Horse Laminitis Treatment

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Abstract

The purpose of this project is to find a simple and affordable treatment for horse laminitis. Current treatments used by the farm are considered below industry standards. Our goal as a group is to create a solution that meets the needs of the horse while staying within the physical limits of the barn. We also hope to explore simplifying the creation process. This research was conducted in collaboration with the University of Illinois (UIUC) Animal Science Horse Farm.

Horses Biology

Horse Laminitis, also known as the founder, is a degenerative equine disease. Inflammation damages the muscle fibers in the laminae. The hoof may eventually tear off because of this damage. Progression of the disease will cause the coffin bone in the hoof to rotate, causing the horse extreme pain. There is no cure, only treatments to help reduce further progression. A sufficiently progressed laminitis will often result in the lameness of the horse [1]. A diagram of the progression is shown below.

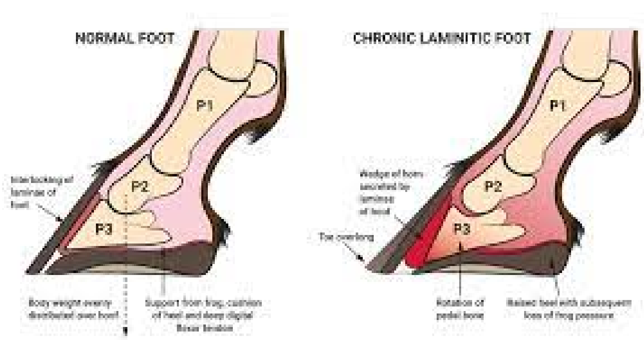

Figure 1: Diagram of Healthy and Afflicted Hoof [2]

Treatments vary depending on the stage at which it is discovered, but a recent study cites that a common course of early intervention is frequent cold temperature treatments [1]. The study recommended that the critical point for temperature is to keep the hoof wall temperature in the 41–45°F range. For the full 48-hour treatment, the hoof wall temperature should be less than 50°F. This helps by reducing the expression of certain messenger RNA and reduces lamellar inflammatory signaling [1].

Alongside many others, the UIUC Animal Science horse farm's treatment plan is not up to these scientific standards. Although effective at preventing the disease, the discomfort of the horse and their leg and hoof is high as they are submerged in ice water. This discomfort naturally makes them want to remove their foot from the bath, and for a large farm or track animal, stopping them once they decide to remove their foot from the bath is challenging. Without sedation, these scenarios can create a dangerous situation for both the animal and the handlers. The device has to be designed in a way that maximizes the comfort of the horse, but still allows for sufficient treatment. Thus, any materials we use have to be soft and easily applicable to the horse's leg, and they need to be insulated enough to maintain the temperature near the horse's leg and hoof in the expanded 41–50°F range.

While working with horses there are several constraints and conditions that need to be accounted for. The first is the physical location. Horses live on farms, where access to power is not always guaranteed. So, our group wanted to achieve a solution that required little to no power input.

Additionally, horses can be very finicky and easily startled. They are often startled by anything that is unknown to them. As such, our equine subject required bringing the device we created with several wires and a wrap for her leg and allowing her to sniff and probe them to get acquainted with the devices for several minutes. After doing so, we were finally able to put the wrap on her and get her leg into the bucket of ice along with the temperature probes. Below is a photo of that taking place.

Figure 2: Photo of Horse Acclimatizing to Device

Our Treatment Plan

We created an insulating wrap that specifically increases the temperature to ensure that while the horse leg was being dipped in ice water, the 41–50°F temperature range was kept on the hoof wall. Similar to a wetsuit, it uses the wearer's body heat so that only the inside part of the wrap is the appropriate temperature. Unlike a wetsuit, it only needs to maintain a small temperature difference, so our insulation would need to be less significant. The wrap is multiple layers of flexible styrofoam sheets (0.125” x 8” x 14”) bound together. The wrap is affixed with two velcro straps. The wrap is simple in design, however, presents the problem of an unknown optimal number of layers to keep the leg in the temperature range. While constructing and testing these variations, we also explored the possibility of a simpler way to iterate through these variations with a naive laboratory model that requires no horse.

Figure 3: Photo of Wrap Both on and off the Horse

Data Collection

We collected our data using a custom-designed printed circuit board. The central functionality comes from an Adafruit Feather M0 Adalogger and three TMP36 analog temperature sensors. To interact with the Adalogger we included an LCD Display, 3x4 Keypad, MicroSD Card, and red LED in the circuit. The layout of the circuit can be seen below.

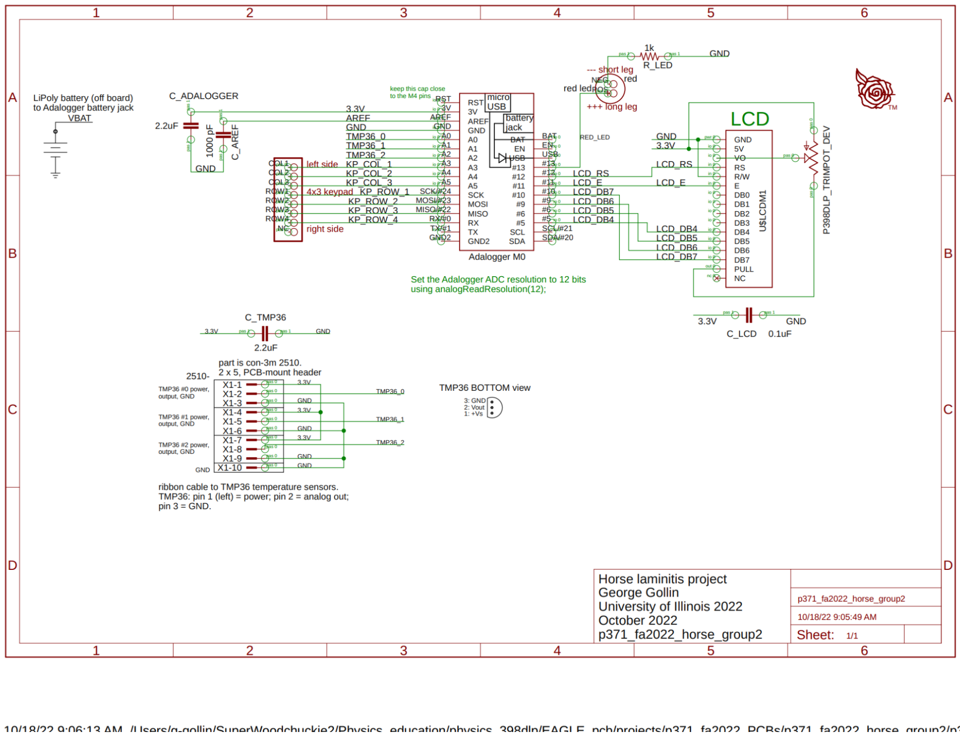

Figure 4: Circuit Diagram of Data Collection Device

The Adalogger is a programmable development board that interacts with all the other components. When provided with the proper C++ code instructions over USB, it can detect inputs on the keypad and write messages to the LCD. It can turn on and off the LED, read and write to an SD card, and measure the voltage of all three TMP36 analog temperature sensors with its built-in Analog to Digital Converter. It can do this over periods of milliseconds to periods of months. None of our trials ever reached over an hour long though. Additionally, the device has a temperature resolution of 0.07°F with the voltage resolution of the built-in Analog to Digital at 12 bits [3] and the range of temperatures TMP36 from -58–+257°F [4]. That resolution exceeds the resolution necessary for our purposes.

The completed printed circuit board was no larger than a postcard. The majority of the bulk came from the long wires which connected to the three temperature sensors. They were on multiple feet of ribbon cable which split off into three braided wires. The length allowed the device to be far from the horse. Below is a photo of the device.

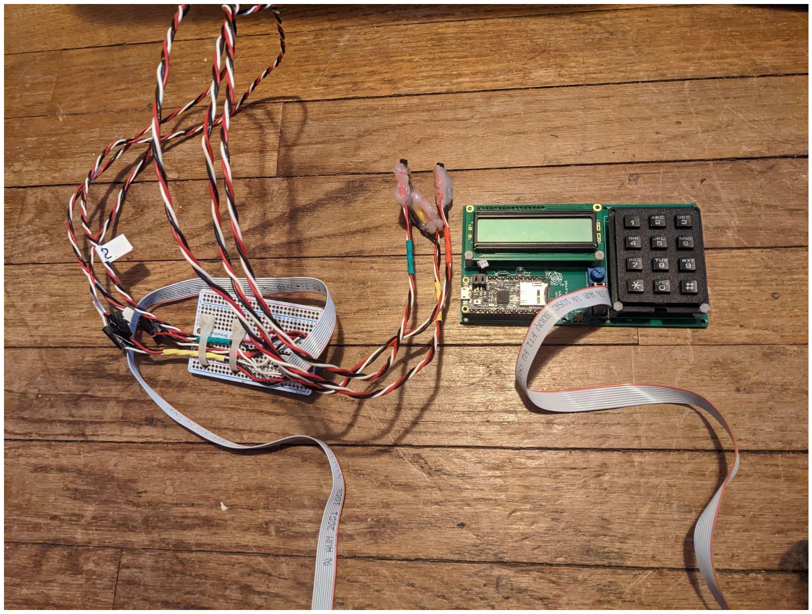

Figure 5: Photo of Data Collection Device

We programmed the device to have two main functionalities. The first functionality was for long-duration data collection. Each second while in this mode, the device calculates an average for each temperature sensor after sampling them 1,000 times. When the mode terminates, it writes the averages to a new CSV file on the SD. We added this mode to test the effectiveness of our wrap.

The second functionality was for rapid data collection. As quickly as possible, the device samples each sensor. After 6,000 data points, it writes the values to a new CSV file on the SD. We added this mode to test the effectiveness of our temperature sensors.

The temperatures are simple to compute from the measured voltages. The sensors obey the equation below [4].

$$\text{Temperature (°F)} = 9/5 * 100 * (\text{Voltage (V)} - 0.5) + 32$$

This requires the voltage from the sensors. This is accomplished with the Adalogger’s Analog to Digital Converter. The voltages are easy to compute from the analogRead() counts it provides. With the resolution set to 12 bit and a reference voltage of 3.3 V, the voltage obeys the equation below [5].

$$\text{Voltage (V)} = 3.3 * (\text{Counts (N)}) / (2^{12} - 1)$$

Further analysis and visualization of the data collected is done in Python using the software libraries Pandas and MatPlotLib. Pandas allows for reading and manipulating the data we collect, and MatPlotLib allows for the creation of the graphs throughout this paper.

Temperature Sensors

When first working with the TMP36 analog temperature sensors, we assumed that they would function submerged in water. Much of our early data collection revealed lots of irregularities and wild swings in the readings. We discovered the issue only occurred when the sensors were in water. The temperature readers should be waterproof in theory, because the plastic casing and metal tips should be able to handle the water. Our suspicion was that water was getting inside the plastic cover and ruining our sensors. Thus, we got new sensors and sealed the ends with hot glue. This proved to work and solve this technical issue. A photo of the sealed sensors is shown below.

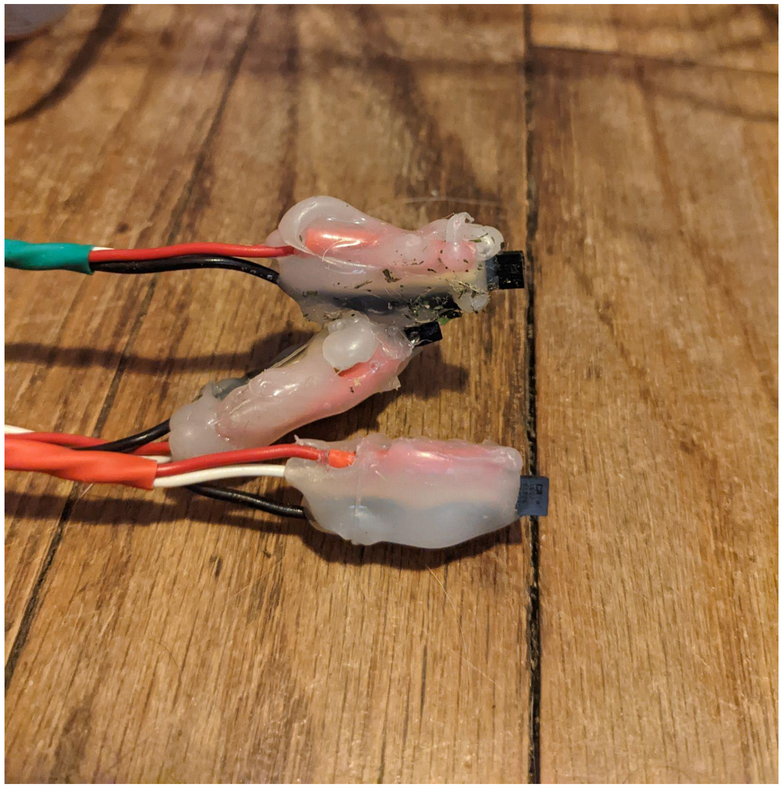

Figure 6: Photo of Temperature Sensors after Hot Glue Seal

Next is the inaccuracy of the temperature sensors. Temp0, Temp1, and Temp2 refer to Temperature Sensor 0, Temperature Sensor 1, and Temperature Sensor 2 respectively in the graphs that follow. According to Adafruit, the sensors have a documented inaccuracy of ±3.6°F [4]. This is significant when our target range covers only 41–50°F. We recorded the temperature measured by the sensors over 100 seconds when placed in a large ice bath. Those measurements are shown in the graph below.

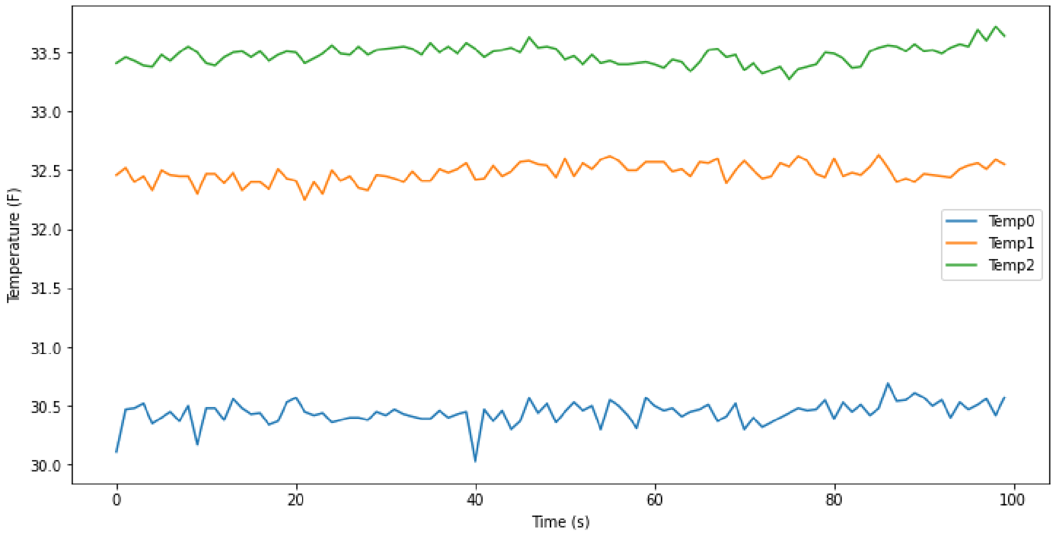

FIgure 7: Graph of Temperature Sensors in Static Ice Bath

The inaccuracy between the sensors is clear in the graph above. The values measured by each sensor over the 100 seconds were averaged and the correction offsets were computed. Those are shown in the table below.

Sensor	Mean Temperature (F)	Correction (F)
Temp0	30.44	+1.56
Temp1	32.48	-0.48
Temp2	33.48	-1.48

Figure 8: Table of Averages and Corresponding Corrections

The inaccuracies measured fall within the range provided by the distributor. The next question is if these offsets are maintained across other temperatures. We inserted an immersion circulator into the ice bath with the temperature sensors. A thermal immersion circulator is a machine that maintains a specific above-ambient temperature in the water it is submerged in. It is most commonly known for its use in sous vide cooking [6]. After melting all the ice, it continuously increased the temperature from 32°F to 100°F linearly over the course of 30 minutes. That data is shown in the plot below.

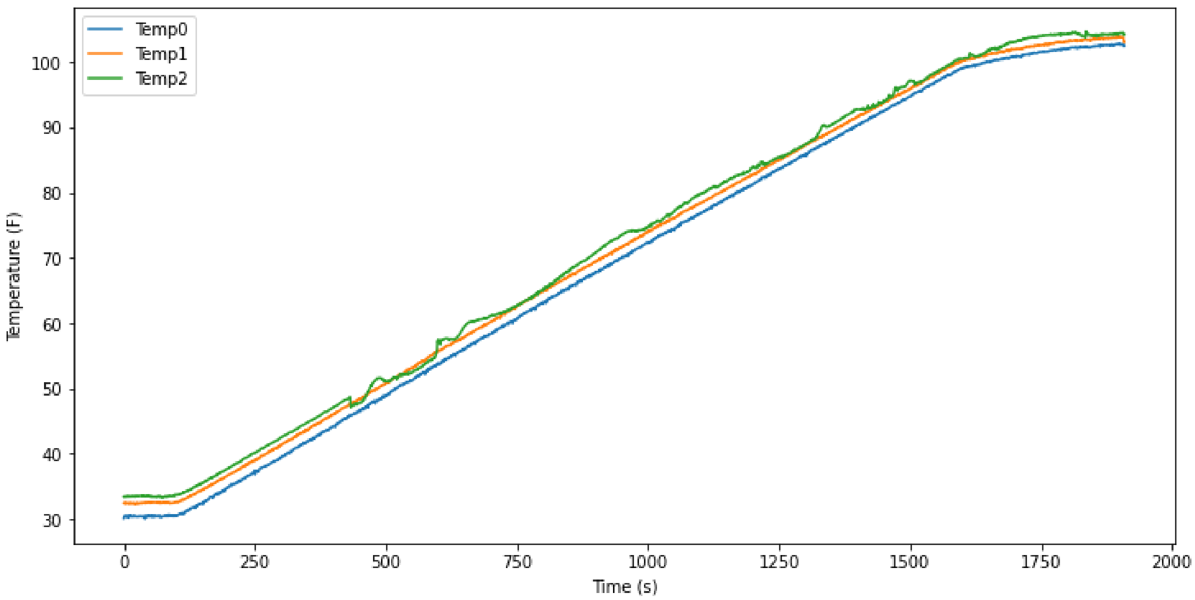

Figure 9: Temperature Sensors in Linearly Increasing Bath from 32–100°F

The temperature sensors maintain their relative difference up until 50°F. At that temperature, Temperature Sensor 2 wanders while the other two sensors stay in sync all the way to 100°F. This highlights the sporadic failures of Temperature Sensor 2. In this case it is restrained, but it behaves much more wildly in other scenarios. Those other scenarios had the other sensors at different temperatures. Looking at the device, we suspect its connection from the braided wire to the ribbon cable was flawed. After many attempts to troubleshoot the problem with Temperature Sensor 2, no solutions were found. Luckily two functional sensors are enough for our trials, so discarding it from our trials can avoid the issue.

The last consideration is the noise inherent to the temperature sensors. Submerging the sensors in 32°F water, we recorded the following data as quickly as possible. A graph of that and density estimation are shown below.

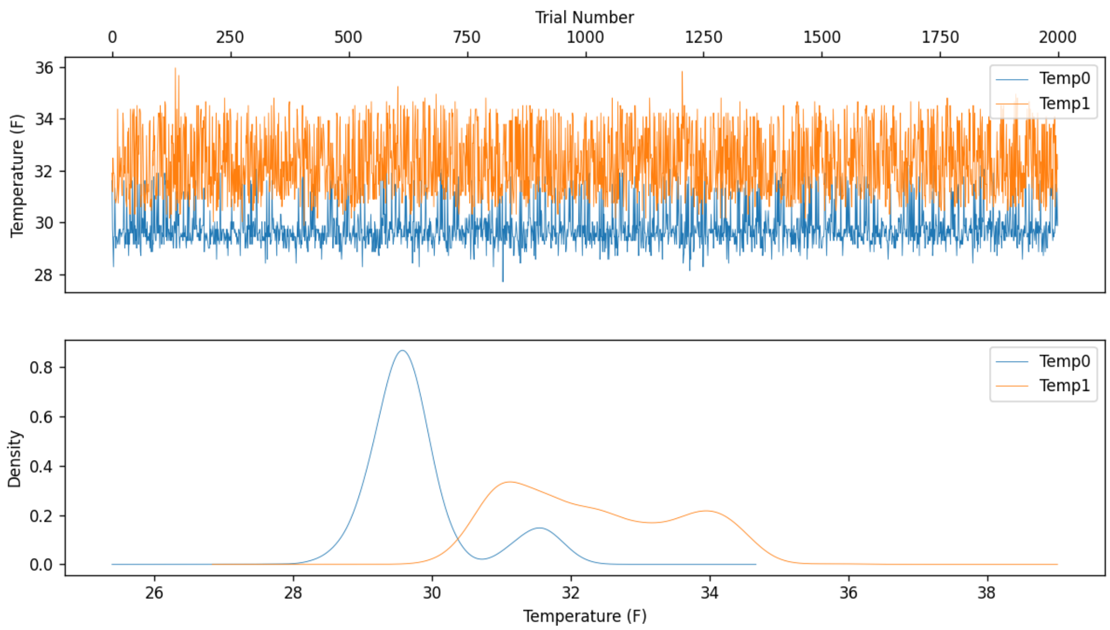

Figure 10: Noise Profile of Temp0 and Temp1 at 32°F

According to this, the temperature recorded by Temperature Sensor 0 oscillates rapidly by ±2.5°F. The temperature recorded by Temperature Sensor 1 oscillates rapidly by ±2°F. Fortunately, an average of 1,000 trials is more than sufficient to eliminate any trace of it.

The sensors are acceptable for trials given we do three things. The first is we must eliminate Temperature Sensor 2. The second is we must correct our data by the found offsets before data analysis. The third is that we must average over multiple seconds.

Horse Trials

For all the trials that follow, Temperature Sensor 0 was used to measure the internal temperature and the space between the insulator and the horse. Temperature Sensor 1 was used to measure the immediate exterior of the insulator, and the space outside.

For our first trial at the horse farm, we had the wrap with three layers of foam. We attached the temperature sensors to the inside and outside. We velcroed the wrap onto the horse's leg such that it covered the hoof and ankle with a small amount of overlap. We added ice packs to a five-gallon bucket of water. Once the water was at 32°F, we coaxed the horse leg with wrap into the bucket. Due to the nature of working with a horse, we could only manage a modestly sized recording after a disproportionate amount of work. That trial is shown in the graph below.

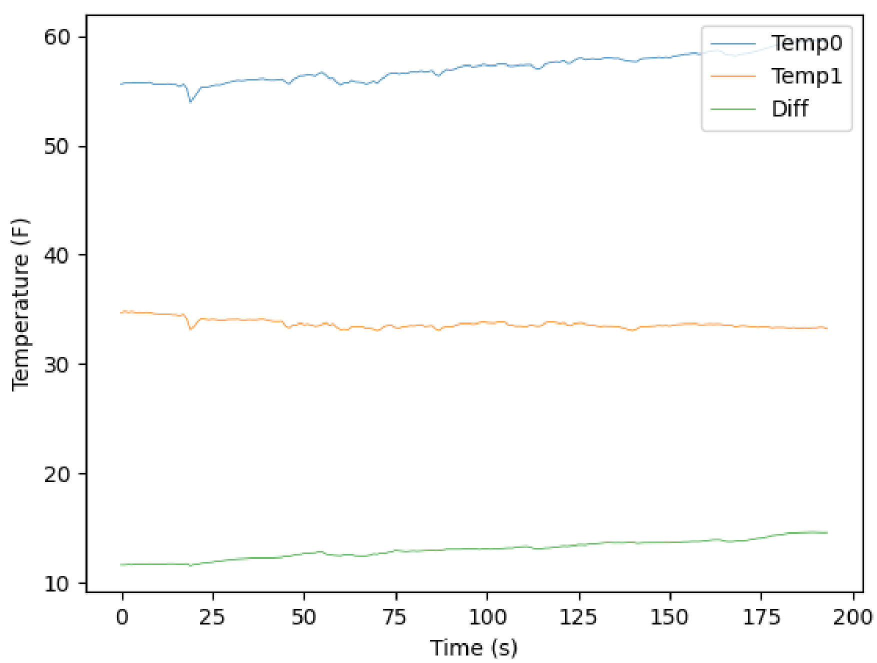

Figure 11: Graph of Horse Trial with Three Layers

After the trial, we returned to the horse farm again. We had the wrap now with only two layers of foam. Following the same procedure, we ran another trial with the same difficulties. That trial is shown in the graph below.

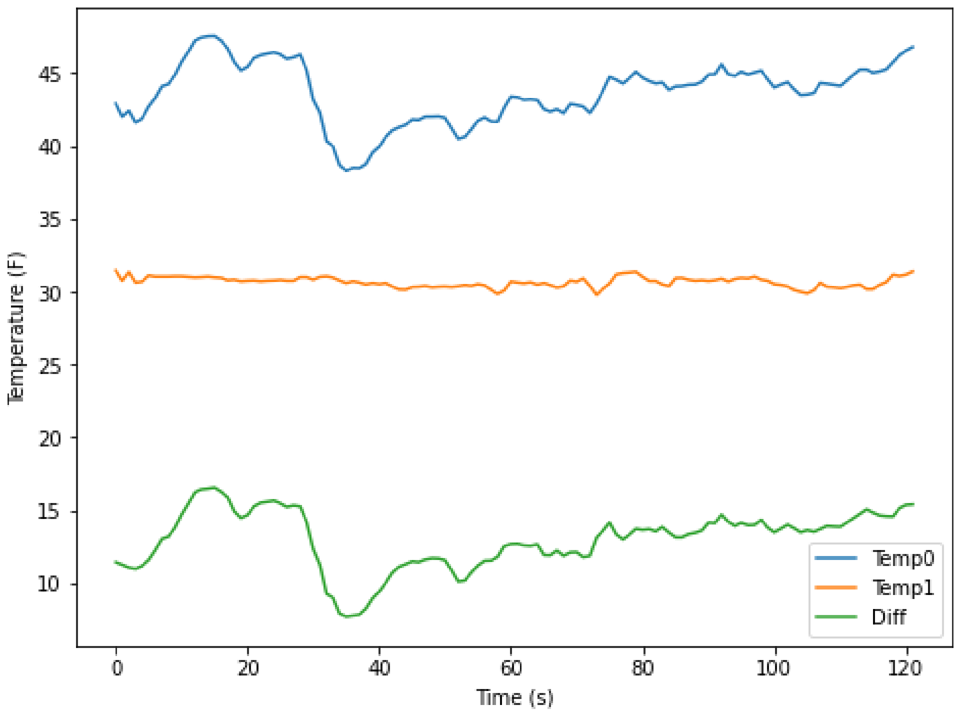

Figure 12: Graph of *Horse Trial with Two Layers*

A cursory analysis of the data revealed that we were in the proper range with this second trial. Because of this, we concluded our horse trials. The internal temperature (Temp0) in the last 50 seconds of each trial was averaged, corrected, and compiled into a table. That table is shown below.

Number of Layers	Temperature (F)
3	60.27
2	46.16

Figure 13: Table of Internal Temperatures for Varying Number of Layers on Horse

Lab Trials

Whilst running those tests on the horse, we also constructed a naive laboratory model of the horse to determine whether exploration of the problem could be simplified to not involve a horse. Two deep plastic containers (9”x9”x12”) each had one rectangular hole (3”x4”) cut into them. The holes were vertically aligned, centered, and approximately 4” from the base of the container. The two holes were bolted together with four right-angle brackets with a quarter-millimeter sheet of aluminum between the holes. Crazy glue sealed all the connections making the cuts completely waterproof. A 3D-printed channel was fixed on one side of the aluminum with an abundant amount of duct tape. The channel was 6 cm in length, 8 cm in width, and 14 cm in height.

Both sides were filled with water. We treated the container with the channel as the ice bath and kept it constantly filled with ice. We treated the other container as the interior of the horse. It contained a thermal immersion circulator. We kept its temperature at a constant 99 °F which falls in the normal 99–101°F rectal temperature range for horses [7].

The last element to complete our model is the insulation of the horse hoof. This is not a known quantity that we can replicate directly. Instead, we tuned the amount of insulation by continuously adding insulation until we reproduced the result we saw in our first horse trial with three layers of foam. To match that, we inserted three layers into the channel using a metal clip at their base. We placed Temp Sensor 0 between the aluminum and layers, and Temp Sensor 1 between the layers and the ice. The first trial had an uncorrected interior temperature of 58.71°F. Insulation of foam and duct tape was added to the aluminum on the side of the horse interior until Temp Sensor 0 dipped to near that temperature. That tuning process is shown in the figure below.

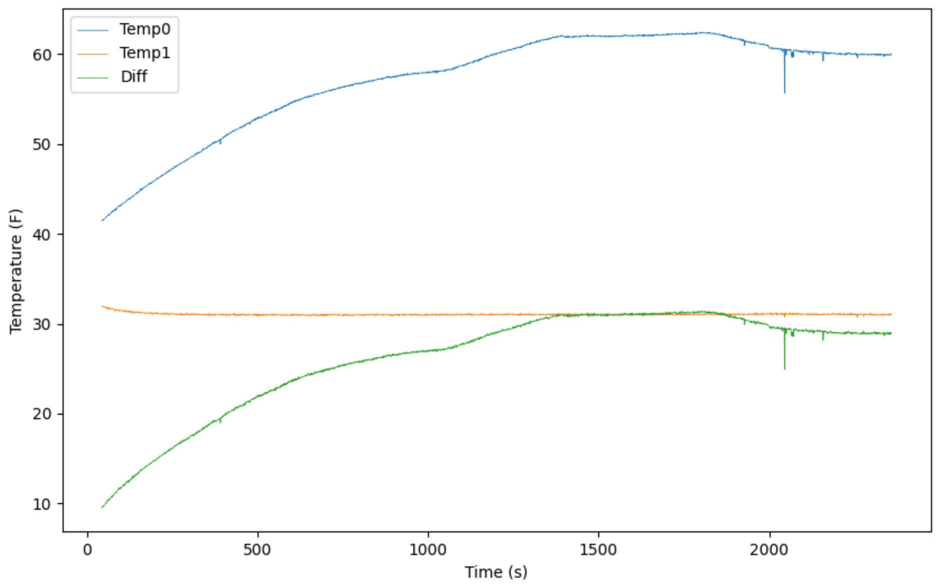

Figure 14: Graph of Tuning Lab Trial with Three Layers

The temperature initially overshoots 58.71°F as there is not enough insulation at that time. As more insulation was applied the temperature shifted closer to that desired temperature. The trial ended with a temperature of 59.9°F as shifting the temperature further became increasingly more challenging due to the limitations of duct tape in circulating water. From that trial, we could then vary the number of foam layers, and thus quickly test multiple variations. Below are graphs of those trials.

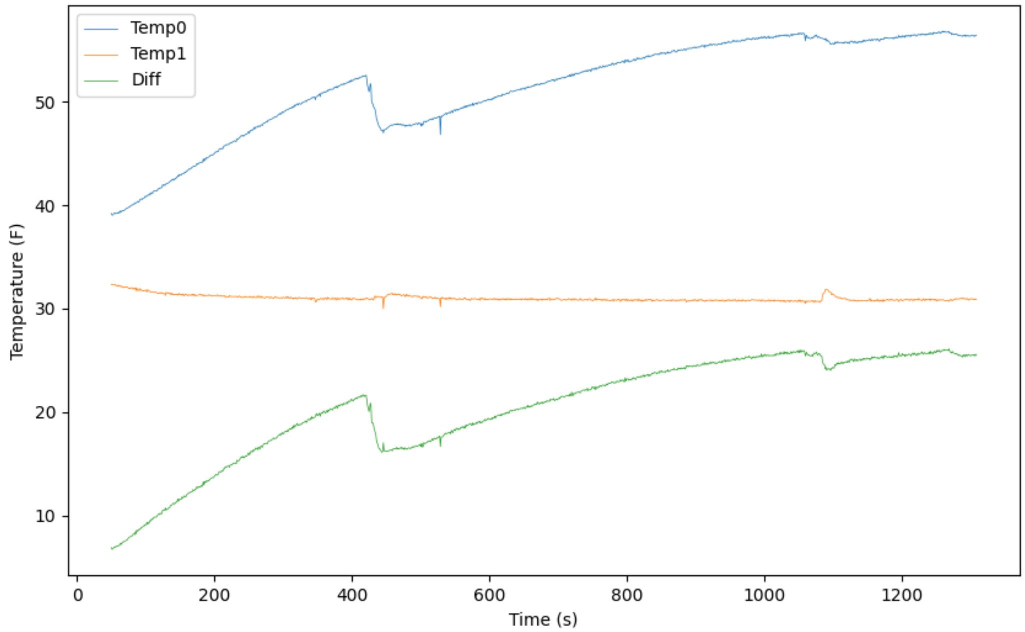

Figure 15: Graph of Lab Trial with Two Layers

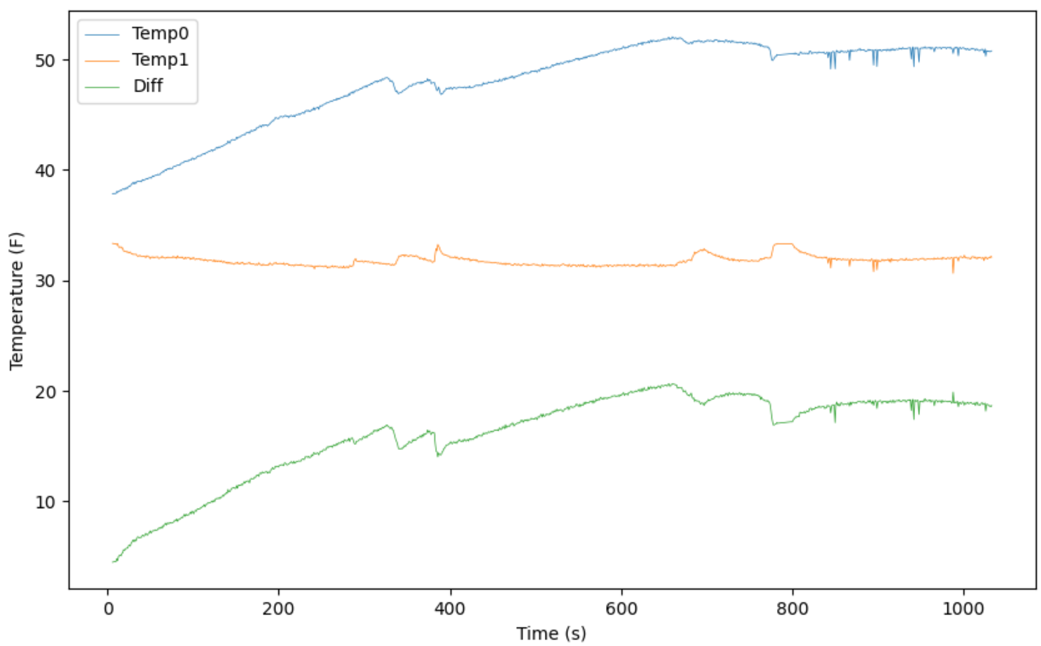

Figure 16: Graph of Lab Trial with One Layer

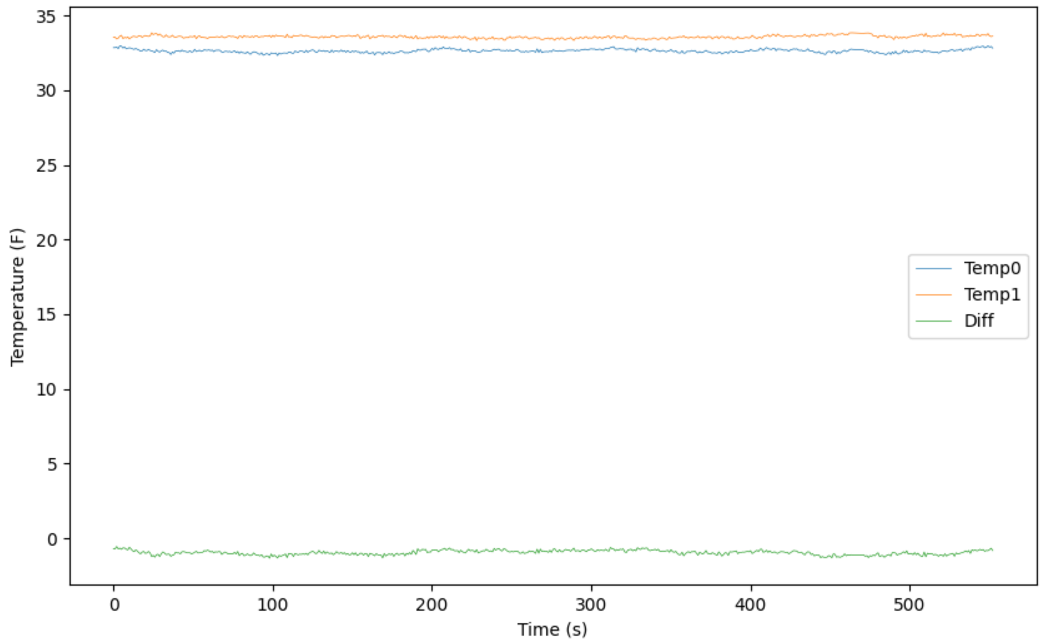

Figure 17: Graph of Lab Trial with No Layers

The trials are not perfectly smooth as there are moments where water was able to escape as the temperature equilibrated. A better way of affixing the layers in the channel would most likely alleviate this problem as with few layers it would sometimes give way to add water. Despite this, the trials continued until a satisfactory smooth equilibrium was seen. The last minute of each trial is what contains the most significant data of the trial after all.

One additional trial was done to examine the amount of water flow in this setup. Aluminum does very little to impede the flow of heat. In this trial, it only acts to block the flow of water. That trial is shown in the graph below.

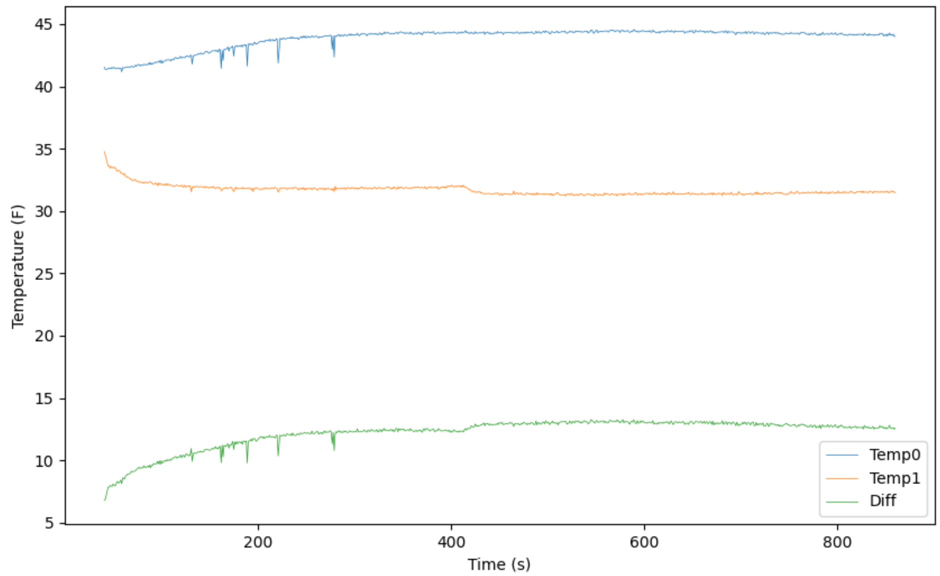

Figure 18: Graph of Lab Trial with Thin Aluminum Layers

The internal temperature (Temp0) in the last 50 seconds of each trial was averaged, corrected, and compiled into a table. That table is below.

Number of Layers	Temperature (F)
3	61.49
2	58.10
1	52.44
0	34.26
Aluminum	45.71

Figure 19: Table of Internal Temperatures for Varying Number of Layers in Model

Data Analysis

With those trials we can form conclusions about our treatment and model. All trials of varying number layers were plotted into one graph. The range of temperatures were highlighted in green. That graph is below.

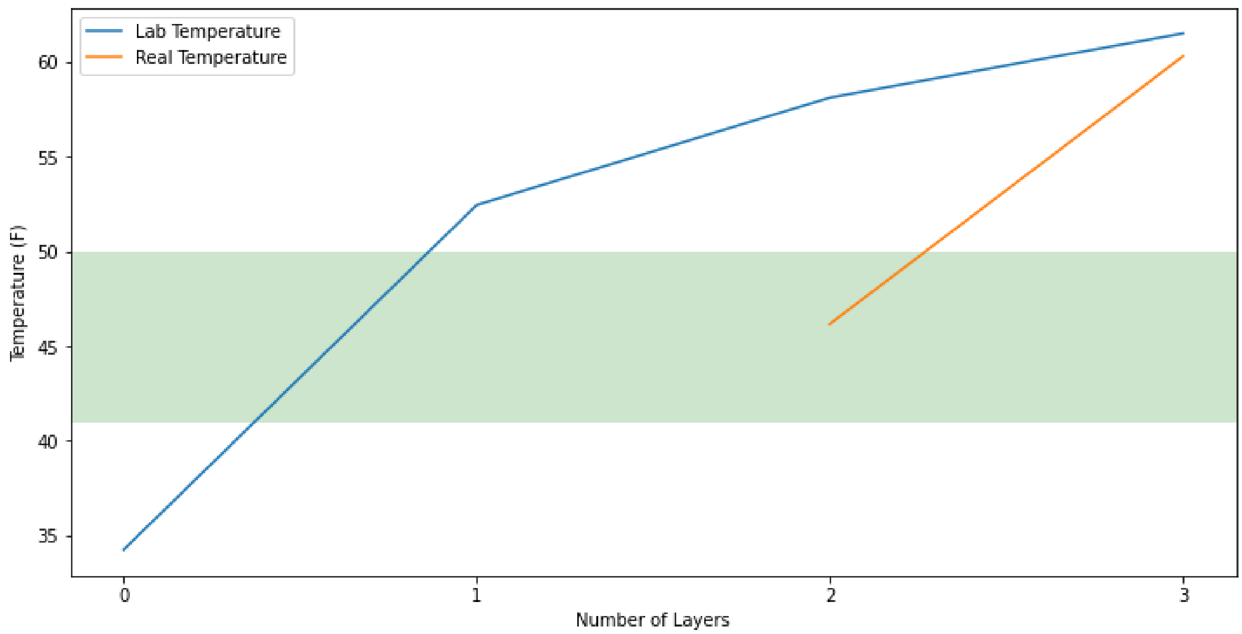

Figure 20: Graph of Internal Temperature while Varying Number of Layers

It is quite apparent that the curves diverge. In the case of N = 3, the model temperature had a percent error of 2%. In the case of N = 2, the model temperature had a percent error of 25%. That is a 1200% increase. A small deviation in temperature at N = 3 should not create a massive deviation at N = 2, as thermodynamic equilibriums are not chaotic. Therefore it is shown that our naive model is not appropriate for replicating the conditions of the horse and wrap system.

The aluminum lab trial supports this conclusion. We measured an internal temperature of 45.71°F. This is near what we measured for the N = 2 horse trial. As mentioned earlier, aluminum provides very little insulation. The high temperature of the model must be from something besides insulation. Most likely it is a difference in convection. Convection refers to the tendency of increased movement in heated liquid. The naive model is more restrictive on water flow than the wrap. Therefore the naive model was tuned with the incorrect amount of convective flow. Bad tuning led to bad results.

The naive model predicts that less than one layer is required. It remains inaccurate for those same reasons. The optimal number of layers is two according to the N = 2 horse trial.

Conclusion and Future Developments

We were able to accurately maintain a temperature of 41–50°F when using 2 layers of insulation. This shows that our concept works and it is possible to get a specific temperature treatment. Our naive model did not work to simplify the process of creating the treatment. Instead, it gave us incorrect predictions.

Some future development would include the ability to be able to find a way to account for the fact that the horse leg changes temperature over time. We need to account for the change in this temperature, from our trials our wetsuit keeps the temperature within the range of the full trial time but there are opportunities to optimize this aspect.

There is another technology that could potentially be utilized as well to make the device more precise. We could potentially add heaters into the wrap that turn on to make sure the skin of the horse does not get too cold. Another potential development would be flow controls on the wrap. This would work where based on the temperature reading of the device, we could have a method where the warp tightens or loosens to change the flow of water onto the leg.

Lastly, further work could be done in modeling the horse and wrap in a lab setting. Our model only included tuning for the horse hoof insulation. Tuning for water flow could be added to possibly achieve more useful results.

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