Summer 2023 Research Summary

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1 About the Author

My name is Jaehah Shin. This project is the summer research project that I am currently working on. I will be second year student this fall in the University of Toronto and I am studying Engineerign Science. In third year, Engineering Science student will get to choose their major, and I am planning to choose the Robotics major. I am interested in the field of robotics, and I am planning to study more about the robotics in the future. I am currently working in the Prof.Franklin's lab in the University of Toronto. More information can be found in the following link. Prof.Franklin's Lab I am currently working on the project that is related to the Induced Local Thermal Hyperemia Coupled with Laser Doppler Flowmetry to Assess Endothelial Function. The following section will describe the overview of the project that will be worked on this summer.

2 Proposal of the Project

PDF file on the next page is the overview of proposal of the project that I am currently working on.

Induced Local Thermal Hyperemia Coupled with Laser Doppler Flowmetry to Assess Endothelial Function

Biomedical Background and Motivation Endothelial dysfunction is one of the earliest markers in most cardiovascular diseases (CVD). Vascular endothelial cells line the entire circulatory system. A key indicator of a healthy endothelium is appropriate nitric oxide (NO) synthesis and release by vascular endothelial cells in response to a vasodilatory stimulus. Conversely, reductions in endothelial function are detrimental and precede the development of CVD. Currently, there are limited non-invasive methods that can assess endothelial function. Flow Mediated Dilation (FMD) is the most widely known non-invasive technique to measure endothelial function, but it is not well-adopted by clinicians due to the technical challenges of standardizing measurement of FMD and the relatively modest evidence of incremental change in risk assessment. Clinicians need standardized method of assessing endothelial health without the need to put patients through invasive procedures, especially when endothelial health information can be extracted using non-invasive optical methods. Laser Doppler Flowmetry uses the doppler phenomenon to detect changes in flow, typically used as a non-invasive measurement of microcirculation. Recent exploration of using Laser Doppler Flowmetry technology to measure changes in cutaneous microvascular blood flow in response to heat (vasodilatory stimulus) as an indicator of endothelial function has been promising, although further research is required before recommendation for clinical use.

The goal of this work is to develop and evaluate a non-invasive wearable device that will be able to measure changes in microvascular blood flow in response to heat, which can then be used to assess endothelial health. An effective wearable device successfully developed will empower clinicians to consistently and reliably assess endothelial function in patients to assess risk and employ intervention in advance of devastating clinical events such as myocardial infarction, stroke and other CVD.

Experimental design, methods, and analysis

To achieve this goal, Jaehah will help explore and evaluate various skin heaters to find the optimal heater that induces the expected vasodilatory response. Jaehah will also help optimize a method for precise temperature control for the skin heaters as achieving a local skin heating to $42°\mathrm{C}$ is a critical requirement to induce cutaneous hyperemia. Once an optimal heater and temperature control method is determined, healthy individuals will be assessed using the selected heater coupled with a laser doppler flowmetry machine. In healthy individuals, the response to thermal hyperemia results in a distinct and predictable pattern, where an initial dilator response where skin blood perfusion (SkBF) peaks in a few minutes (usually within first 10 mins) is observed, followed by a postpeak drop in SkBF (termed the “nadir”), and a secondary dilation to a plateau (usually 20-30min post heating). Results will be analyzed to confirm chosen heaters and temperature control methods are effective. This work will help inform how to best incorporate these elements into a future wearable device designed for non-invasively assessing endothelial function.

Figure 1: The overview of the `Summer Research Proposal`

3 About the thermister

On May 15th, my job was to learn about the thermister, and find out how to use this. Therefore, I did some research about the thermister.

We have all the values for 40.0 degress and 45.0 degrees in the data sheet. Therefore, we can use datas to cacluate those two temperatures. Aim is just to calculate the temperatures in general for lab purposes.

As the resistance of thermister is 10kohm, therefore, resitance of wire is negligible. Thermister doesn't actually read the temperature. This reads the resistance of the thermister changes with temperature.

The thermister used in this project is TDK B57230V2103F260 which has 10k ohm. This is NTC thermister therefore, it has negative temperature coefficient thermistors. Resistance decreases as temperature rises. this is due to the increase in the number of conduction electrons energized by the thermal agitation from the valance bond. Actually, using the termistor is not the best for the accuracy of the temperature. Since we measure the change of the resistance first and then convert it to the temperature. Therefore, there are possible errors in the measurement.

However, there is the equation that can calcualte the temperature throuogh the resistance. Then also the Arduino code can solve that equation. That equatino is called as steinhart - Hart equation.

4 Steinhart - Hart Equation

$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3 \tag{1}$$

where A, B, C are the constants that are determined by the thermistor and written on the datasheet.

- T is the temperature in kelvin
- R is the resistance in ohms
- A, B, C are the constants that are determined by the thermistor

However, there was one big problem with this equation to solve the problem. On the datasheet provided, there was no A, B, C values. Therefore, there was only one way to solve this equations which is measuring the resistance at three fixed different temeperature. As there are three unknowns, we need three equations to solve for A, B, C. For example, at 40.0 degrees, 45.0 degrees, and 50.0 degrees, we can measure the resistance.

And then compute the values to calculate for A, B, C, then implement that equation with all the coefficients in the arduino code. However, as the lab bought the heater temperature controller, this method is not necessary anymore. As the heater temperature controller has the thermister, it can read the temperature directly which is more accurate than the method that we were planning to use.

5 Heater Temperature Controller

Lab bought the TC300 - Heater Temperature Controller from Thorlabs on May 18th. Document on Heater Temperature Controller Following paragraph will be the sumamrized note for heater temperature controller on how to use it. Thefore, this part will be written based on that doucment.

First, as you can see from below figure, heater can be connected to heater temperature controller. There is a space that wire can be connected, therefore, connect heater into hole 1 and 2.

5.2. Heater Connection

Most resistive heaters do not have a polarity, so simply wire the heater to pin 1 (Output Heater +) and pin 2 (Output Heater -) of the Hirose connector on the front panel, as shown in Figure 3. The TC300 is compatible with most resistive heaters but can achieve maximum efficiency when paired with heaters with 12 Ω resistance.

Figure 3 Heater Connection

Figure 2: The overview of the `Heater Temperature Controller`

Second, connect the thermister to the hole 4 and 5. As you can see from figure below, thermister also can be connected to this device.

5.3.1. Thermistors

The TC300 is compatible with thermistors with resistance ranging up to 999 kΩ. Most thermistors do not have a polarity. To connect a thermistor to the TC300, simply wire the thermistor to pin 4 (Sensor +) and pin 5 (Sensor -) of the Hirose connector as shown in Figure 4.

Figure 4 Thermistor Connection

Figure 3: The overview of the `Heater Temperature Controller`

Eventhough, there are more featuers in this device, we will focus on the temperature control feature mostly, therefore, thermister and heater will be connected to this device.

5.1 How to use the Heater Temperature Controller

After, connecting the heater and thermister to the device, this is ready to be used.

1. Conenct the powr line to the AC inlet on the back panel with the included power cord.
2. Press the rocker switch on the front panel to turn on the device.
3. Wait for the device to be initialized, then it will enter home screen.

However, there is Warning that we need to be careful about.

WARNING : HIGH VOLTAGE INSIDE.

To avoid electrical shock, the power cord protectivee groudning conductor must be connected to the ground. Without cover installed, the device must not be operated.

5.2 Front Panel Operation

Below is the figure of the front panel of the heater temperature controller.

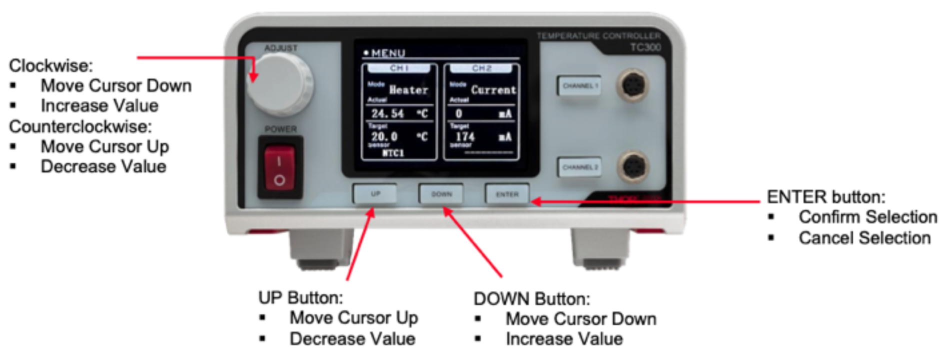

Figure 4: The overview of the `Front Panel Operation`

In my opinion, there is one typo in the picture based on the description in the document. In document, it says that " Pressing the "UP" button will then increase the value and pressing the "DOWN" button will decrease the value." which is opposite from the picture.

Important Point: When a value is selected, the color of the text will become Yellow.

5.3 Home Screen

Below is the figure of the home screen of the heater temperature controller. This figure itself is self-explantory, therefore, no more explanation is needed.

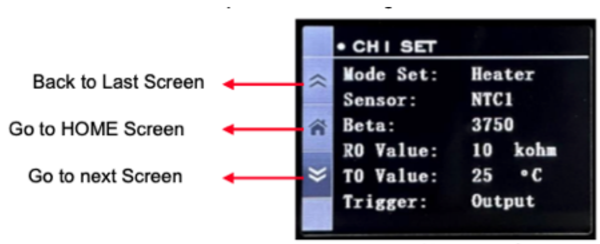

Figure 5: The overview of the `Home Screen`

5.4 Menu Structure

When there is one single channel connected, then one channel will be displayed in the home screen. When there are dual channels connected, then two channels will be displayed in the home screen.

6 Thermister

Since we have B-value in the data sheet, therefore, we can use the following equation to calculate the temperature. We can manually type in the B-value, R0 and T0 value into the device.

$$R(T) = R0e^{B(\frac{1}{T} - \frac{1}{T0})} \tag{2}$$

$$T(R) = \frac{\beta \cdot T_0}{T_0 \cdot \ln\left(\frac{R}{R_0}\right) + \beta} \tag{3}$$

When we manually type B-value, R0 and T0 value into the device, then device will use the following equation to calculate the temperature.

7 Voltage, Current, limit and temeperature range

All of voltage, current, temeprature range will be set on the second setting screen of each channel. The range of voltage is 0v to 24v, range of current is 0A to 2A.

8 Heat On PCB Panel

First of all, we need to know what is the PCB panel. PCB panel is short for Printed Circuit Board. As in this lab, the focus is how we can implement the heater into the PCB panel while measuring the temperature of the skin with the heater. This is crucial to know the possible effect of the heat on PCB panel as PCB panel and heater will be implemented together into the werarble device at the final stage of the project.

8.1 What is the PCB panel?

PCB panel is the board that is used to mechanically support and electrically connect electronic components. This PCB panel is used almost in every electronic devices, and this will be used in the wearable device that we are going to implement at the final stagae.

8.2 What element usually implemented in the PCB panel?

There are many elements that can be implemented in the PCB panel. However, the most common elements that are implemented in the PCB panel are the following.

- Resistors
- Capacitors
- Inductors
- Potentiometers
- Transformers
- Diodes
- Transistors
- Silicon - Controlled Rectifiers (SCR)
- Integrated Circuits
- Crystal Oscillators
- Switches and Relays
- Sensors

8.3 Possible effect of the heat on PCB panel

Research from this website Heat on PCB shows that the limitation that PCB panel can handle depends on the type of PCB panel. However, for example, with the FR-4 has a TG(transtion temepratature) of about 135 degree Celcius. FR-4 is the most common PCB panel that is used in the industry.

When the temperature goes upon the limit, there might be some probles that can occur. The most common one is the malfunction casuing dissipation. However, as commonly, PCB pannels can handle at least 90 degree Celcius, it won't affect on this project. As this project aims for the temperature of 41 degree Celcius, this will not casue any problem on the PCB panel.

9 Soldering

9.1 What is soldering?

Soldering is the process of joining two or more electronic parts together by melting solder around the connection.

9.2 Where is soldering used?

Soldering is used in almost every electronic devices. While the temperature controller requires the thermister and heater to be connected, we didn't have 6-pin cable, and the end of wire of thermister and heater was flattend. Therefore, we decided to solder the new cable and the end of wire of thermister and heater. Below figure shows how I did my first soldering. This was not perfect as you can tell, but I will improve this skill as I practice more.

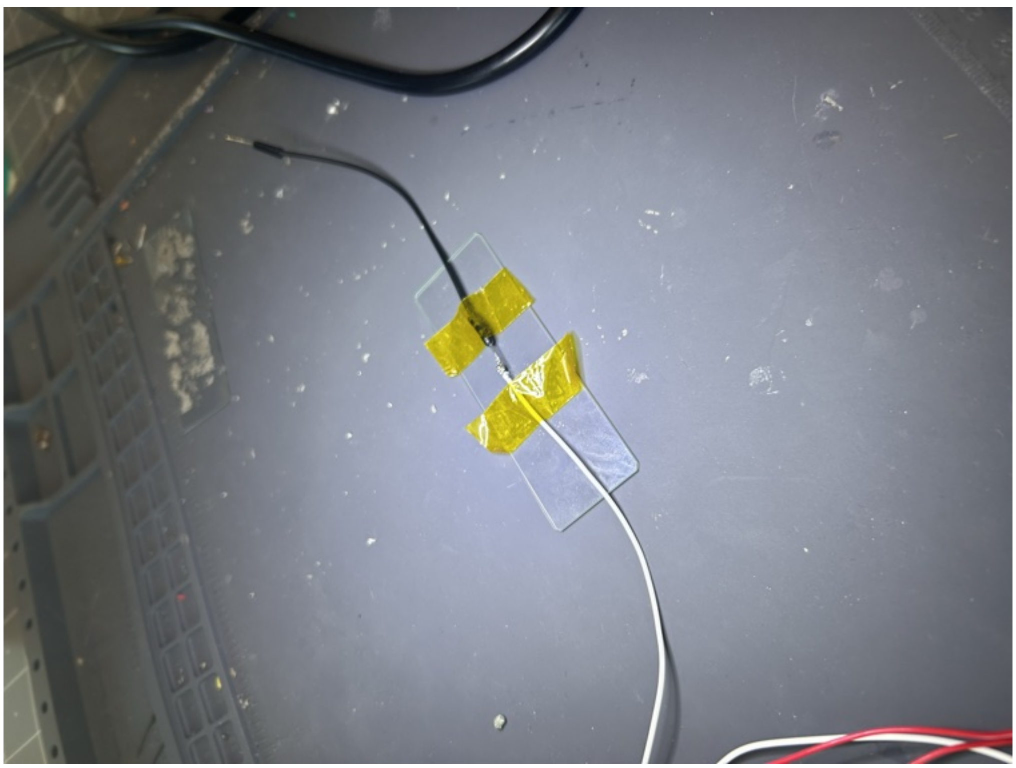

Figure 6: The overview of the `soldering`

9.3 How to solder?

Basiclaly there are 5 steps to solder.
1. Clean the tip of the soldering iron.
2. Heat the parts, not the solder.
3. Apply flux-core solder to the heated parts, not the soldering iron, and heat it until the solder melts and flows freely.
4. Remove the solder and the soldering iron, and allow the solder to cool naturally.
5. Do not move the parts until the solder has cooled.

9.4 What is the soldering iron?

Below figure shows the soldering iron that I used for the soldering.

Figure 7: The overview of the `soldering iron`

Soldering iron is the tool that is used to solder the electronic parts together. This will melt and flow the solder around the connection of the electronic parts. After cooling down, the solder will be solidified and the electronic parts will be connected.

10 PID Algorithm

10.1 Diagram of PID Algorithm

Below figure shows the diagram of PID Algorithm.

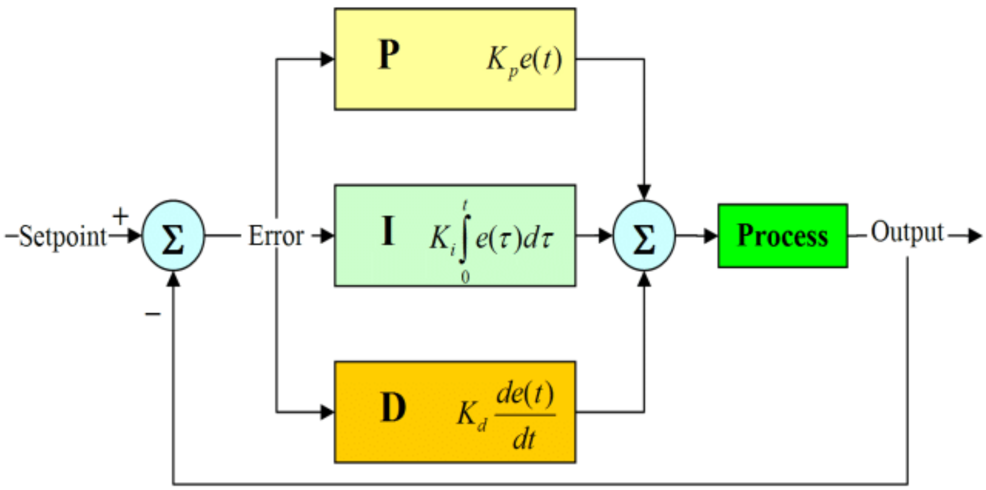

Figure 8: The overview of the `PID diagram`

10.2 Quick information of TC 300 related PID Algorithim

First, TC 300 works in closed loop. This uses feedback control. Therefore, Zieger-Nichols method can be used, and the Cohen-Coon methods can be also used. Theses methods are used whenever the mathematical model of the system is not avaliable. Even though there are more advanced approach, since we have sepcific set point for temperature for this project, and the system is not complicated, manually changing the variable can be the answer. Also, the Zieger-Nichols method works in more structured way as the manually doing it, this method can also be used.

10.3 What is PID Algorithm?

PID Algorithm is the algorithm that is used to control, using the feedback algorithm. P stands for Proportional. I stands for Integral. D stands for Derivative. This is the most common algorithm that is used in the industry because of its simplicity and effectiveness.

- P is used to decrease the rise time.
- D is used to reduced the overshoot and settling time.

- I is used to eliminate the steady-state error.
  – In our project, time it takes to reach the set point is not the most important factor, therefore, we can minimize the overshoot by changing this value.

10.4 Why do we need PID Algorithm?

The temperature controller that we are using has the feature of PID Algorithm. Therefore, we need to get the specific value for the PID Algorithm to get the best result. PID helps us to get the best result for the temperature controller.

10.5 How do we tune the PID Algorithm?

Good news is the PID algorithm is already embedded in the temperature controller, therefore, we don't need to calculate the PID algorithm. However, as this device doesn't have feature of auto-tuning, we need to manually tune the PID algorithm. There are two ways to tune the PID algorithm.
1. Manually changing the value of PID algorithm.
2. Using the Ziegler-Nichols method.
Ziegler-Nichols method is a bit less accurate than the manually changing the value of PID algorithm, but this will provide the reasonable starting point. Therefore, I will use the Ziegler-Nichols method to choose for the starting point, and then manually change the value of PID algorithm for the best result.

10.6 Trial And Error Method

Even though there is a more systmeatic way to tune the PID algortithm, which is Ziegler-Nichols method, I used the trial and error method to tune the PID algorithm. There are few reasons for this. First, the Ziegler-Nichols method is not the most accurate method to tune the PID algorithm.
Second, as on our porject we just aim for 42 degree Celcius, we don't require lots of trials.
Third, as the Ziegler-Nichols method is not the most accurate method, we need to manually change the value of PID algorithm anyways.

Therefore, I decided to use the trial and error method to tune the PID algorithm. And, below part will show what is the PID value I gained for this project.

10.7 Optimal PID Value for this project

Below figures shows the optimal PID value for this termsiter and heater.

As you can see from here, PID value I gained is the following.

- Kp = 0.03

Figure 9: The overview of the `PID value for 42 degree`

- Ki = 0.20
- Kd = 0.01
- Set Point = 42.0 degree Celcius
- Period = 150ms

Now, this is time for validating with the other thermister, and it turns out that this PID value is the optimal value for other thermister that has same beta value, as well.

10.8 Next steps on PID Value

When I operates the experiment, it oscilates from 41.5 degree Celcius to 43 degree Celcius. Therefore, I can adjust the PID value a little bit to remove that uncertainty.

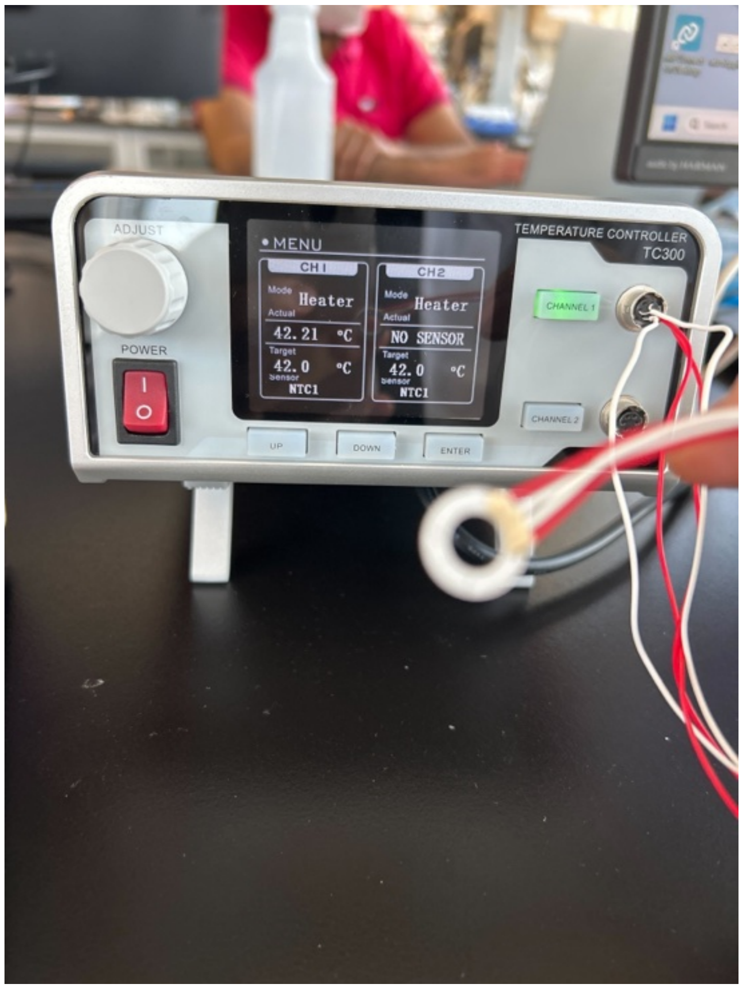

Figure 10: The overview of the `HT10kR1 thermister with the same beta value and PID value`

11 Citation

Figure 8: PID block diagram PID stands for proportional, integral, derivative . . . [1].

References

[1] PID Block Diagram (PID stands for Proportional, Integral, Derivative control) [Online image]. Available: https://www.researchgate.net/figure/PID-Block-Diagram-PID-stands-for-Proportional-Integra [Accessed Jun. 1, 2023].