Smart Sling - Group 13

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April 16th, 2025

Abstract
Heat, cold, and compression therapies have historically been used in medicine to provide pain relief, stimulate blood flow, and other forms of injury management. Although there exist medical casts and sleeves that sport heating, cooling, and compression individually, we could not find a device on the market that provided a combination of all three, nor could we find one that both heated and cooled. In this paper, we detail a linen sleeve with heating, cooling, and compression capabilities that can be controlled by an iOS app via Bluetooth. Temperature data was recorded with both a KY-013 temperature sensor and an external contactless thermometer. Although the product is a strong proof of concept as it is, we plan on further developing it through the 2025 summer semesters.

Introduction
Since the infancy of modern medicine, heat and cold therapy have been foundational treatments for managing injuries, muscle aches, and localized pain [1]. These methods are used to reduce inflammation, ease discomfort, and support the body's healing process. Along with them, compression therapy has also been used for a long time for clinical practice, commonly used to enhance circulation of blood flow, minimize swelling, and stabilize injured areas [2]. Together, these three medical approaches—heat and cold therapy and compression—form a thorough and non-impacting strategy for treating both acute and chronic musculoskeletal conditions. The need for such interventions is significant; 53.2 million US adults suffer from just arthritis, but there are so many other chronic conditions, like acute injuries such as sprains and strains, all of which can be managed through temperature and/or pressure-based therapies [3]. Despite this widespread need for these treatments, most available solutions are limited to many people. As many current products typically only offer either heat or cold, or compression, but rarely more than one treatment in a single device.

Furthermore, using these treatments isn't always dependable or simple. It's difficult for many individuals to heat or freeze pads, particularly when they're not at home or in locations without a refrigerator, microwave, or even hot water. Simple cold therapy, for instance, could have prevented greater damage or swelling in the early stages of an accident, but this delay in pain alleviation can cause it. This delay in pain relief during the early stages of an injury can lead to more swelling or damage that could've been avoided with simple cold therapy, for example. In these situations, not being able to manage symptoms early can increase healing time and cause even more problems for the patient, along with leaving them in excruciating pain. With so many different materials now, even when patients do have the option between hot or cold, they are often unsure of which one to use, along with what temperature to use, how long to apply the therapy, or whether to introduce compression into their therapy regimen [1]. This uncertainty can lead to improper treatment, reduced effectiveness, and overall frustration in the recovery process.

This shows a clear need for a more streamlined solution: a single, doctor-approved device that integrates all three essential functions to help patients with all sorts of different pains and injuries. This system of the three treatments would not only improve accessibility but also eliminate guesswork, ensuring that patients receive the right treatment at the right time, reducing the chance of further damage to the injured part.

Building on this goal of integrating all three treatments, the team worked together to innovate a biotherapeutic device - a smart sling - that will treat injuries through heat, cold, and compression treatments. This device will provide short-term, easily accessible therapy for consumers, helping manage symptoms before and after a proper diagnosis and treatment plan is in place.

Methods & Approach

Initially, brainstorming was conducted by sitting around a table with a whiteboard and having members share their ideas and potential drawings with the group in an open forum. After having everyone share a few ideas, each idea was iterated through until one rough concept of the sling emerged. Once the rough concept was established, the team decided on a set number of goals in order to guide the project and allow for a more cohesive understanding of what the final product should achieve.

Objectives	Low Cost	Temp Control	Pressure	Supportive	Durable	Lightweight	Versatile	Comfortable	Stylish	Sum
Low Cost		0	0	0	0.5	1	1	0.5	1	4
Temp Control	1		1	1	1	1	1	0.5	1	7.5
Pressure	1	0		0.5	1	1	1	0.5	1	6
Supportive	1	0	0.5		0.5	1	1	0.5	1	5.5
Durable	0.5	0	0	0.5		1	1	0.5	1	3.5
Lightweight	0	0	0	0	0		1	0	1	2
Versatile	0	0	0	0	0	0		0	1	1
Comfortable	0.5	0.5	0.5	0.5	0.5	1	1		1	4.5
Stylish	0	0	0	0	0	0	0	0		0

Figure 1: Ranked Choice Order Analysis

Since the project had many different goals, a Rank-Order Choice Analysis was conducted to rank the priorities of the project. As it turned out, the highest two priorities were that the project had successful temperature and pressure control, which will be further discussed below. The ordering of these priorities allowed the team to focus on the goals that mattered most and easily make decisions that would result in a bolstering of certain priorities at the expense of others. After the

Ranked Order Choice Analysis was completed, a rough visionary sketch based on the established priorities was created to provide the overall direction of the project.

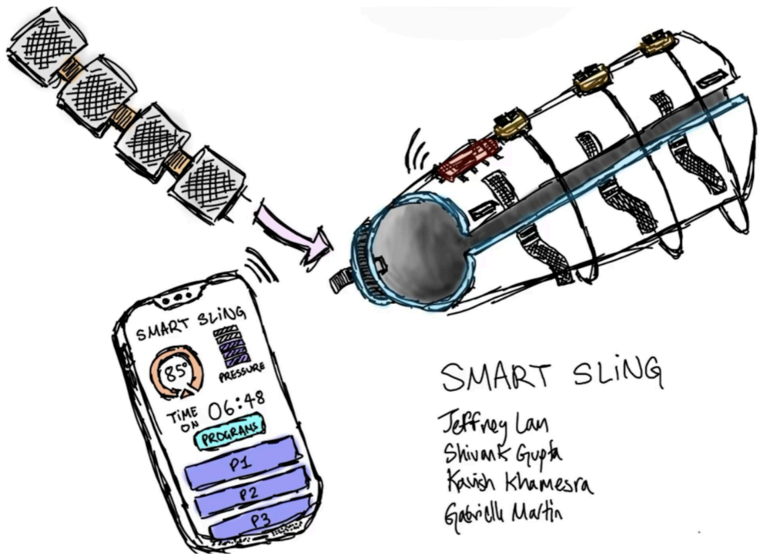


Figure 2: Initial Visionary Sketch

For the users not to have to use a microwave or refrigerator to change the temperature of the device, it was decided that thermoelectric heating and cooling through Peltier cells would be used for temperature regulation. The Peltier cells work via the Peltier effect, which essentially means that when a current is run through the cells, it results in a hot surface on one side and a cold surface on the other. The reversal of the current would keep the same effect but would flip the hot and cold surfaces [4]. The Peltier cells allowed for the usage of one component for both heating and cooling and eliminated the need for external appliances, which could create barriers to access to an effective thermal therapy device.

The compression was accomplished by motor constriction, which used a rotating winch attached to a motor to constrict a string-like strap around the affected body part. The motor constriction works by rotating the motor, which causes the strap to wrap around the winch, creating tension that causes constriction around the object. The degree of compression was modulated by adjusting the direction and duration of motor rotations, allowing for a repeatable application of varying pressures. The variety and ease of implementation of the compression allowed users to easily adjust the pressure to what works best for them, which is incredibly important for such devices.

Additionally, it was decided that the best way to control the pressure and temperature was to connect the device to a phone via Bluetooth, which would allow the user to not need an external device and would afford them a clean UI. Finally, the overall shape of the device was chosen to be a sleeve worn around the arm, as arm injuries are rather common, and to put it quite simply, arms are easy to work with.

After the initial brainstorming phase, where the overall concept and goals of the device were established, the work was divided into four subsystems: temperature regulation, compression, external communication, and the wearable sleeve. The division into subsystems allowed each team member to focus on one area and complete their work somewhat independently of the rest of the team. To ensure that the overall product was cohesive, the design and implementation strategy for the overall device and each subsystem were planned as a group, and the execution of each of the subsystems was handled individually.

Design Details

As previously mentioned, the project was divided into four subsystems, so each of the subsystems will be discussed in turn prior to showing the completed assembly.

Temperature Regulation

The final assembly of the Peltier strip consisted of three TEC1-12706 Peltier cells wired in parallel. A strip consisting of five cells in parallel, powered by one 9V battery, and another strip consisting of three cells in series, powered by three 9V batteries, were also tested. The former did not produce a significant amount of heat upon touch, and the latter heated unevenly, with the first cell experiencing the most significant temperature changes, thus both designs were scrapped.

To keep the structure of the cells stable, PVC foam was used to frame each cell roughly an inch and a half apart from each other. This material allowed the strip to maintain its form while also being malleable enough to conform around the user's forearm while attached to the sleeve.

Each cell was equipped with twelve mini heatsinks attached with thermal glue. Upon initial testing, where a 9V battery was plugged directly into the cell, the cold face of the Peltier strip quickly heated up and became warm as well, as the heat from the hot face was likely bleeding through. Thus, it became apparent that there was a need to dissipate the heat from the hot face during cooling modes to minimize the amount of heat bleeding through to the cold face. Some ideas proposed included mounting fans, feeding cooling liquid, and attaching heat sinks. However, fans would take even more power and were delicate, and the risk of a leak occurring and spilling cooling liquid onto the circuitry directly on top of a user's skin outweighed its benefits. Heat sinks, on the other hand, did not need to be fed battery power, were low-maintenance and hardy, and offered minimal safety risks apart from overheating. Thermal glue was used as it allowed for the adhesion of the cells while providing decent thermal conductivity.

A KY-013 analog temperature sensor module is attached to the strip as a safety mechanism, with its thermoresistor soldered to be extended and taped underneath the central cell, such that it can monitor the temperature being emitted to the user. If the temperature it reads reaches the unsafe temperature of 109° Fahrenheit [5], power to the Peltier cells is cut. Originally, TMP-36 analog temperature sensors were used. However, the readings that they did give, even for steady room temperatures, tended to vary by ~±15° F per sample. Furthermore, it was discovered that following prolonged usage, the TMP-36 sensors tended to break and give wildly inaccurate readings that ranged from the negatives to several hundred degrees Fahrenheit. LM-35 analog temperature sensors were also tested, but they had the same issues as the TMP-36. On the other hand, the KY-013 sensor provided very consistent readings per sample, did not break with use, and the thermistor was also around <1 millimeter thick, making its presence between the cell and sleeve cloth significantly less feelable than the TMP-36 and LM-35 (both around 3.5mm thick).

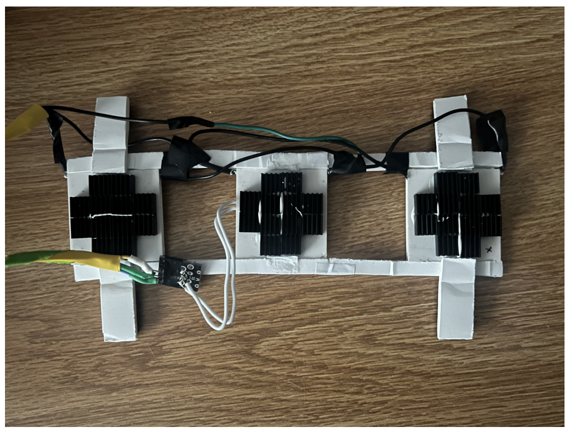


Figure 3: Peltier strip, removed from sleeve.

The electricity fed to the Peltier strip is controlled through a SparkFun TB6612FNG motor driver, which is a component originally designed for the control of a DC motor. This motor driver allows for the variation and directional change of the voltage plugged into the Arduino through the power port, which should have been -9V to 9V, as 9V batteries were used as a power supply. It is worth noting that, in actuality, it was only outputting -8.8V to 8.8V, according to a voltmeter.

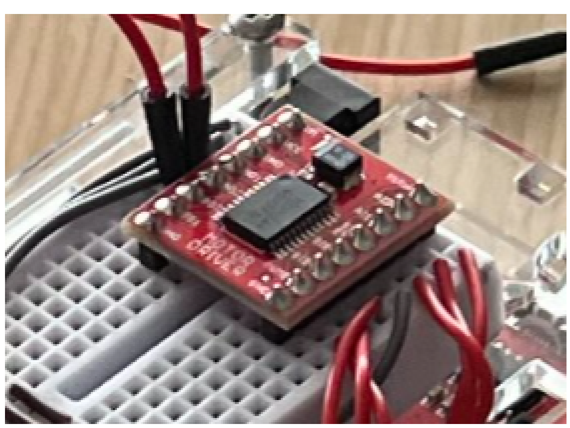


Figure 4: SparkFun TB6612FNG Motor Driver on top of Arduino-mounted mini breadboard.

The seven different temperature modes available for use in the final product are listed in Figure 5. Mode 1 cuts all power to the strip to achieve an inactive state, which is the default (or “off”). Modes 2-5 (heating modes) had a set amount of time 9V was applied to the strip, and another set amount of time during which no power was applied to the strip. Modes 6-7 (cooling modes) work in the same way, but the direction of the current is reversed in order to achieve cooling. The on/off times repeated indefinitely in a cycle while the selected mode was active.

MODE #	NAME	On time (s)	Off time (s)
1	Off	-	-
2	Mild Heat	1	3
3	Med. Heat	2	3
4	High Heat	5	5
5	Max Heat	10	5
6	Cool 1	28	24
7	Cool 2	10	16

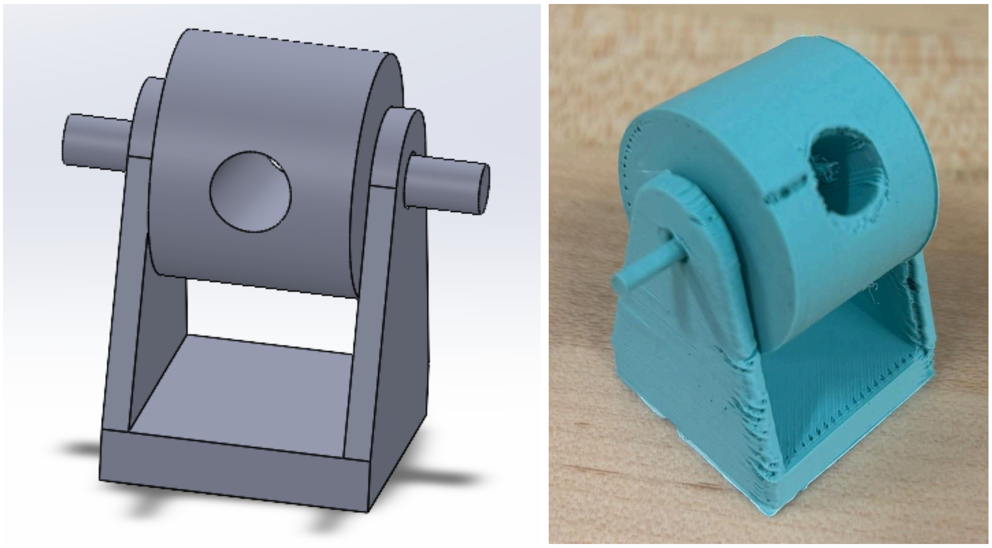
Figure 5: Temperature mode number, name, and the amount of time power is applied, as well as the amount of time power is cut in a repeating cycle.

The whole product was powered by three 9V batteries chained together in parallel. When initially tested, a singular 9V battery would get really warm and would fail to power the Peltier cells after a short period of time. But by connecting three 9V batteries together in parallel as the power supply, a longer-lasting, more stable 9V power source was secured for the Peltier strip and the rest of the electronics. At one point, a 9V DC power supply connected to an outlet was tried as a replacement or alternative to the batteries, but bizarrely enough, that outlet power supply would interfere with Arduino code. When plugged into the outlet, for loops would break, variables would not be iterated upon, and other variables would be set to zero. Upon plugging a battery back in, however, the code logic would immediately go back to functioning perfectly. This strange occurrence may have been an isolated issue with either the power supply being faulty or the board’s firmware/something shorting, but the exact cause of the issue was, and still is, unclear.

All the wiring was centralized on a mini breadboard mounted to the Arduino case. Both of these elements were then attached to the strap to prevent extra weight from being applied to the sleeve, as that could cause discomfort for the user.

Compression

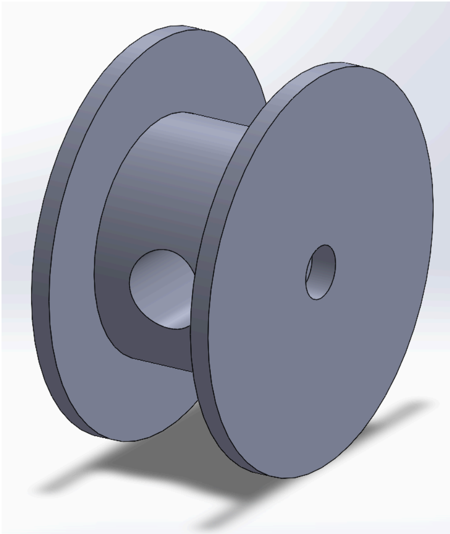
Originally, the compression was designed to be implemented through a winch system as seen in Figures 6 and 7. A base was meant to hold up a rotating axle where the compressing strap would feed through and constrict around the arm as the motor rotated. This was designed to maximize movement by the motor to capitalize on torque. The large distance of the base of the winch was designed to allow space for the constriction strap to feed through while minimizing friction against itself. The rotating would have been done with a servo motor, which would then be attached to a mini-gearbox with a 1-12 ratio, allowing the servo to turn its half a rotation to 6. The constriction strap was decided to be a shoelace folded in half, as it would provide strong tightening without being too harsh on the user.

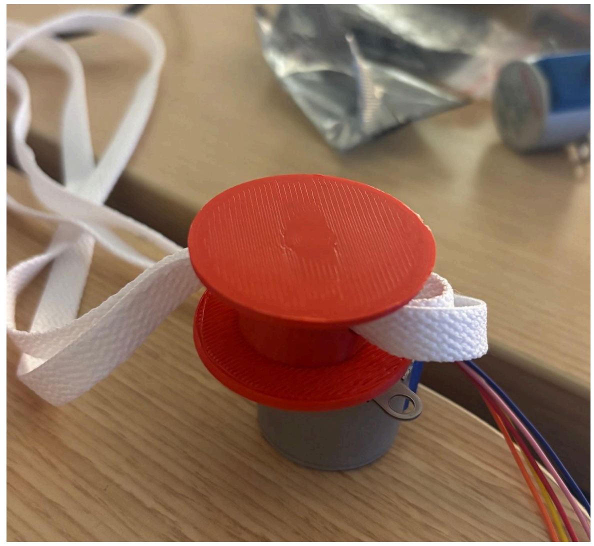


Figures 6 and 7: Initial winch CAD and Initial winch print

After printing the original model, the dimensions were adjusted to ensure maximum stability and reduce fragility, however, that caused the design to become far more bulky and heavy. Similarly, this winch design would require the motors to be placed perpendicular to the cast which created a more messy environment around the strap. Adding to this bulk would have been the gearbox, which would have taken as much space as the motor.

Due to all of the aforementioned weaknesses of the original design, the winch was redesigned into a spindle, as seen in Figure 8, that would lie parallel to the strap instead of perpendicular. This would remove the need for the large distance between the spindle and the strap, as the expansion would now be horizontal instead of vertical. The type of motor was also changed from servo to stepper, as research showed that while a servo motor excelled in speed, stepper motors could provide both more torque and unlimited rotation in a smaller package. Speed was decidedly less important, as a more gradual rotation would allow for more accommodation for consumer needs, a higher torque would be more useful for higher-pressure constrictions, and the unlimited rotation removed the need for a gearbox. The whole apparatus put together can be seen in Figure 20.





Figures 8 and 9: Final spindle CAD and printed motor apparatus

When the motor system was added to the cast, the main concern was the comfort of the user, which was achieved through various methods. Firstly, it was decided to evenly spread two motors across the length of the strap to ensure an even constriction across the entire strap instead of focusing it all in one area, as seen in Figure 20. The motors were attached to the cast through a Velcro system, which allowed the motors to easily be removed and supported the modularity of the motor system. This ensured that the motors can be adjusted and tweaked to maximize the therapeutic effects of the pressure on the arm without the need for permanent fixations. The shoe laces were strapped around the arm, but under the temperature system. This kept the constriction from damaging the cells and allowed the cells to act as an anchor, locking the laces in position while they are attached.

To minimize any unnecessary burden on the pressured area, the motors were hung on the bottom side of the strap, opposite the temperature system. This kept the bulk of the weight on the strap away from the area of pressure and allowed for the temperature system to have closer access to the area of pressure. The wiring of the motors ran across the strap where they connected to the motor driver module at the base of the sling. This allowed for a neat and unobtrusive design, keeping the electronic drivers centralized between the motors and the Arduino, which was located on the sling.

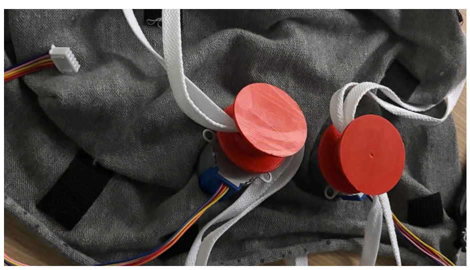


Figure 10: Motor Placement

The motors were set to accommodate three full rotations before stopping. This was determined by testing the pressures caused by the rotation of the motor. Essentially, three turns applied ample pressure for an average-sized arm without constricting too much blood flow, as seen in Figure 11. The control of the motor will happen through an input percentage of the maximum rotations relative to a base zero. Once the input is received, the motors rotate from their current position to the imputed percent of three full rotations relative to their start point. This approach enabled a precise and repeatable modulation that can be tailored to the specific needs of consumers.

Figure 11: Max constriction test

Wearable Sleeve

The main structural component of the prototype, which houses the Peltier cells, was modeled in SolidWorks to provide a clear visual of how the system would sit atop the sleeve, as shown in Figure 12. This model includes three wire loops around the main body, representing shoelace-style straps designed to apply adjustable compression while maintaining comfort for the user. The overall enclosure was shaped to contour the limb and allow for the even distribution of thermal energy.

Also shown in Figure 12, the top surface contains four square compartments initially intended to hold four Peltier cells, each measuring approximately 40mm × 40mm. However, due to the power limitations of the RedBoard, the fourth cell did not reach sufficient temperature thresholds during testing. As a result, the final configuration included only three active Peltier cells optimized for consistent heating and cooling performance. Velcro straps were positioned on the lateral sides of the device (Figure 12), enabling the module to be securely fastened regardless of limb size, ensuring a snug and effective fit for all users.

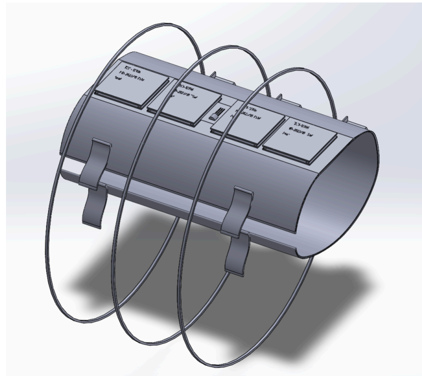


Figure 12: 3D model of Cast Sleeve

The initial version of the cast was constructed using polyester fabric for both the arm sleeve and the strap that secures it around the body, as shown in Figures 13 and 14. Polyester was chosen due to its low thermal conductivity, which allowed it to retain heat more effectively than many other fabrics, thereby enhancing the thermal effect of the Peltier cells on the user's skin [6]. A sewing machine was used to fabricate the components, ensuring precision and consistency in the construction of both the sleeve and strap. It also allowed the connection between the strap and the cast to be secure and strong.


Figures 13 and 14: Polyester Cast and Polyester Strap

However, initial testing revealed several issues with the polyester design. The cast retained excessive heat, making it uncomfortable for extended use, and the strap did not provide the level of adjustability initially anticipated. In response to these limitations, the cast was redesigned using linen fabric (Figure 15), a breathable natural fiber derived from the flax plant. Linen allowed heat from the Peltier cells to effectively reach the user's arm while simultaneously releasing excess warmth, resulting in a more balanced and comfortable experience [7]. To improve adjustability and overall usability, the strap was replaced with a repurposed guitar shoulder strap (Figure 16). This strap was easily adjustable to fit users of varying heights and arm lengths, offering greater comfort and flexibility without compromising support.

Figures 15 and 16: Linen Cast and Guitar Shoulder Strap

Communication

The final component of the device was the Bluetooth-driven wireless control of both the pressure and the temperature. The goal for this was to create an iOS app that could take user inputs and could also allow for users and their healthcare providers to write specific programs for both pressure and temperature-based therapies. Finally, the app would also provide real-time feedback on the current temperature and pressure of the system to let the user know if anything had reached unsafe levels. Overall, the idea of having users use their phone to control the device was to allow for a simple, user-friendly interface that made it easy for users to input their desired settings for the device.

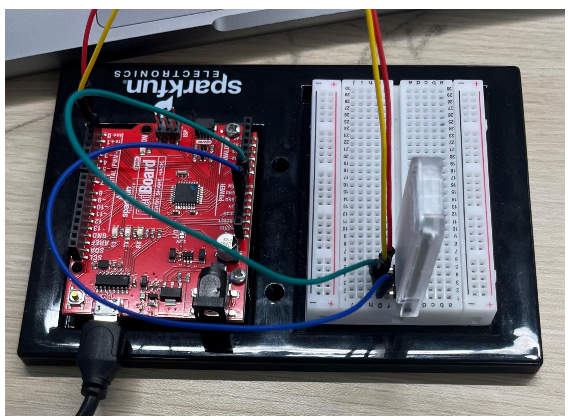
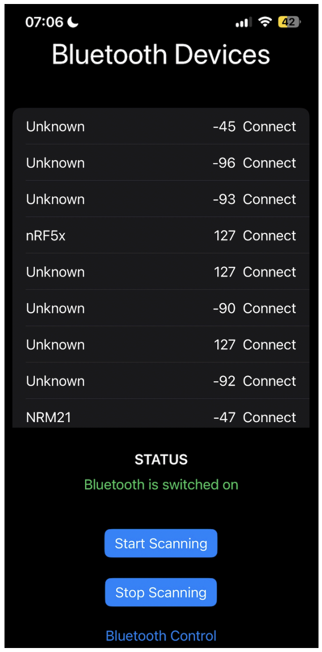
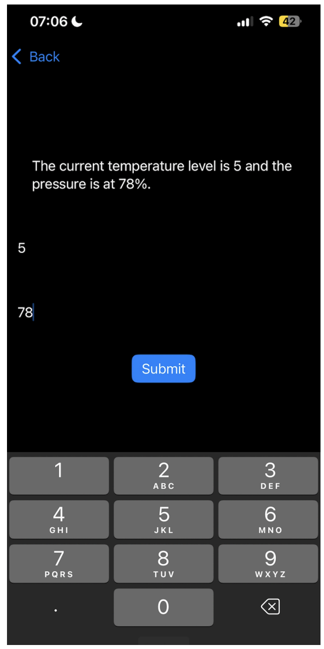


Figure 17: Isolated HM-10 Wiring

The overall control of the device was managed through an iPhone, a BLE (Bluetooth Low Energy) device, in this case, the HM-10 was used, and the RedBoard itself. The HM-10 wiring was simple; it was grounded by the RedBoard and took power from the 3.3 V port on the RedBoard and used digital pins 6 and 7 to receive and transmit data. The wiring and setup of the HM-10 were validated by sending AT commands to the HM-10 through the Arduino IDE and ensuring that it responded appropriately. This ensured that there were no problems with the HM-10, as there are many fakes on the market, prior to troubleshooting the Bluetooth connection itself.

The iPhone app sent data as characters wirelessly to the HM-10, which then sent them to the RedBoard. The RedBoard was programmed so that it interpreted each character to either a temperature mode setting or a pressure percentage value. Characters ‘A’ through ‘G’ corresponded to temperature settings 1 through 7, and characters ‘H’ through ‘R’ corresponded to pressure percentages 0% to 100% (with increments of 10%) respectively. As the characters were received, the integer values that controlled the pressure and the temperature were altered to fit the given value.

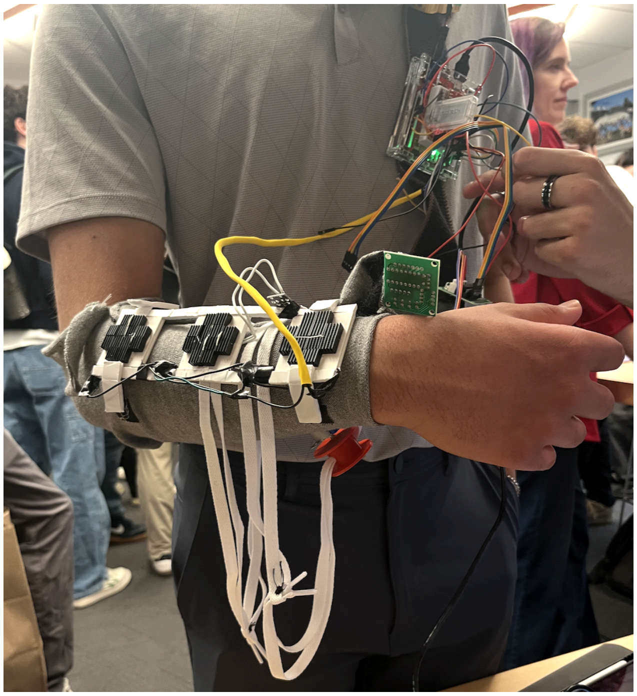
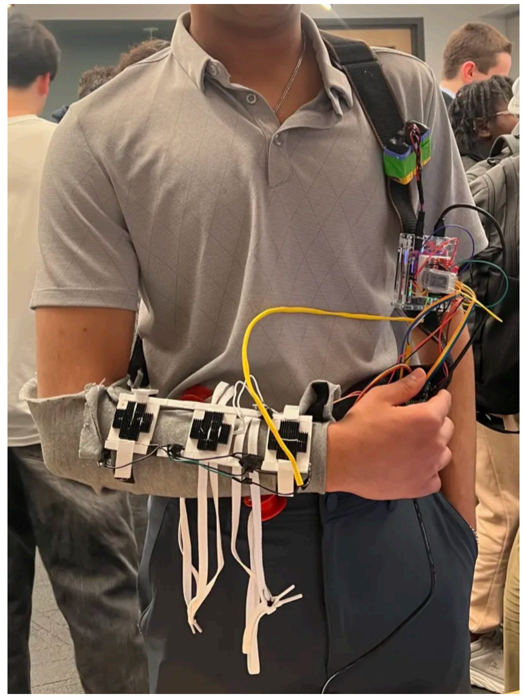




Figures 18 and 19: Internally Developed Bluetooth Detection and User Input

Initially, the plan was to create an app in XCode that handled all of the communication. Unfortunately, this was not successfully executed, and an external app (LightBlue) was used to send the previously stated characters over. However, the app that was created from scratch did successfully search for, connect to, and disconnect from all Bluetooth devices and could take in user values and update a display to reflect the user-entered values. The issue with the app was that it could not successfully detect the characteristics of the BLE, which would allow the app to send data to it. For this reason, the LightBlue app was used to demonstrate that the HM10 and the Arduino code did allow the external app to successfully control the device, which will be shown in the results section. Given the nature of Bluetooth communication, the majority of the work was done on the Arduino IDE or in XCode, and the code for both of these portions can be found on GitHub (https://github.com/frogg5/Smart-Sling).

Final Assembly

Figures 20 and 21: Assembled Device

When assembled, the device had all of the aforementioned subsystems attached to it and wired up. The RedBoard was attached to the shoulder strap, and the Peltier strip and compression systems were attached to the sleeve itself using Velcro. Note that the iPhone, complete with the LightBlue app, was not included in the Figures above. The complete integration of all of the parts was successful, as they were all able to be attached and wired to the RedBoard. Additionally, the temperature was successfully controlled through the app. Theoretically, the pressure control via the app was also successful, but as will be discussed in the results section, it could not be validated due to the compression system breaking down.

Results

In order to provide effective therapy to the user, all of the subsystems must be working effectively individually and must be integrated appropriately. As such, the results of each of the subsystems will be discussed individually, and then the entire system will be evaluated as a whole. In the table below, six videos are attached that show the various tests that were performed on the device. All of the video titles provide an appropriate overview of the mechanism that was tested, and the “Main Demo Video” includes a test of the Bluetooth control.

Demo Videos	
Video Title	**Video URL**
Final assembly Peltier strip demo	

Contactless thermometer as a data recorder Note that the thermometer could not return readings for temperatures cooler than ~86 degrees Fahrenheit.	
Main Demo Video	https://drive.google.com/file/d/1IqDbbHkZXRxBC2Gs46vXTh8rRdhChueM/view
Mode 1 (no power)	https://youtube.com/shorts/r8nSA9DS7c8?si=rrEge1IEfztNUv0H
Mode 5 (hot)	https://youtube.com/shorts/qZz-HBz2C68?si=d9apWM7IqMHmuDZt
Mode 7 (cold)	https://youtube.com/shorts/elB_Ju10Vic?si=QMRIDii3iRYpvPOl
Detached from the assembly, Peltier strip standalone demo Taped-on TMP-36 as data recorder Readings are displayed on the Arduino serial monitor	
Mode 3 (hot)	https://youtube.com/shorts/WyXAj2wV5EA?si=izuFLi0yZOeibFXm
Mode 7 (cold)	https://youtube.com/shorts/NyUWCD4PuNI?si=TjHcJvoZv6zqMb-R

The temperature system was overall a success and was evaluated quantitatively using a thermometer. Seven different temperature settings were successfully implemented and validated using the testing below. For the testing, two temperature readings were taken, one from the KY-013 and one from a contactless thermometer. As an important note, the contactless thermometer would not return readings for temperatures cooler than around 86 degrees F, so in data points below that threshold temperature, only the KY-013 reading was used. As a part of this testing, the assembly was not attached to a test subject and was tested at room temperature (or around 70 degrees F).

Degrees (F) of Mode vs Time

Mode Number	Time Passed (minutes): 0	1	3	5
1	70.18	70.18	70.18	70.18
2	68.63	73.46	75.34	76.76
3	69.87	76.76	86.405	87.585
4	69.87	87.585	88.495	88.575
5	70.18	87.495	90.04	92.335
6	73.14	67.7	69.87	67.7
7	72.68	70.49	69.87	70.49

Figure 22: Recorded temperatures at each temperature control setting

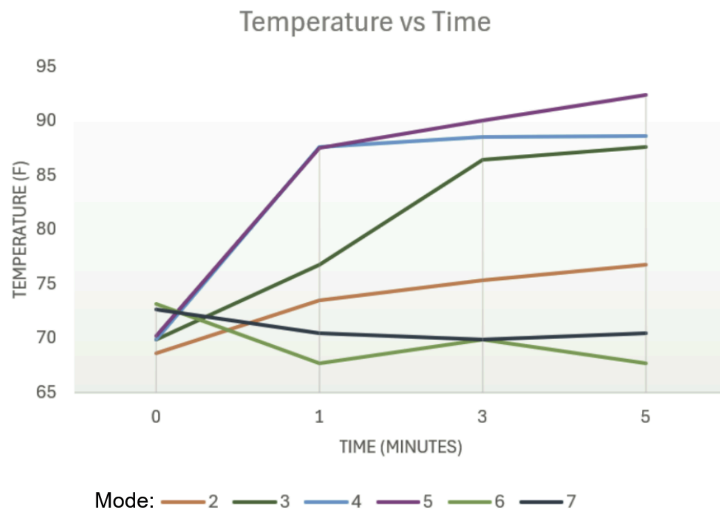


Figure 23: Data from Figure 22 presented graphically.

MODE #	NAME	On time (s)	Off time (s)	Δtemp (F)	Temp (F)
1	Off	-	-	0	70
2	Mild Heat	1	3	8	77
3	Med. Heat	2	3	17	88
4	High Heat	5	5	20	89
5	Max Heat	10	5	22	93
6	Cool 1	28	24	-3	70
7	Cool 2	10	16	-3	70

Figure 24: A user's table of operation for temperature control

It is clear from the above data that all of the temperature settings result in distinctly different temperatures, indicating that the implementation of the thermoelectric heating was successful. It is worth noting that after plugging the Peltier strip straight into the 9V power supply for five minutes, the maximum temperature reached was 109 degrees according to the thermometer. This temperature is very unlikely to occur during actual operation, as none of the modes feed power continuously. Also, the coldest temperature recorded during testing was 67.7 degrees, which is not cold enough to be hazardous.

The compression system, which was evaluated qualitatively, demonstrated a high level of consistent control and constriction. They were able to smoothly transition from different levels of compression and accurately respond to the input values. Each step applied a strong, steady movement without any large jerks or slippage, which critically maintained comfort and security without causing potential damage to the Peltier cells. When a desired level of constriction was reached, the motors were able to pause and hold while resisting any backdriving or loosening due to the torque of the motor design.

One issue with the compression was that the placement of the laces sometimes resulted in them being tangled in the motor. While this was a rare occurrence and was relatively negligible in the context of all of the successful tests, it highlights one critical area for improvement. Additionally, in the final days of construction, the motors began to break due to the weeks of testing beforehand. Although they had worked in earlier test assemblies, the motors critically failed before a proper video demonstration could be taken. Several of the plastic gears in the gearbox of one motor broke, which rendered it useless for its designed purpose. The other motor had unknown damage to the wiring, stopping any functionality entirely. While attempts were made to secure other motors, they did not arrive in time to test by the time this report was written.

For the sleeve itself, while it could not be quantitatively analyzed, qualitatively it works. The sleeve does comfortably wrap around the average forearm and was worn by multiple test subjects, none of whom reported any sort of discomfort. Additionally, the sleeve, in conjunction with the shoulder strap, held all of the necessary components to deliver the target therapies and communicate wirelessly with an external device. Some of the drawbacks of the sleeve were that it was not easy to put on and also had a significant amount of exposed wiring, which made it somewhat unwieldy for the user.

Finally, the Bluetooth communication system was qualitatively analyzed two separate times prior to being officially tested with the Peltier strip. The first test looked at whether the HM-10 was set up appropriately and was conducted by sending AT commands to the HM-10 through the Arduino IDE and evaluating the responses. Since the HM-10 responded with "OK" it was clear that it was working. The second test assessed the app's (LightBlue) connection to the HM-10 and the processing of the data sent by the HM-10. This was performed by setting up the code that would translate the values sent by the HM-10 into values that were used to change the temperature and pressure of the sling. After changing the values for the temperature and pressure, the RedBoard then printed out a statement of the updated values to the console. The app was then connected to the HM-10, and values were entered in. The targeted updated values were successfully printed to the console, which indicated that the connection and translation of the values sent by the HM-10 were successful. The last test was to wire up the Peltier cells and the pressure modules and then use the app to actually induce pressure and change the temperature of the sleeve, which will be discussed in the overall results.

As previously stated, the main improvement for the communication system would be to have the data being taken in and sent from an app developed by the team, as opposed to an external app. This would allow for the implementation of a more friendly UI as well as for users and their healthcare providers to set their own programs.

Unfortunately, by the time all of the subsystems were put together and were intended to be tested together, the motors had already broken, so there was no way of validating whether the app successfully controlled the constriction of the device or if the constriction was successful when integrated into the complete sleeve. However, the Peltier strip was effectively tested with Bluetooth control and controlled temperature as expected (as seen in this video). Additionally, while this could not be qualitatively confirmed, the setup was comfortable for the user and was easy to control.

Discussion

Overall, the results indicate three key successes. One, that the sleeve worked and could be worn by the patient, complete with the mounted temperature, pressure, and Bluetooth subsystems. Secondly, it shows that the Peltier strip worked and could successfully heat and cool the sleeve. Thirdly, the test video demonstrated that the Bluetooth control was successful and easy for the temperature element. While these successes were no doubt a crucial part of the project and made it a successful one, as with any project, many improvements could be made.

On the temperature system side, one key improvement would be implementing a better cooling system to vent out the hot Peltier face at a faster rate during cooling, which would lower the temperatures able to be achieved during cooling modes. Although fans or liquid cooling have inherent flaws with fragility and failures leading to hazards, they could be tested to see how well they work and then reevaluated for use on the product. A less drastic change would be to replace the thermal glue the heat sinks currently have with thermal paste, which tends to be better at conducting heat.

Additionally, each Peltier cell that was used also heats and cools slightly differently, as confirmed by isolating each cell and testing. For future iterations, Peltier cells with more uniform heating effects than the TEC1-12706 would yield a more consistent product. Another key improvement would be to optimize the energy usage or the power supply. The Peltier effect is inherently energy inefficient and drains a lot of battery. Thus, it may be wise to instead opt for finding a 9V power supply that has a higher capacity. Also, looking into a power supply that can be recharged would be cost-efficient for development and for the users themselves, as the authors of this paper did burn through a fair amount of 9V batteries.

With regards to the pressure system, the motors used for constriction did work in early testing and in theory, but failed after long-term testing and implementation due to poor quality manufacturing. The mechanical and functional failures can be minimized through the acquisition of higher-quality stepper motors from more trusted sources. This, along with more secure and reliable wiring, would allow the motors to have a much longer lifespan and minimize the chance of any breakages. Additionally, the current lacing system, while evenly distributing the tension and creating an even compression around the strap, could be made thinner to minimize the chance of tangling in the motor/spindle. This will reduce the visual clutter and allow the device to be easier to wear, reducing the obtrusiveness of the apparatus.

For the sleeve itself, some improvements would be to make it out of a thicker material that was better cushioned and more comfortable for the user, and to have it set up so that the wires were hidden and out of the way. Additionally, the Velcro attaching the two sides of the sleeve together could be replaced with adjustable straps that allow for a tighter and more secure fit, and the Velcro attaching the motors and Peltier strip to the sleeve could be replaced with a more secure-fitting mounting apparatus.

As final improvement, previously mentioned, would be to properly implement an internally developed app that improves data to the HM-10. This internally developed app would allow users to implement their own preset programs complete with timing and live feedback, and would also enable healthcare providers to send their own programs to users.

Conclusion

In short, the finished device was a strong proof of concept as the sleeve successfully integrated the pressure system, thermal system, and Bluetooth communication. The system had varied thermal settings that were successfully controlled via Bluetooth and were comfortable for the user. While the system had its successes, it also lacked a successful proof of the pressure system and could have been improved by having an internally developed app, a sleeve with better adjustability and mounting systems, and a more consistent and energy-efficient temperature control system.

Acknowledgement

The authors of this report would like to thank their professor, Professor Bala Maheswaran, for providing instruction and guidance throughout the creation of the device. Additionally, they would like to thank the First Year Engineering Learning and Innovation Center and the Makerspace at EXP for both their materials and support. The authors in this report would also like to thank Red Bull, Reign Energy, and 5-Hour Energy for providing the power to finish this project.

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