempts using thinner TPU and a heat gun produced inconsistent seals. The final solution uses 12mil TPU heat-sealed with a flat iron, a 1" edge margin, and an integrated pneumatic fitting outlet.

Heating Pad Power Sequencing: Powering all six pads in parallel drew insufficient current. Two banks of three pads in parallel also underperformed. The final solution sequences three pads from a single 12V source (10s on / 20s off per pad, completing a 30-second cycle). MOSFETs are used to regulate the amount of power going into the controller.



MOSFET Wiring:
Both pumps and all six heating pads are wired in the same way relative to their power source and their corresponding controller pins. Each pad/motor is connected to the + rail of the power supply and the MOSFET drain.

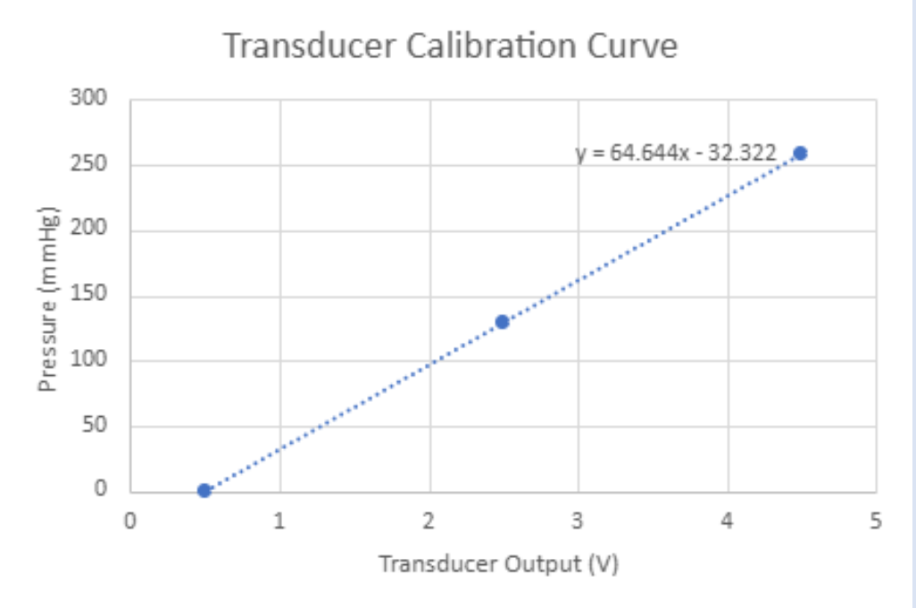


Figure 1. Transducer Calibration curve

An analog pressure transducer with a 0–5 psi range was connected to the Elegoo controller via 5V, GND, and an analog input pin. Although powered by 5V, the sensor output is scaled between 0.5V at 0 psi and 4.5V at 5 psi, a relationship verified experimentally by the calibration curve in the graph above. In the Arduino code, the raw Analog-to-Digital Converter integer is converted to voltage via V = (ADC × 5.0) / 1023, then scaled to psi by removing the 0.5V zero-offset using P = (V – 0.5) × (5.0 / 4.0). Values were then converted to mmHg using 1 psi = 51.715 mmHg.

HEATING TESTING

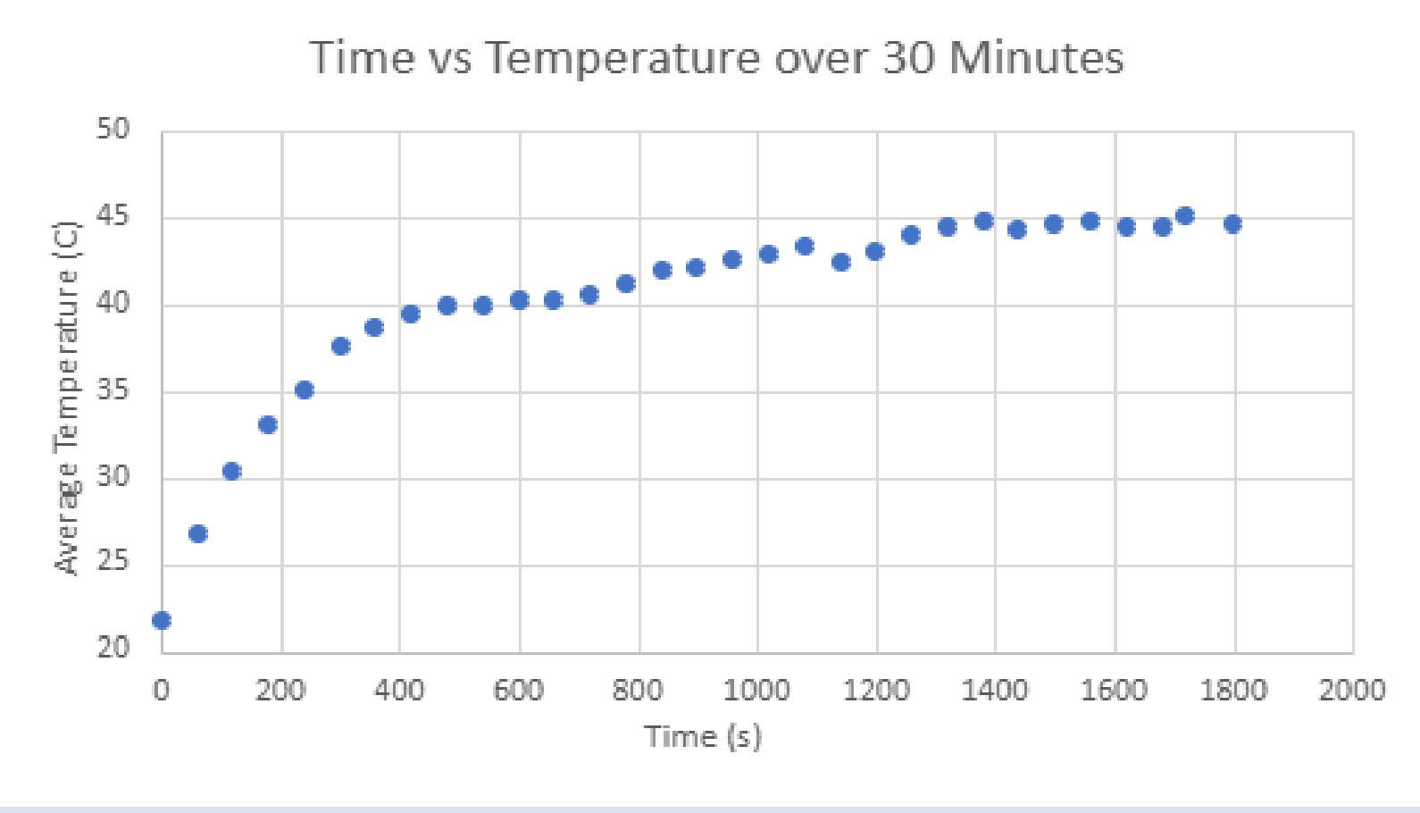


Figure 2.

Fig 2. Average surface temperature of three heating pads measured over a 30-minute period using thermocouples placed external to the fabric layer. Pads began at an ambient room temperature of 21.8°C and reached the therapeutic range of 40–45°C within approximately 7 minutes of operation. The average temperature remained stable within this range for the duration of the 30-minute test, demonstrating the system's ability to achieve and sustain clinically relevant thermal output.

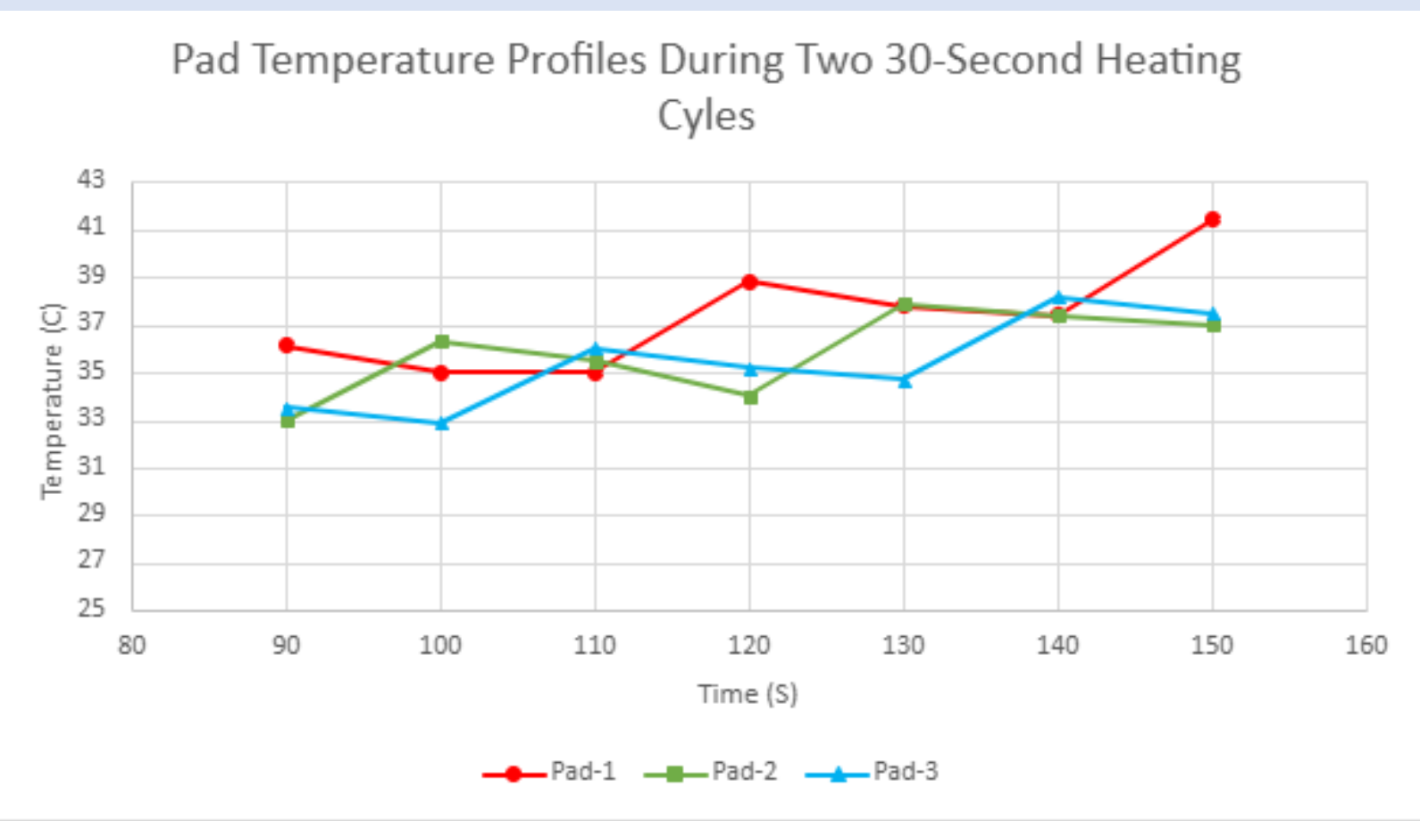


Figure 3.

Figure 3. Individual pad surface temperatures recorded over a 60-second interval during active heating pad sequencing, in which each pad cycles through a 10-second on / 20-second off duty cycle. The overlapping temperature profiles of all three pads illustrate that the sequencing protocol effectively maintains elevated pad temperatures while preventing thermal overshoot, and produces consistent, comparable temperature responses across all three pads throughout the cycle.

PRESSURE TESTING

To verify air bladder integrity, the bladder was inflated and pressure was monitored via the transducer over a sustained hold period. Pressure readings remained stable under external factors such as squeezing and moving the bladder, indicating no detectable leakage. However, the time to reach adequate pressure was found to be dependent on sleeve and bladder orientation during inflation.

COOLING TESTING

Surface temperature of the cooling sleeve was measured against a subject's calf over a 30-minute period. Temperature increased from 8.8°C to 9.3°C in the first minute and reached only 9.6°C at the 30-minute mark, demonstrating that even after prolonged use the sleeve continued to maintain therapeutically cold temperatures.

CONCLUSIONS

The ARES system demonstrated the ability to deliver heating, cooling, and pneumatic compression in a single wearable sleeve. Heating pads reached the 40–45°C therapeutic range within 7 minutes and maintained it over 30 minutes, the cooling sleeve sustained therapeutically cold temperatures throughout prolonged use, and the air bladder showed no measurable pressure loss under external manipulation. Future work should focus on reducing system wiring complexity, improving bladder inflation consistency across sleeve orientations, and transitioning to a fully wireless control interface to improve portability and user experience.

Inside of Sleeve

REFERENCES

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