Electrical Engineering

Capstone Project

Department of Electrical and Electronic Engineering

Final Report

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Project Title:	Smart Thermal Jacket	
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Abstract

The aim of this project is to design a heating and cooling jacket that can heat up to 45°C, cool down to 20°C and have a battery life to last for at least six hours of operation. The jacket's heating and cooling components is entirely electronically based with no chemicals needed to perform heating and cooling.

Different methods for heating have been considered and tested, including using resistance wires, heating fabrics and thermoelectric plates. The advantage of using thermoelectric plates is that they can be used for cooling as well as heating without the use of chemicals.

Temperature sensors are built by using resistors and thermistors. These sensors give acceptable accuracy while having good sensitivity for temperature.

The use of H-bridge is investigated as a switch and controller to supply current to the thermoelectric plates. H-bridge is used because it allows current flow to be reversed.

To allow more precise temperature control on the thermoelectric plate, different rates of cooling and heating is needed. This is done by using Pulse Width Modulation (PWM) to control the base current in the H-bridge by varying the base voltage of the transistor.

PID control is used to complete the feedback mechanism of the heating and cooling modules. It is used to determine the amount of power to be used on the thermoelectric plates to achieve the target temperature.

A user interface is also designed which includes an LCD display, a menu system and buttons for the user to control the functions of the jacket.

A survey is conducted to reflect demands of potential buyers. The jacket was then customised to fulfil satisfy the responses received. Common requests include: being lightweight, waterproof/windproof and to feel comfortable when wearing the jacket. Heating/cooling spots are also placed in locations that are based on the preference of the survey respondents.

List of Figures

List of Tables

Table of Contents

1. Introduction

The idea of a jacket capable to heat and cool itself with electronics components is a highly practical concept. The ability to heat is implicit in a jacket but to generate heat with electronics for extra heat is useful when the user does not want to wear a thick and possibly heavy and uncomfortable jacket. The heating jacket can be highly desirable for people such as skiers who would prefer lighter jackets that can keep them warm, or elderly people who would like to keep warm and not sacrifice mobility or comfort. The cooling function can be used for athletes to cool their bodies after or during exercise. Heating garments are already available on the market. They commonly use resistive wires, such as nichrome wire, to radiate heat and a battery as a power source. Although this design is useful as a makeshift solution to heat body parts up, it has disadvantages such as non-uniform heating, takes too much current to heat up and is uncomfortable on the skin. Part of this project is to find alternative heating sources if available.

Cooling vests are also available on the market, but they normally involve chemicals and soaking the jacket in water in order to cool down the chemicals before usage [1]. This creates a messy process in which the user needs to dry the vest before using and also the user needs to prepare cold water in order to cool down the chemicals. The vest also doesn't have temperature control thus an uncomfortable situation arises when the vest is not cold enough or too cold to use. The project aims to have a cleaner approach for the cooling process with precise temperature control.

With conventional heating jacket, battery typically last around 6 hours and cooling vest effect last around 2 hours. The project aims to match or improve upon this figure. A microcontroller will be used to control how much current will run through the heating and cooling module using PID control to help manage power.

This project will involve investigation into Nichrome wires, Peltier Plates (also called Thermoelectric Plates, both names will be used interchangeably), H-bridge, Pulse Width Modulation, PID control, User Interface and the creation of a commercially viable heating and cooling jacket.

2. Jacket Customization

The jacket needs to be designed such that it can satisfy the demands of the target market. Therefore it is important to customize the jacket appropriately to fulfil customers' need as well as maximizing heating and cooling potential.

2.1 Survey

In order to investigate how to design and customize the jacket, a survey is constructed to understand the demands of potential customers in the market. The survey is constructed via the online survey conducting website "Survey Monkey". [2] The survey is distributed through Facebook and personal blogs for friends and internet surfers to participate. The reason for conducting the survey online is that the survey can be distributed easily on the web and can be done quickly.

Below shows the Survey questions and responses:

<u>Question 1</u>

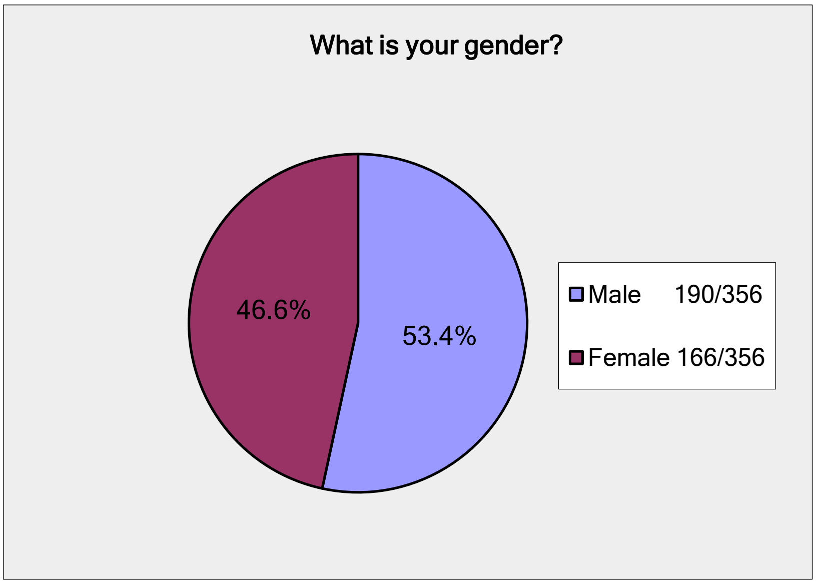

Figure 1: Percentage of Male and Female Participant

The survey respondent's gender is evenly spread therefore minimizes gender bias.

Question 2

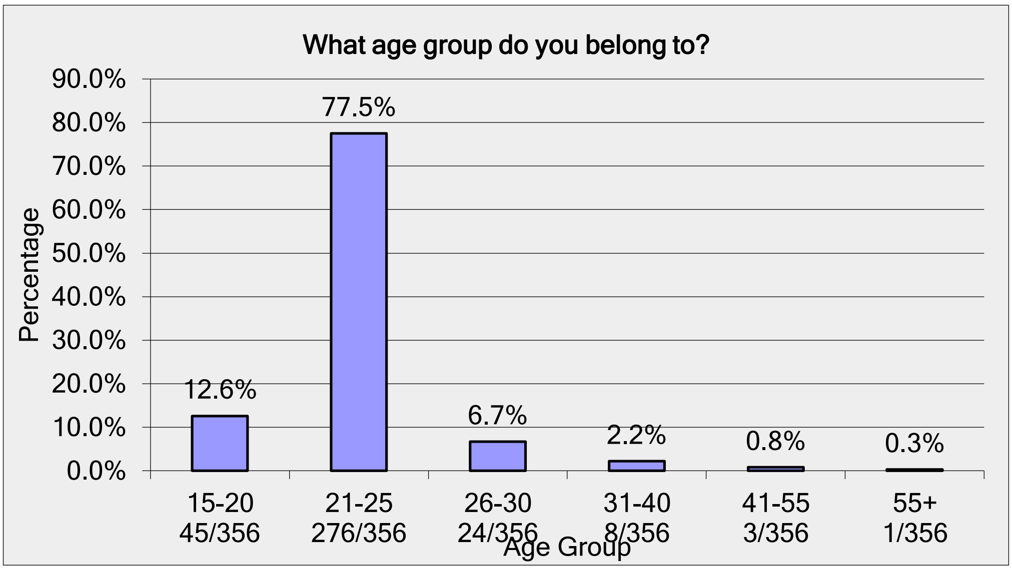

Figure 2: Age Group of Participant

Since the survey is posted online, it is more likely to be completed by the more technology savvy generation. As seen from the graph, volunteers are mostly in younger age group. Most volunteers are from 21 to 25 years old.

Question 3

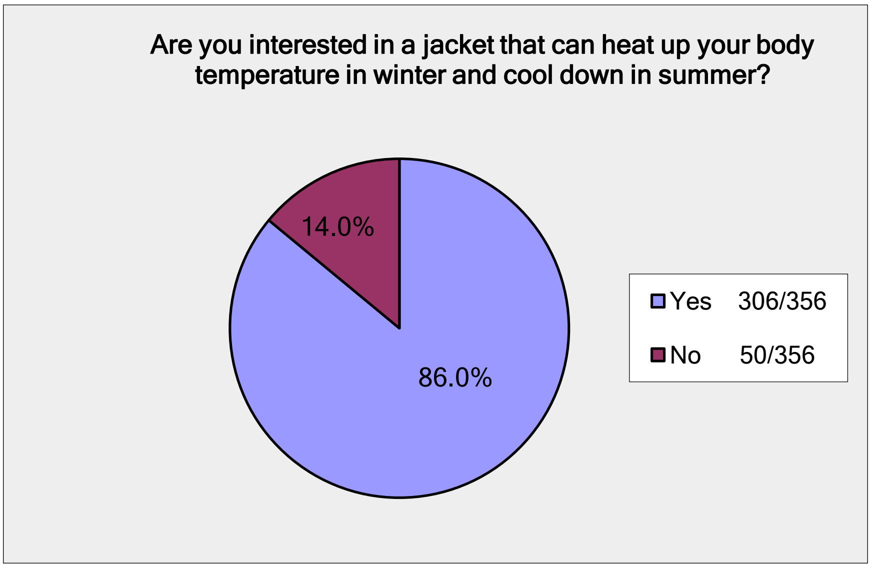

Figure 3: Interest in the Smart Thermal Jacket

It can be seen that there is a need in the market for such a jacket as 86% of the sample population are interested.

Question 4

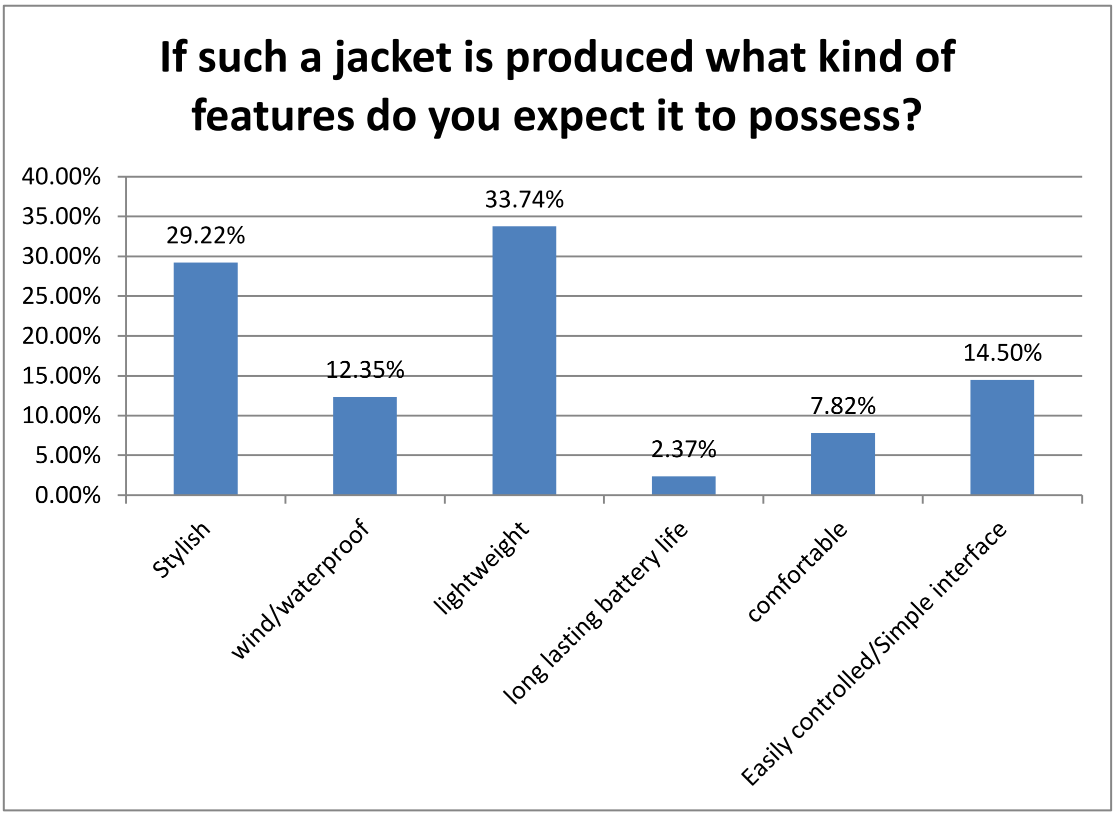

Figure 4: Features Expected by Participant

Despite all the basic functions of the thermo jacket (Heating and cooling), most of the customers in the target market also prefers the jacket to be stylish and lightweight. This result may be biased because most respondents are in the young adult age groups. Viewing from the graph it can be seen that a simple interface and wind/water resistance are also important to customers. The jacket will focus on achieving a simple user interface, long lasting battery life, and lightweight as described in the introduction.

Question 5

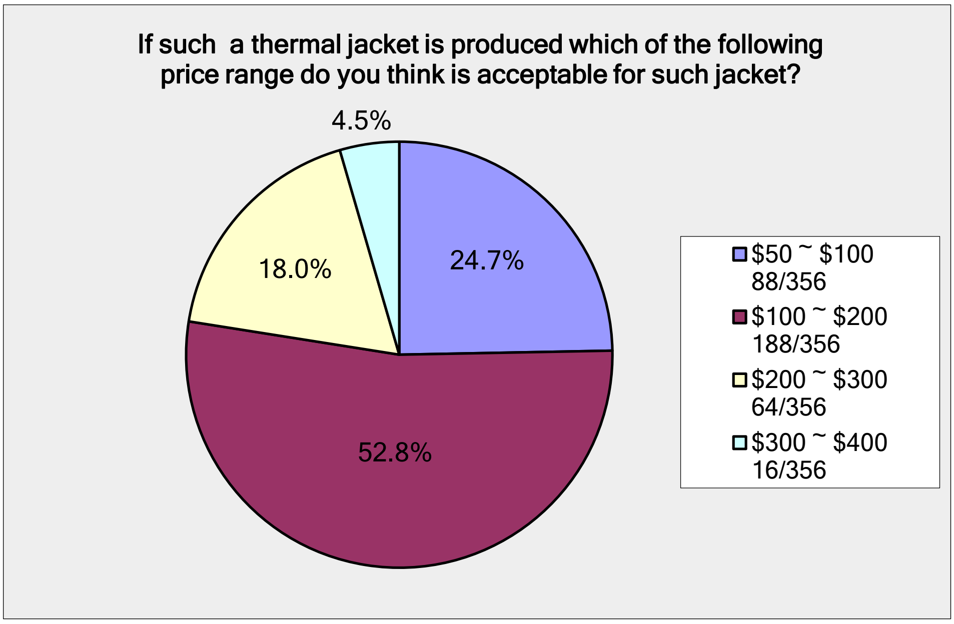

Figure 5: Acceptable Price Range

A majority of respondents would prefer the jacket to be in the price range of $100 to $200 with a roughly even split in preference for prices higher and lower than this range.

Question 6

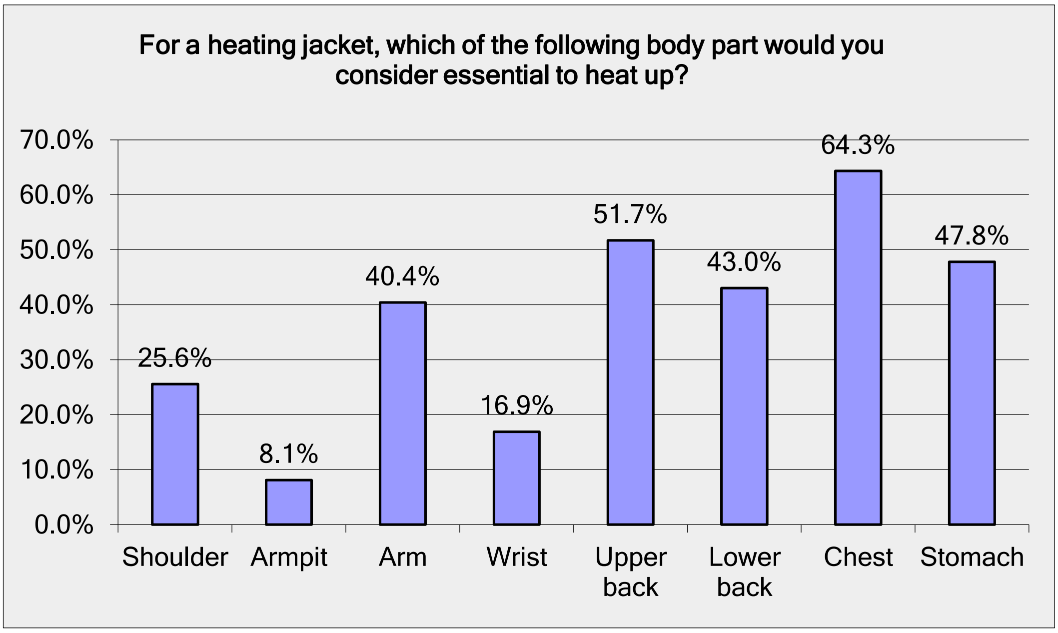

Figure 6: Body Part Participant Considers Essential to Heat Up

Considering budget versus efficiency, six heating/cooling spots are placed in the jacket. Placing more than six spots will drain too much power out of the battery, shortening operating time. Placing less heating/cooling spots will increase operating time, but the heating and cooling effect inside the jacket will be less efficient. Locations to place heating/cooling spots follow the preference of respondents from the survey. There are two spots on the chest, two spots on the upper back and two spots on the stomach. This is also viable from technical standpoint since the spots are where the jacket will be tightest. The jacket is fitted with a tightening rope around the stomach area thus making it possible for user to maximize the effect of heating and cooling on this area.

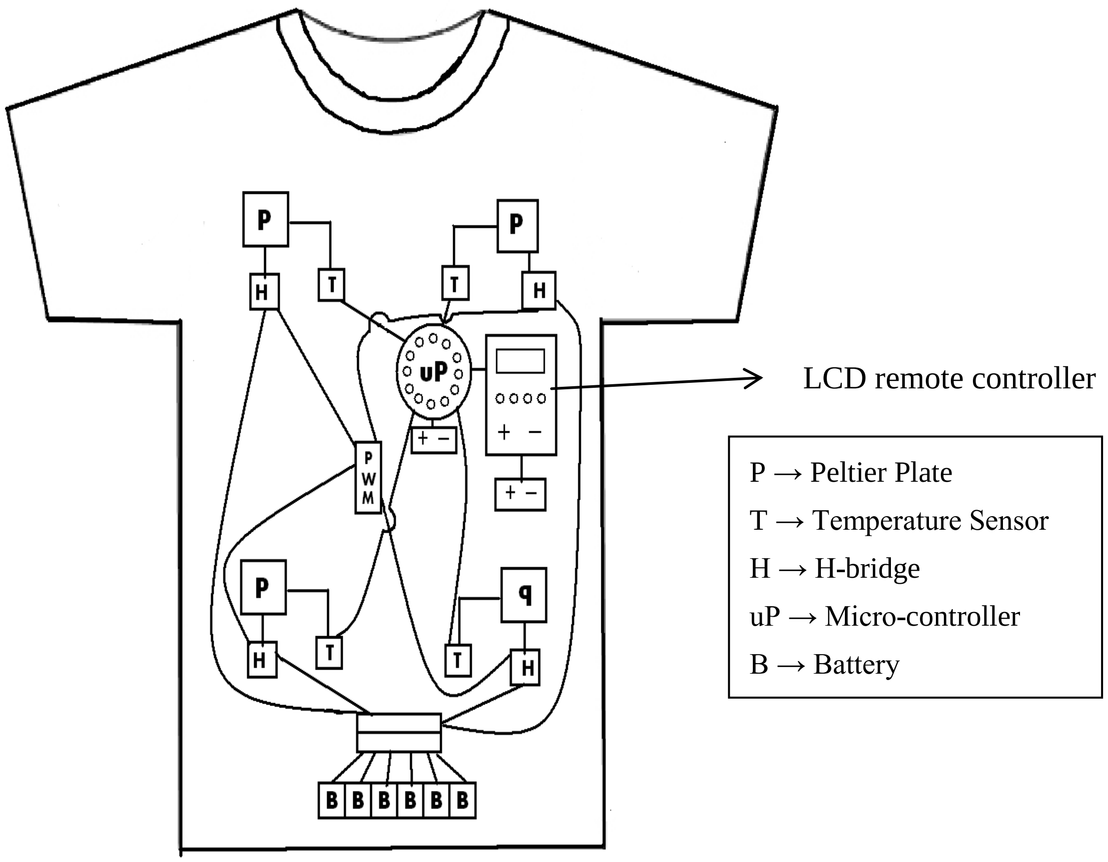

Figure 7: Layout of circuits in the jacket.

Heating/Cooling spots for upper back are not shown in the figure.

2.2 Additional features

A feature that the Jacket should possess is to have tightening rubber at the wrist and stomach. The reason for this rubber is that it will insulate airflow of the outside atmosphere from the inside of the jacket. Another advantage is that it can trap heat inside the jacket to increase heating effect. However, this is disadvantageous for cooling function as heat is not desired to be trapped in the jacket. Therefore zips are needed on top of heating/cooling spots. When a user changes from heating to cooling function, the user should open the zips to allow heat dissipation. This is needed because without such mechanism, the heatsink will not be able to dissipate heat to the outside of the jacket and hence the cooling function will not work. When heating function is used, zips can be closed to maximize heat trap in the jacket.

2.3 Jacket layers

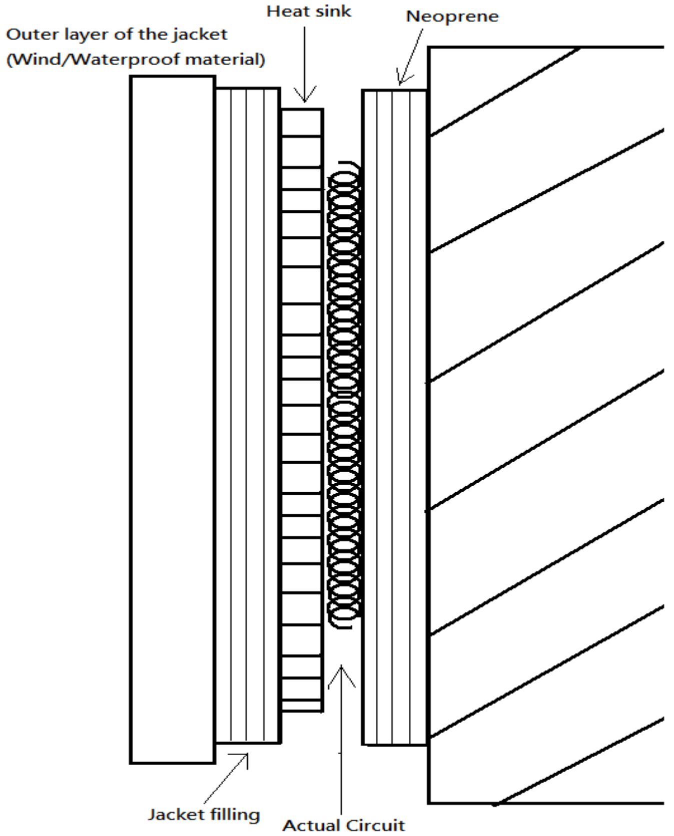

Figure 8: Cross-sectional view of jacket layers

Neoprene is used to enhance heat insulation of the jacket. It is also used to improve water/windproof ability of the jacket. Circuit and heatsink are placed between jacket filling and neoprene to provide circuit with additional wind/waterproof effect. By doing so also brings extra protection to user so user's skin does not touch the circuit directly.

2.4 Putting electronics into the jacket

The PCBs need to be attached strongly to the jacket. The PCBs could be sewed onto the jacket using conductive thread as a conductor medium between all the modules. Although conductive threads will be a more comfortable solution than using wire, it is not practical since it typically has 50Ω/m resistance [3]. Chips like PWM which needs precise logic level to control the transistors in the H-bridge will be badly affected with voltage drops in the conductive thread.

If wires are used to connect all the modules together, a solution is needed to attach the modules in the jacket. This could be achieved by using all purpose glue.

Figure 9: All Purpose Glue Used to Attach PCB and Neoprene in the Jacket

By sticking the PCBs in the jacket using this glue, conductive thread is not needed. Neoprene layer will also be glued on to the jacket as it is not possible to sew a 2mm thick neoprene onto the jacket.

2.5 Final look of the jacket

Figure 10: Interior Lining of the Jacket

Figure 11: Zips on top of the Heating/Cooling Spots to Dissipate Heat

Figure 12: Remote Control of the Jacket

3. Temperature Sensors

In order for the jacket to be able to heat or cool itself to a desired temperature, the current temperature must be measured. In this section we explore different designs of temperature sensors. The thermistor is used as the central device in these designs. A thermistor is a device that varies its resistance depending on the temperature, therefore by measuring its resistance, a temperature can be calculated.

3.1 RC design

In this section the usage of the "RC Design" is observed. The design composes of a resistor and capacitor in series and it will be investigated whether this design will be reliable as a temperature sensor for the jacket.

The goal is to measure temperature using a thermistor, and the beta equation (shown below) can be used to derive temperature from the resistance of thermistor.

Beta equation:

$$R_T = R_o e^{\left(\frac{\beta}{T} - \frac{\beta}{T_o}\right)}$$

Can be rearranged into:

$$T = \frac{\beta}{\ln\left(\frac{R_T}{R_O}\right) + \frac{\beta}{T_o}}$$

R_T is the resistance of thermistor in Ω,

R_O is the resistance at 25° Celsius in Ω,

T_o is 25° Celsius but we must convert it to Kelvin to use it in this equation,

$$T_{Kelvin} = T_{Celsius} + 273.15°$$

Therefore T_o = 298.15° Kelvin

β is a constant which depends on the thermistor being used, this is can be found in datasheet [A1].

R_O = 10kΩ, β is 4100.

Different resistances will cause different times required to charge the capacitor. A curve could be produced for the relationship between different values of resistors with the time required to charge the capacitor. This is done by wiring the circuit as below using a resistor instead of a thermistor. The resistor is then varied while charging time is measured using the Arduino.

The value of capacitor chosen will affect the relationship between the time taken to charge the capacitor and resistance. Although acquiring this relationship does not require a specific capacitance, smaller capacitance is preferred in order to reduce charging time. The faster the time needed to charge, the faster measurements could be taken thus increasing the feedback speed of the system.

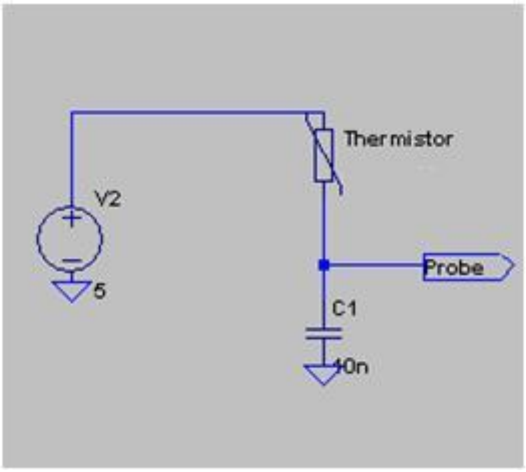

Figure 13: Circuit diagram of RC design

Arduino can be used to measure the time taken to charge the capacitor from digital LOW to digital HIGH. Below is the program to measure charging time.

```
int probe = 7; //Choose digital pin 7 as probe
int supply = 3; //digital supply pin, keep supplying HIGH
unsigned long time_charge;
unsigned long time_elapsed;

void setup(){
  Serial.begin(9600); //This is to show measurement in computer
  pinMode(supply,OUTPUT);
  pinMode(probe,INPUT);
}

void loop(){
  //First need to discharge capacitor
  digitalWrite(supply, LOW);
  delay(1000);
  //Start charging capacitor
  digitalWrite(supply, HIGH);
  //Start counting time
  time_charge = micros();
  //Exit loop only when Capacitor is charged
  while(digitalRead(probe) != HIGH){
  }
  //measure the time again and subtract the starting time
  time_elapsed = micros() - time_charge;
  //print on computer screen the charging time
  Serial.println(time_elapsed);
}
```

It is important to note that the HIGH constant when used as an input is not 5V but 3V.

The delay of 1 second is enough to discharge the capacitor, calculated as follows,

Our biggest resistor will be 14 kΩ and a capacitor of 10 nF is used. Using the formula,

$$\tau = RC$$

$$\tau = 0.14\ ms$$

Time to discharge will be around 5τ which is 0.7ms. Thus the delay of 1s is more than enough to make sure the capacitor has been discharged.

The result from the experiment is:

Resistance Ω	Time charge (ms)
6660	480
7660	554
9320	672
10940	788
11930	856
12920	924
13910	996

Table 1: Charging time with varying resistance

The resistance values are chosen because we want the thermometer to be accurate at around comfortable temperature of 25°C. The resistance of the thermistor at 25°C is 10kΩ, therefore we choose resistor values of around 10 kΩ in order to construct a good model around 25°C.

The resistor values are not precise since they have a tolerance value, thus to be accurate, each resistor is measured by multimeter.

The graph produced by plotting the result is shown below,

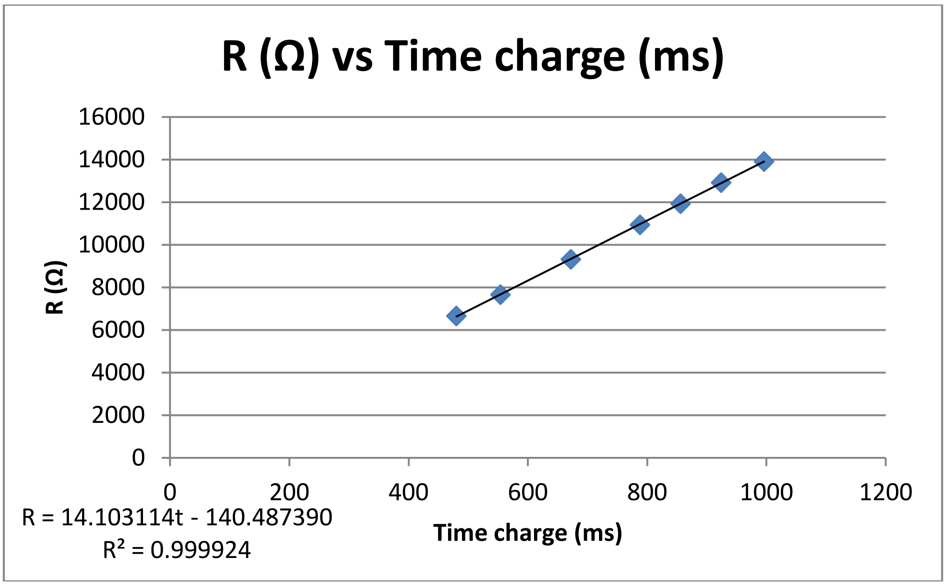

Figure 14: Relationship between Time to Charge Capacitor and Resistance

The plot shows a linear relationship, in which charging time increases as resistance increases. The resulting equation of the trend line is also shown with 6 decimal digits to be accurate. The trend line is a very good fit from the R^2 value of 0.999 which is very close to 1. Using this equation, the unknown value of R_T can be found when a thermistor is exposed to a certain temperature, which in turn allows the temperature to be calculated from the beta equation.

Below is the program to calculate temperature,

```
int probe = 7;
int supply = 3;

                4100
unsigned long time_charge;
unsigned long time_elapsed;
double beta = 3988; //beta constant
double Temp = 0;

void setup(){
  Serial.begin(9600);
  pinMode(supply,OUTPUT);
  pinMode(probe,INPUT);
}

void loop(){
  digitalWrite(supply, LOW);
  delay(1000);
  digitalWrite(supply, HIGH);
  time_charge = micros();

  while(digitalRead(probe) != HIGH){
  }

  time_elapsed = micros() - time_charge;
  Serial.println(time_elapsed);
  //Calculate Thermistor resistance
  Rt = 14.103114 * time_elapsed - 140.487390;
  Serial.println(Rt);
  //Calculate Temperature using beta equation
  Temp = (beta/(log(Rt/10000)+(beta/298.15))) - 273.15;
  Serial.print("Temperature is ");
  Serial.println(Temp);

}
```

The time elapsed and Rt are also printed for debugging purposes.

The constant 273.15 is subtracted from the temperature to convert the temperature back to Celsius as the beta equation gives temperatures in Kelvin.

Now resistor can be replaced with a thermistor in order to create a thermometer. All the configurations such as the reading pin and supply pin remains the same as figure 1 above.

To further evaluate the accuracy of the design, the program is executed for 100s. This timeframe is chosen because the temperature needs to be stable, if the timeframe is too big, there may be a drop or rise in temperature.

The standard deviation is calculated in excel using the formula:

=STDEV(K1:K100)

'K1:K100' is the range of the cells that holds the temperature values.

Calculating the standard deviation gives a value of 0.209. This value will be important later on to compare the precision of the RC design with other designs.

The variation of temperature is shown below,

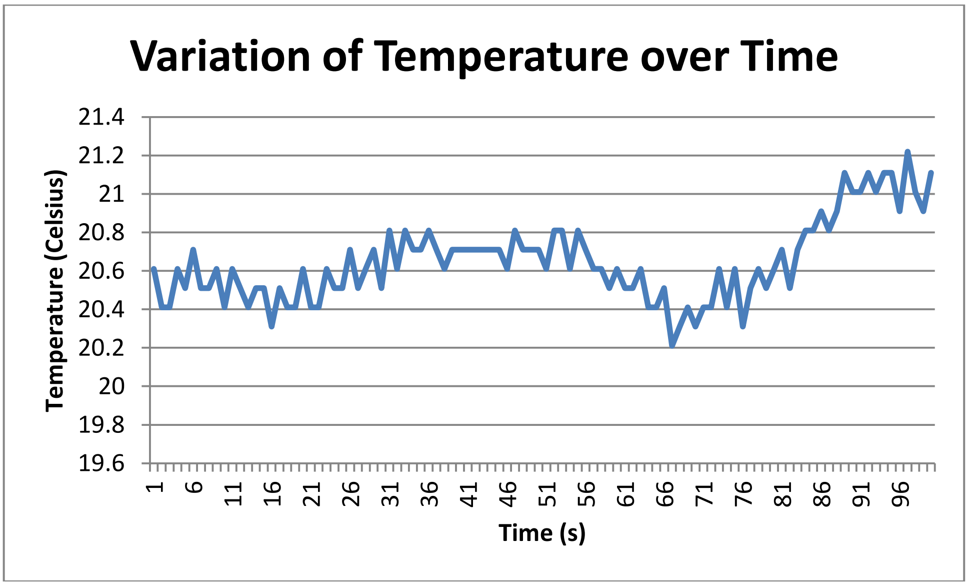

Figure 15: Variation of Temperature over Time for RC Design

This temperature sensor design is accurate enough to about 1°C error as digital thermometer used to measure ambient temperature shows reading of 20 degrees.

3.2 Potential Divider Design

The Potential Divider Design is another design for measuring temperature using the thermistor. It uses a simple potential divider to measure the resistance of a thermistor which in turn can be used to calculate temperature. But before the resistance of a thermistor can be measured, the relationship between voltage and resistance of a thermistor is needed. An experiment is conducted to find the relationship.

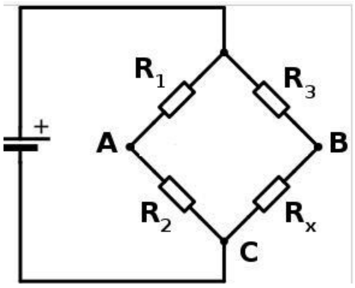

Figure 16: Circuit Diagram for Potential Divider Experiment

This relationship between Rx and Vb can be used to calculate temperature using the resistance of a thermistor.

R1 = R2 = 10kΩ so that $V_A = \frac{V_S}{2}$, Where V_s is supply voltage = 5V.

R3 = 5 kΩ to ensure that $V_B – V_A$ lies in the range of 0-5V which is the range that the analogRead() function in Arduino can measure. Va will be connected to analog pin 3 of Arduino while V_B will be connected to pin 4 in Arduino. Resistances is then varied in Rx to create a curve just like in the last design but this time it is a curve of Vb in the x-axis and Rx in the y-axis. Below is the program for the Arduino to measure Va and Vb.

```
int analogPin = 3;
int val = 0;           // variable to store the value read
int ana_read = 4;
int val2 = 0;
void setup()
{
  Serial.begin(9600);          //  setup serial
}

void loop()
{
  val = analogRead(analogPin);    // read the analog pin 3
  Serial.print("Va = ");
  Serial.println(val);            // Print Va
  delay(1000);
  val2 = analogRead(ana_read);
  Serial.print("Vb = ");
  Serial.println(val2);          //Print Vb
  delay(1000);

}
```

analogRead() function in the Arduino will read the voltage value between the range of 0-5V and map into integer values between 0 and 1023. The resolution will then be 5 volts / 1024 units or, .0049 volts (4.9 mV) per unit. Thus the result shown in the computer must be multiplied with .0049 V to get the actual voltage. The value of Va is measured from analog port pin 3 and Vb is measured from analog port pin 4. Although the delay is not needed as there is no discharging time needed like RC design, the delay helps to prevent flooding of the screen temperature readings.

After varying the resistance Rx from figure 16, the result is as follows:

Rx(Ω)	Vb (v)
5000	2.4892
9033	3.2438
10000	3.3124
11000	3.4153
13333	3.6603
14333	3.7289
15000	3.7436
16000	3.8073

Table 2: Corresponding Vb against Rx

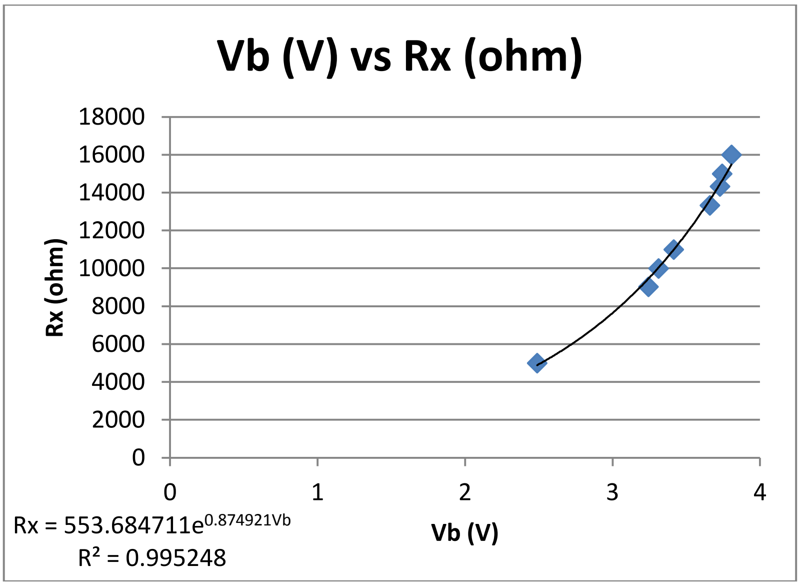

Figure 17: Relationship between Voltage (Vb) and Resistance (Rx)

Exponential trend line gave the best fit for the curve compared to other trend line such as quadratic or linear.

With this equation, Rx can now be replaced in the circuit with a thermistor and the circuit can now be used to calculate the temperature using the beta formula as in the RC design above. The Va value is not needed to calculate value of thermistor resistance, thus the circuit can be simplified as follows.

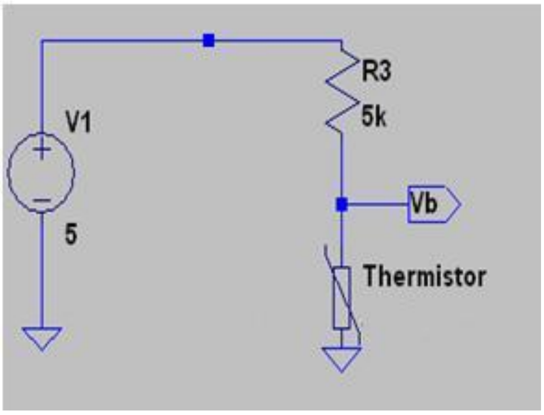

Figure 18: Circuit Design for Potential Divider

Below is the program to measure temperature.

```
int ana_read = 4;
int val2 = 0;
double beta = 4100;
double Rt = 0;
double Temp = 0;
void setup()
{
  Serial.begin(9600);          //  setup serial
}

void loop()
{
  val2 = analogRead(ana_read);      //pin 4
  Rt = 553.684711*exp(0.874921 * val2 * 0.0049);
  Temp = (beta/(log(Rt/10000)+(beta/298.15))) - 273.15;
  Serial.println(Temp);
  delay(250);
}
```

After running this program for 100s, variation of temperature over time can be plotted,

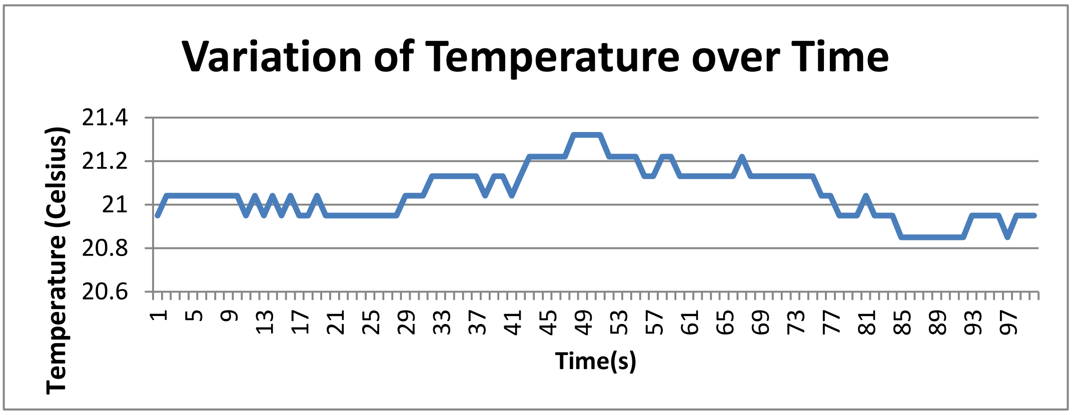

Figure 19: Variation of Temperature over Time for Potential Divider Design

The temperature is around 21 degrees Celsius in a room which digital thermometer shows a 21°. Thus this design is accurate enough.

Using the same method as RC to calculate the standard deviation, this design has standard deviation of 0.12083. Comparing to RC value which is 0.209, this potential divider design gives more precise values as there is less deviation from the mean.

Since this design is more precise, it will be used in the project.

4. Heating Module

Resistance heating or Joule heating is a commonly used technique that uses electricity to raise the temperature of a certain object. The phenomenon was first discovered by James Prescott Joule in 1841 when he realised that a particular length of wire with a current flowing through it, will raise the temperature of the water it is submerged into [4]. He then deduced the relationship between the heat produced, current, length and resistance of the wire. 'Joule Heating' which the phenomenon was named after the discoverer, arises from charge carriers colliding with atoms in the conductor material which transforms the kinetic energy of the charge carrier into heat. After researching for suitable methods for heating the jacket, four methods of resistance heating is observed.

4.1 Nichrome Wire

Figure 20: Nichrome Wire

Nichrome is a metal alloy with 80% Nickel and 20% Chromium with typical resistances of around 110.79 uM/cm [5]. This Nickel alloy is capable of reaching 50°C with a 20V voltage source within a 30 second time interval [6]. Although the required voltage is high for the purpose of a heating jacket, the heating time and temperature is suitable for the aim of the project. Another advantage of Nichrome wire is that it has a high melting point of around 1400°C [5] which virtually eliminates the risk of melting the heating element in the jacket.

4.2 Testing of Nichrome Wire

In order to test the suitability of Nichrome wires in our jacket, an experiment was conducted. The experiment includes 2 different Nichrome wires which have different resistance at equal length as a result from having different diameters. Wire A has diameters of 0.315mm [7] and wire B has 0.46mm [8], given by the manufacturers. The first experiment is to determine which wire needs less power to reach a higher temperature. Resistance of the wires at 1m was recorded. Using a multimeter, wire A was found to be 14.4Ω while wire B was at 7.8Ω. Resistance is proportional to length, the longer the wire, the higher the resistance. The higher the resistance, the more power required to heat up the wire. Therefore the length of the wire must also be considered to find the most suitable wire/wire length to be used in the heating jacket. Vs will then be varied to see the effect of varying voltage to temperature of wire.

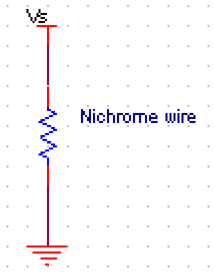

Figure 21: Circuit Diagram for Nichrome Experiment

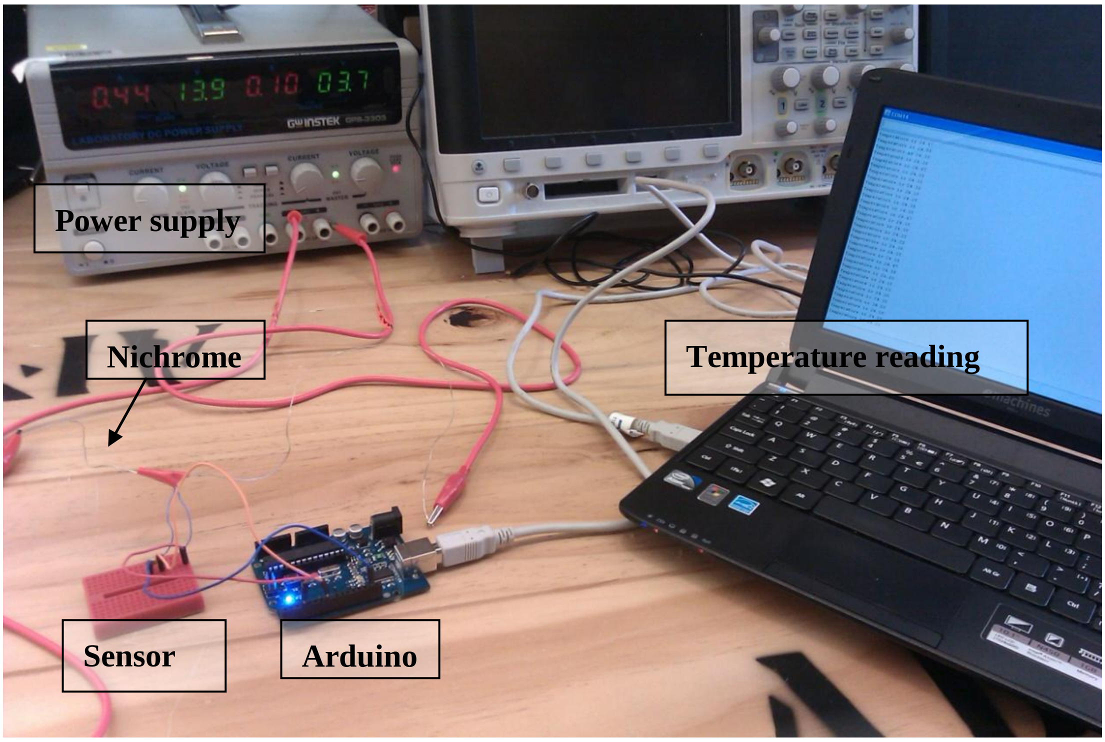

Figure 22: Nichrome Wire Experiment Configuration

The temperature sensor built in the previous section is used to measure the temperature of wire A. The thermistor is attached using electrical tape to wire A. The voltage and current is varied to see the effect to the temperature on different lengths of wire A. Temperature reading is taken every 3 minutes.

Length = 2m	R = 28.8Ω		Length = 1m	R = 14.4Ω	
Voltage (V)	Current (A)	Temperature (C°)	Voltage (V)	Current (A)	Temperature (C°)
0.00	0.00	25.30	0.00	0.00	26.00
1.00	0.03	25.50	1.00	0.07	26.30
3.70	0.13	25.50	3.70	0.26	27.27
5.00	0.17	26.50	5.00	0.35	28.84
7.40	0.26	28.00	7.40	0.51	30.23

Length = 0.5m	R = 7.2Ω	
Voltage (V)	Current (A)	Temperature (C°)
0.00	0.00	26.20
1.00	0.14	27.50
3.70	0.51	30.80
5.00	0.69	44.98
7.40	1.03	70.00

Table 3: Temperature Result with Varied Voltage

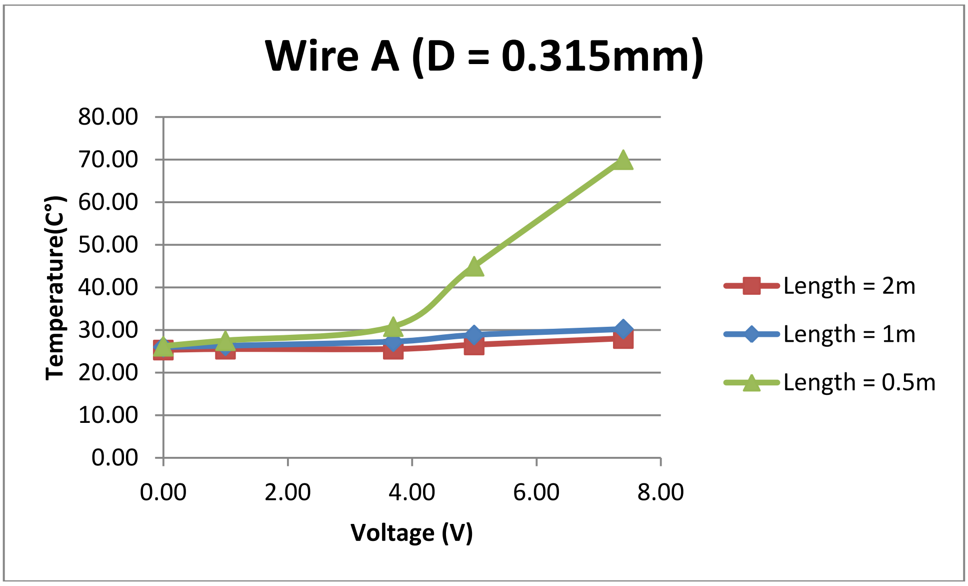

Figure 23: Plot of Wire A Temperature Given Varying Voltage

Wire B follows the same experiment configuration as Wire A. Refer to figure 21 for circuit diagram and figure 22 for experiment set up.

Length = 2m	R = 15.6Ω		Length = 1m	R = 7.8Ω	
Voltage (V)	Current (A)	Temperature (C°)	Voltage (V)	Current (A)	Temperature (C°)
0.00	0.00	25.50	0.00	0.00	26.24
1.00	0.06	25.75	1.00	0.13	27.13
3.70	0.24	26.24	3.70	0.47	29.94
5.00	0.32	27.40	5.00	0.64	43.58
7.40	0.47	28.36	7.40	0.95	68.49

Length = 0.5m	R = 3.4Ω	
Voltage (V)	Current (A)	Temperature (C°)
0.00	0.00	25.72
1.00	0.29	34.72
3.70	1.09	55.26
5.00	1.47	74.30
7.40	2.18	85.68

Table 4: Temperature Result for Wire B for Varying Voltage

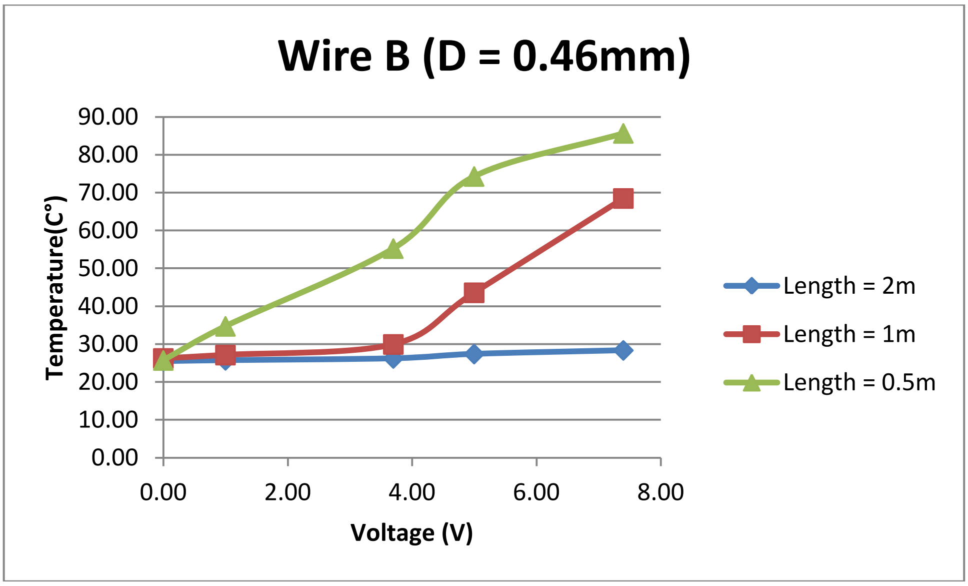

Figure 24: Plot for Wire B Temperature with Varying Voltage

From both experiments, one can see that wire B reaches higher temperature with less power this is an important factor since it conserves battery power. As the project aims for a maximum of 45°C, this means the temperature achieved with wire B is more than enough for heating the jacket. Wire B of length 1m and 2m does not reach temperature of at least 40ºC, therefore 50cm length is the most suitable. Length shorter than 50 cm is not considered as the nichrome wire will get too hot. It is also not long enough to effectively cover a section of the body.

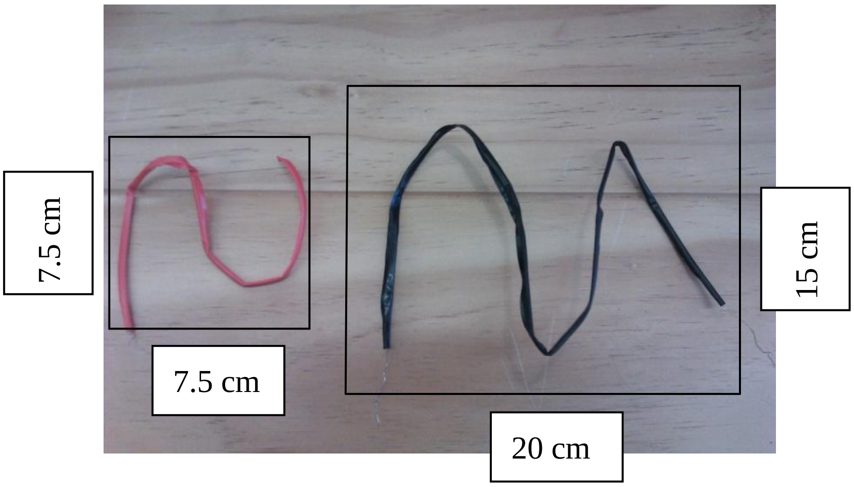

Figure 25: Area of Nichrome Wire

To ensure safety from electrocution, the nichrome wire has to be insulated. Electrical insulating tape was used for this purpose. A multimeter is used to measure the resistance of the insulated wire and it failed to show any resistance when the dial is at 200MΩ which is the maximum resistance it can measure.

Figure 26: Resistance Exceeds 200MΩ

Therefore the insulated tape has resistance much bigger than the megaohms region. Human perceive electric shock at around 1mA while current of around 70mA to 200mA is enough to make the heart fibrillate [9]. In order to show how safe the electrical insulating tape is we do a simple calculation. To be conservative, take the resistance of the insulated wire to be 200MΩ.

$$V = 3.7V$$

$$R = 200M\Omega$$

$$I = \frac{V}{R} = \frac{3.7}{2 \times 10^8} = 18.5nA$$

$18.5nA$ is negligible when compared to 70 mA, which is the current that would possibly stop the human heart. It is also much less than 1mA, which means the user will never feel any shock [10].

The next experiment is measuring the time it takes to heat the wire up to 40°C from ambient temperature and the time it takes to cool down back to ambient temperature. This heating up and cooling down time must be in a reasonable range to be used in the jacket. The period range required for this project is roughly under 3 minutes.

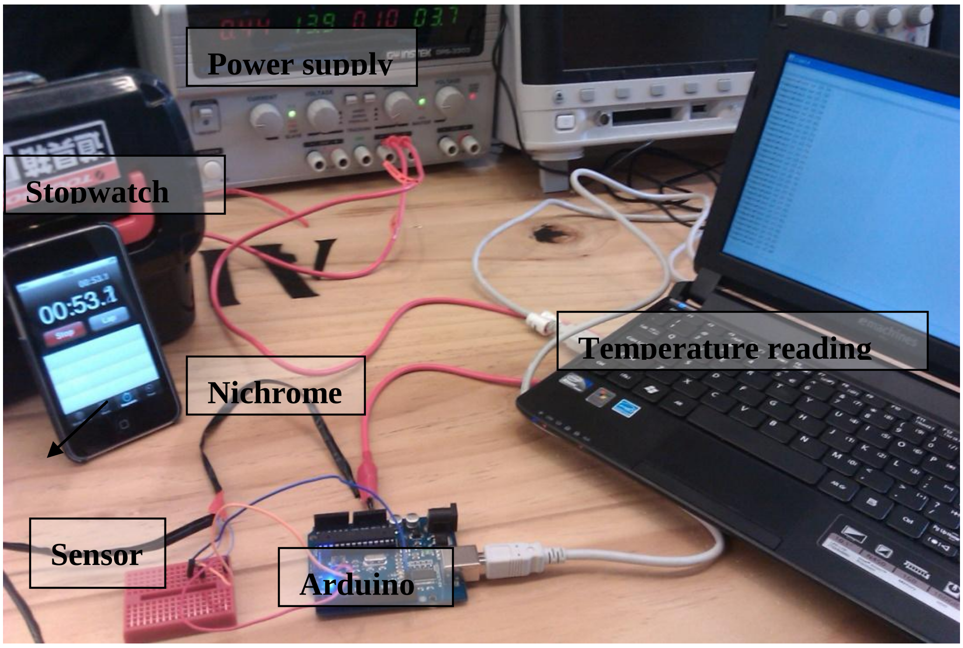

Figure 27: Measuring Heating Up and Cool Down Time

Voltage (V)	Current (A)	Heating/Cool down	Time(s)
3.7	1.2	Heat	50.9
3.7	1.2	Cool down	95.2

Table 5: Heat Up and Cool Down Time

Heating is time is the time it takes to heat from 23°C to 40°C while cool down time is the time taken to drop from 40°C back to 23°C.

The insulated wire up heats to 40°C in 50.9s and cools down in 95.2s. This is within acceptable range, thus this nichrome wire is a viable solution as a heating element in the jacket.

4.3 Heating Fabric

Resistive heating material could be woven onto a fabric or a nonwoven material made by conductive polymer [A2]. The main advantage of heating fabrics is that it has uniform heating, the whole fabric heats up evenly. Another advantage is that heating fabric is soft like a normal fabric [A2] therefore it is desirable in a jacket where comfort is needed. The heating fabric could be layered into the jacket and connected to a power source to produce uniformly distributed heat while being comfortable to wear.

Heating fabric was ordered from a company based in France called Tibtech [11] and the fabric chosen is a model called Tibgrid Duo95 with length of 1 metre.

Figure 28: Heating Fabric

The Tibgrid Duo95 has two sets of wires running parallel across the fabric.

The next experiment involves connecting the wires in parallel to reduce the resistance and maximise heating potential. Vs is then varied to see the effect on temperature.

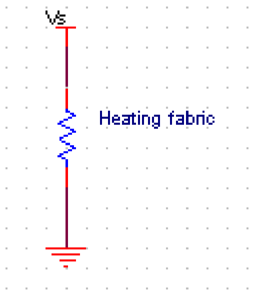

Figure 29: Circuit Diagram for Heating Fabric Experiment

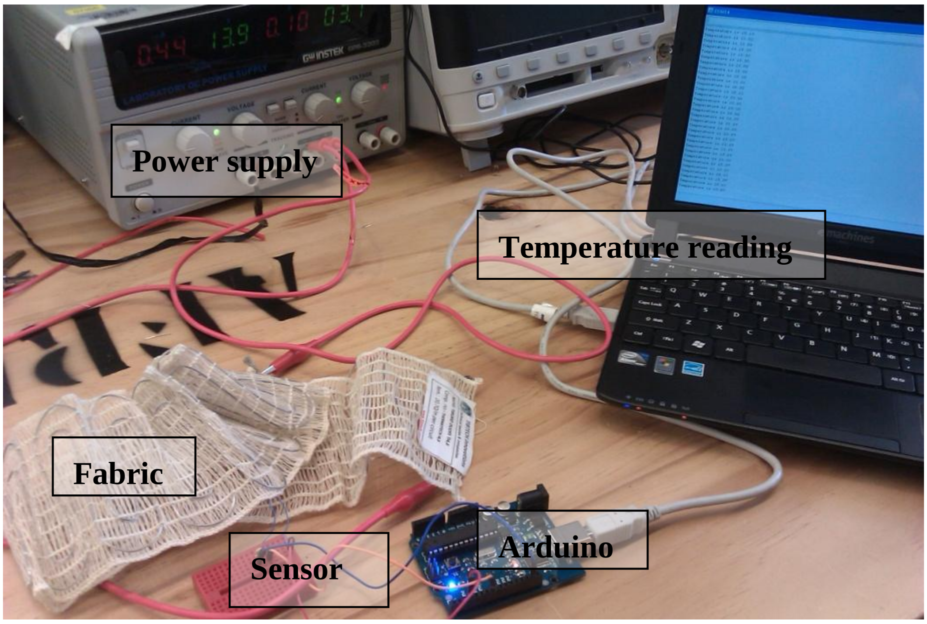

Figure 30: Experiment Set Up for Heating Fabric

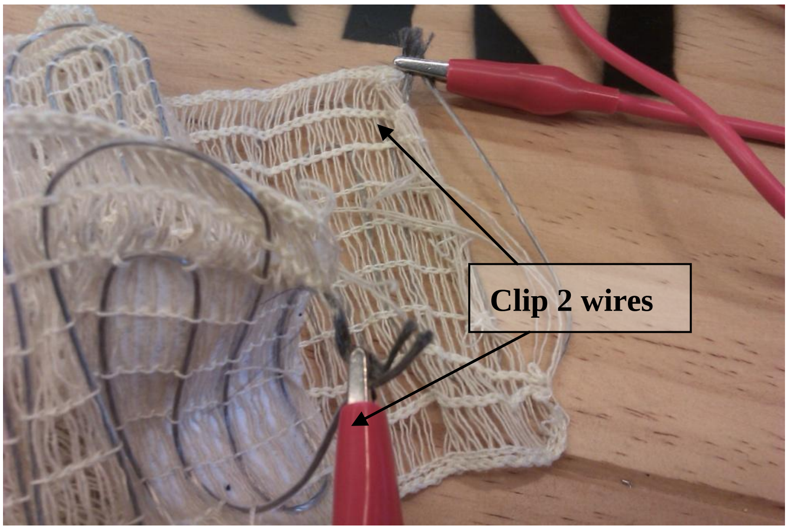

Figure 31: Clipping Heating Fabric Wire in Parallel

Below is the result of the experiment conducted with 1 metre length of heating fabric. Resistance is 20.8 Ω for each wire measured using a multimeter. Therefore if both wires are connected in parallel, equivalent resistance is 10.4 Ω.

Voltage (V)	Current (A)	Temperature (C°)
0.00	0.00	22.50
1.00	0.10	22.56
3.70	0.36	26.13
5.00	0.48	30.60
7.40	0.71	40.78

Table 6: Temperatures of Heating Fabric with Varying Voltages at 1 Metre Length

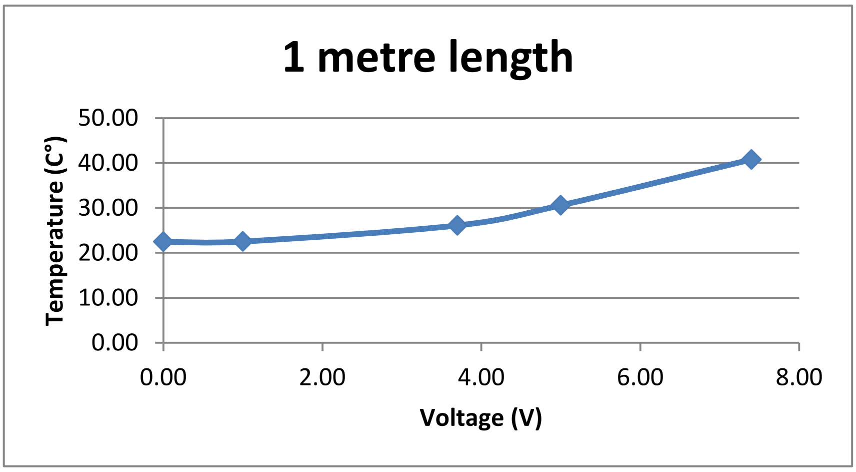

Figure 32: Temperature Plot against Varying Voltage for 1 Metre

Below shows the results of the experiment conducted with approximately 0.5 metre length of heating fabric. Resistance is 10.8 Ω for each wire measured using multimeter. Therefore if both wires are connected in parallel, equivalent resistance is 5.4 Ω.

Voltage (V)	Current (A)	Temperature (C°)
0.00	0.00	22.50
1.00	0.19	22.83
3.70	0.69	29.15
5.00	0.93	35.70
7.40	1.37	52.40

Table 7: Temperatures of Heating Fabric with Varying Voltages at 0.5 Metre Length

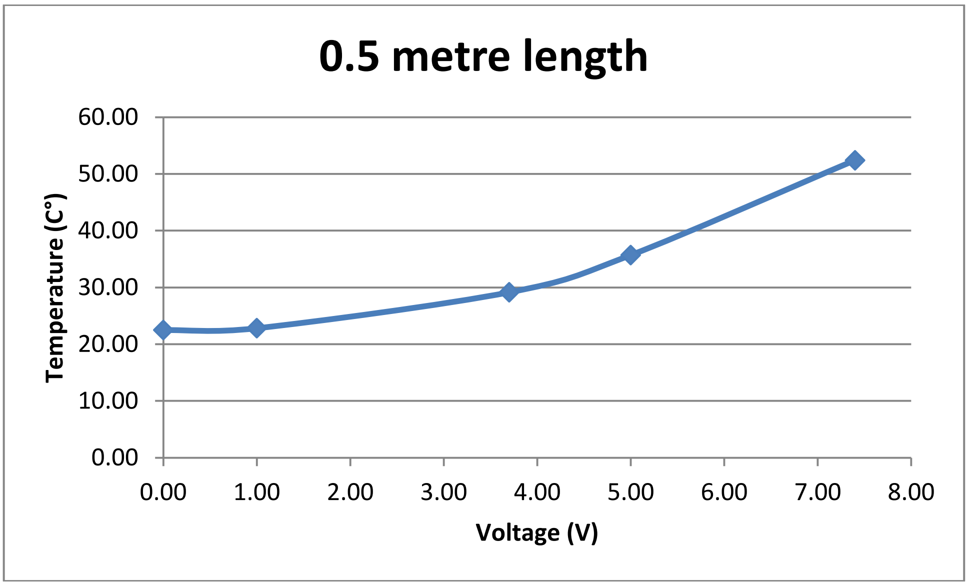

Figure 33: Temperature Plot against Varying Voltage for 0.5 Metre

From the result, one could see that it takes a larger voltage to heat the heating fabric into the range of 40°C. 7.4V is needed for 1 metre length and around 6V for 0.5 metre length. As the project aims to achieve maximum battery life, with low power requirements, heating fabric does not suit the purpose. Although shortening the length of the fabric may help with reducing resistance, as discussed in the nichrome section, length shorter than 0.5 metres would not cover enough area for a section of the body which will prompt the need of more heating modules therefore increasing the amount of power needed to heat the jacket.

4.4 Peltier plate

The Peltier effect was discovered by Jean Charles Athanase Peltier in 1834 [12]. This effect explains the phenomenon when junctions of dissimilar metal, either heats up of cools down depending on the direction of the electric current.

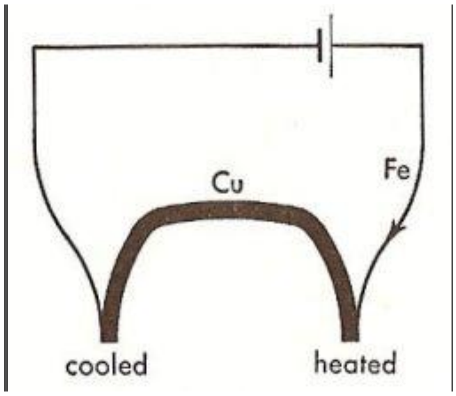

Figure 34: Diagram of 2 Metal Junctions [13]

Peltier effect is commonly used in a Thermoelectric or Peltier plate configuration [14]. The plates incorporate an array of p-n semiconductor junction. Below is a diagram of a pair of junction, note that in one Peltier plate there may be hundreds of these pairs depending on the size of the p type and n type material and the size of the plate.

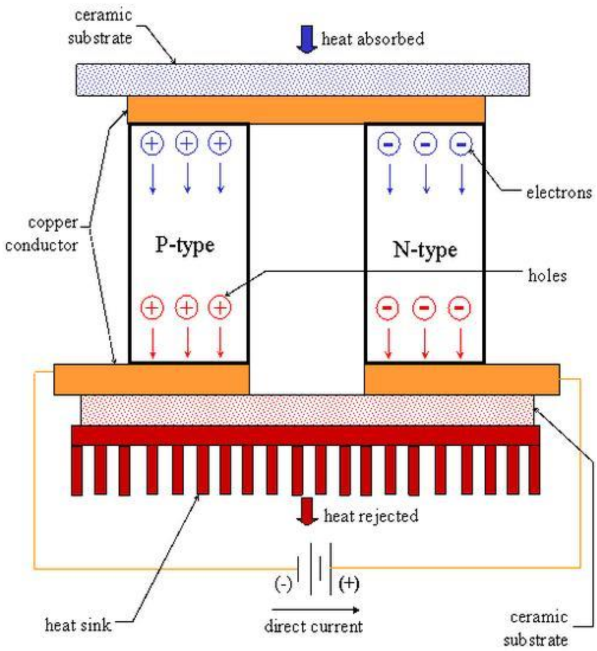

Figure 35: Diagram of a Thermoelectric Plate [15]

The battery creates a potential difference in the system which lets P-type side to have lower potential energy than the N-type. Electrons (major charge carrier in the N-type) go through the copper plate and battery and then recombine with lower energy level of holes in the P-type material. After the recombination of electrons with the P-type holes, electrons releases energy in the form of heat thus the plate is hot on the bottom side.

In order for a circuit to be completed, electrons must flow from the P-type towards to N-type via the top plate. Since the P-type materials don't have much free electrons to give up it must absorb energy to free electrons within its molecular structure. This energy is absorbed from the surrounding environment and in effect 'cools down' the top ceramic plate. When the battery polarity is reversed, the top plate will be hot while the bottom plate will be cold following the same process as above but in reverse direction.

Peltier plate provides a safe and compact heating method. The ceramic plates are non conductive therefore will not shock the user if direct contact is made. A low power Peltier plate can possibly be used in the jacket, since 3V to 4V could possibly generate heat on the hot side of around 50°C [A3].

An experiment is conducted using the same method as testing the nichrome and heating fabric by varying Vs and taking note of the temperature. The thermistor is attached to the hot side via electrical tape.

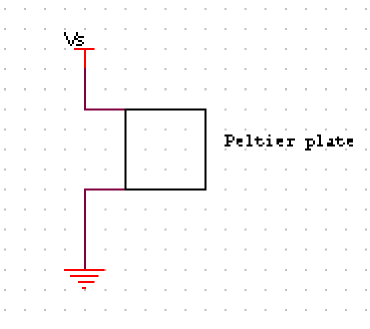

Figure 36: Peltier Plate Experiment Schematic

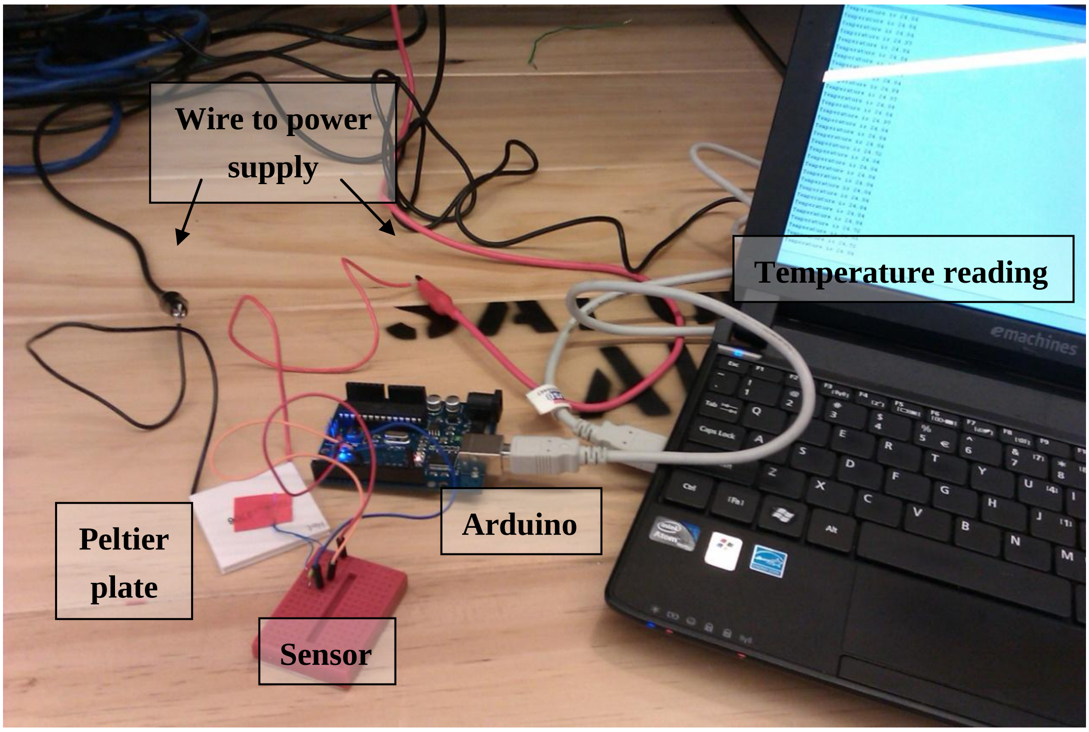

Figure 37: Peltier Plate Experiment Set Up

Voltage (V)	Current (A)	Temperature (C°)
0.00	0.00	24.84
1.00	0.28	30.11
1.5	0.4	39.45
2.00	0.53	44.01
2.50	0.62	49.37
3.00	0.73	58.74
3.70	0.87	63.42

Table 8: Result of Peltier Plate Heating Experiment

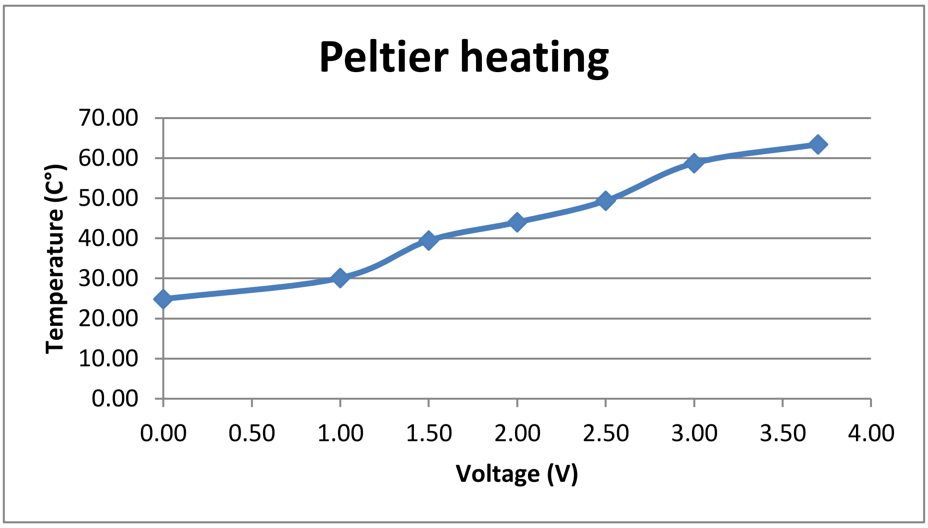

Figure 38: Plot of Peltier Plate Temperature against Voltage

The Peltier plate is able to heat up to 63.42°C with 3.7V, it is clearly a suitable choice for the jacket. Another test is conducted to find the heating time for the Peltier plate. Experiment set up is the same as the nichrome wire experiment.

Voltage (V)	Current (A)	Heat up/Cool down	Time(s)
3.7	0.9	Heat up	42.3
3.7	0.9	Cool down	51.3

Table 9: Heat Up and Cool Down Time of Peltier Plate

Heating time for the Peltier plate is 42.3s which is much lower than required heating time of 2-3 minutes. The cooling down period is under 1 minute therefore Peltier plate is another suitable heating module choice besides nichrome wire.

4.5 Comparisons of the Heating Methods

Heating module	Comfort ranking	Uniform ranking	Power ranking
Nichrome	2	3	2
Fabric	1	2	3
Peltier	3	1	1

Table 10: Comparison Between 3 Types of Heating Methods

Heating fabrics are the most comfortable heating module compared to nichrome wires and Peltier plates as it is very soft. Although it has a good uniform heating, there are still some hotspots. It also consumes more power compared to the other 2 modules (6V for 40°C).

Although nichrome wires is more comfortable than Peltier plates, which has hard ceramic plates, it consumes more power to heat up to 40°C (2V) while the Peltier plate only needs approximately 1.5V to heat up to 40°C. Another advantage using Peltier plate is that it can be used as a cooling module. Although it is possible to use nichrome as heating module while using Peltier plate as cooling module, it will take more space in the jacket which would make the jacket denser and harder to move around in.

Judging from the criteria discussed above, Peltier plate was chosen be used as heating the module.

5. Cooling Module

As the aim of the jacket is to create a dual functioning heating and cooling jacket, Peltier plates fit the specification as it could both heat and cool. If different heating and cooling module is used, this will complicate the wiring and take up more space. Peltier cooling has been used commonly in cooling CPUs on high performance desktop computers and USB drink coolers. Peltier cooling has also been used as a cooling system in helmets [16] and hospital therapy pads [14]. Peltier cooling is popular because of its ability to operate at low voltages [A3], have no chemical emissions, small in size and weight and strong against compression stress. As the only stress that could be repeatedly applied to the jacket by the user is compression stress, the Peltier plate provides a durable solution for heating and cooling. The disadvantages of the Peltier plate are low heat transfer efficiency and the need for a heatsink. Heatsink is needed because the second law of thermodynamics states that heat transfers from hot surface to a cold surface, therefore the heat from the hot side of the plate will transfer to the cold side thus negating the cooling effect. The experiment below shows this effect.

The experiment configuration follows the Peltier heating experiment but instead of measuring the hot side of the plate, the temperature of the cold side is recorded. Just like the heating experiment, the temperature sensor measures temperature over time and the data is presented in the graph below. Refer to figure 36 and figure 37 for circuit diagram and setup. The Peltier plate is left to cool for certain time with a current of 0.5A for first run and 0.75A for second run.

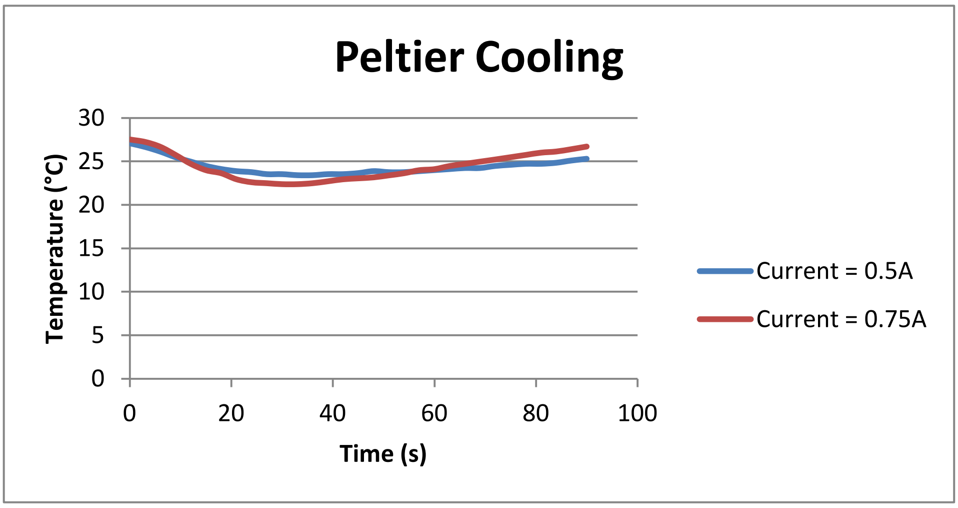

Figure 39: Peltier Temperature after a Certain Time

Without a heatsink, temperature of the cold side goes back to ambient temperature after 80 – 90s. Increasing the current does not help as temperature bounces back quicker. Using a lower current results in higher minimum temperature. Both current values could not achieve requirement of 20°C.

An experiment is needed to find the ideal current for cooling the plate while using the pin heatsink. Refer to figure 36 for circuit diagram.

Figure 40: Pin Heatsink (HH8580) [17]

Size: 21x21x6.2mm [17]

Thermal Resistance: 5.9 deg C/W

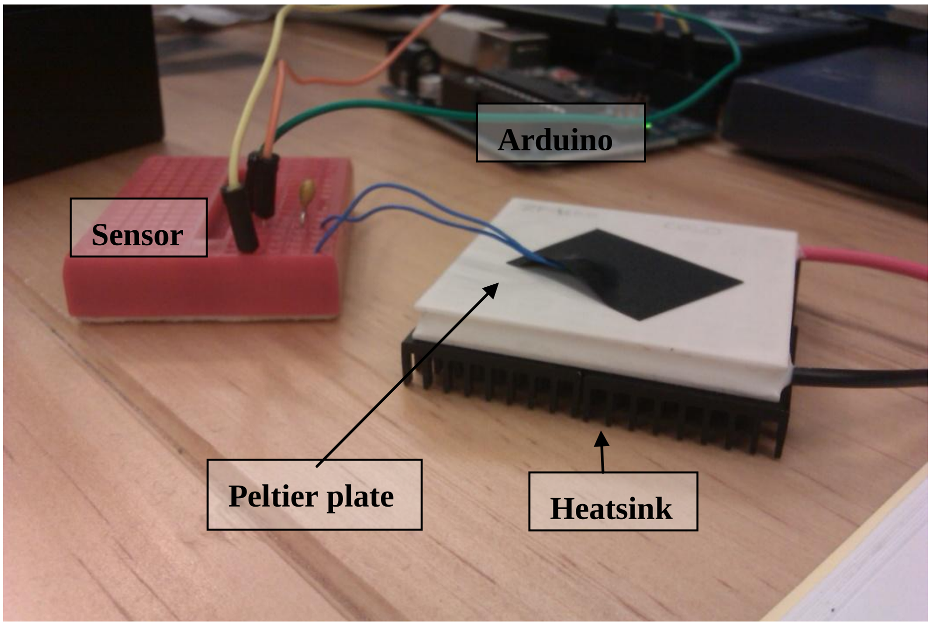

Figure 41: Experiment Set Up for Heatsink

The setup uses the 4 pin heatsink and the temperature of the cold side of the plate is measured using temperature sensor over time.

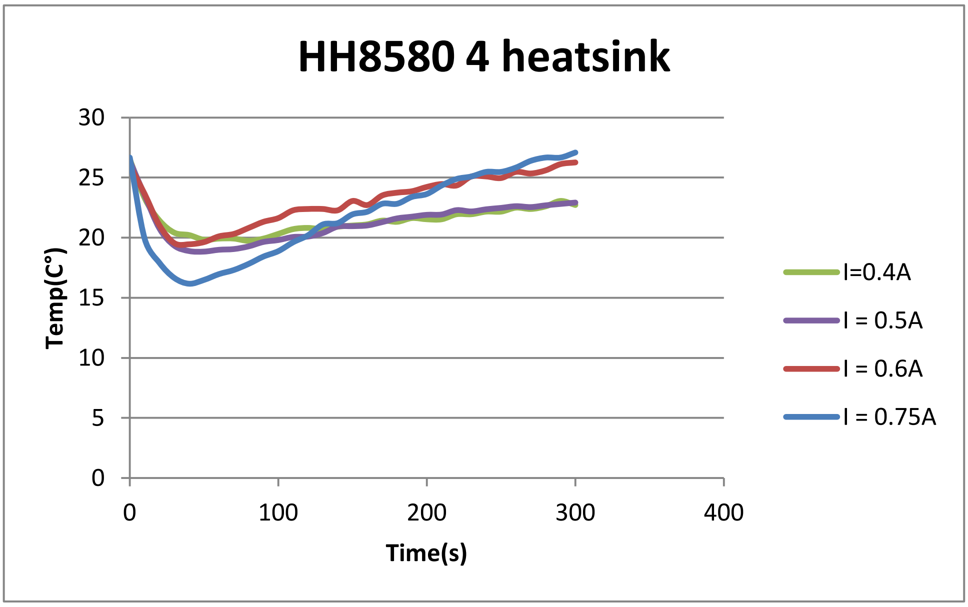

Figure 42: Plot for 4 Heatsinks Experiment with Varying Current

From the graph, it can be seen that either 0.5A or 0.4A is ideal for current on the plate since the temperature does not return to higher values. 0.5A was chosen as it gives less minimum temperature. Although it reaches the same temperature as using 0.4A, a lower temperature could possibly be achieved with the use of a superior heatsink.

Below is an experiment to measure the effectiveness of using 2 heatsinks instead of 4 heatsinks. This measurement is important as it demonstrate whether it is possible to reduce the area of heatsink to make the jacket less dense, lighter and more comfortable.

Another heatsink is also tested, this time using fin heatsink while comparing it with previous pin heatsink. Experiment setup is the same as previous experiment but this time only a 0.5A current is used.

Figure 43: T0-220 (fin/HH8516) Heatsink [18]

Size : 16 (H) x 16.5 (W) x 22mm(D) [18]

Thermal resistance : 19° C/W.

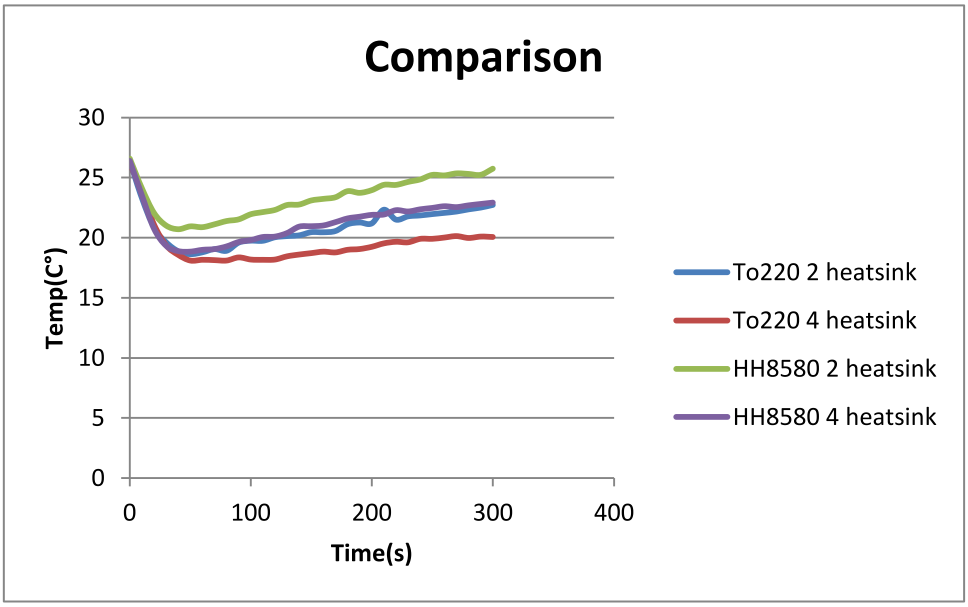

Figure 44: Heatsink Temperature Comparison Over Time

The result demonstrates that using 4 heatsinks is essential as it gives around 3°C difference in the case of fin heatsink. If only 2 heatsinks are used, it would not meet the design requirements. Despite having much lower thermal resistance, pin heatsinks performs more poorly than fin heatsinks. This may be caused by the fact that the fin heatsinks have a larger surface area.

Now that the ideal current and amount of heatsinks is known, more tests can be done by extending testing time to see the real temperature limit and testing 2 other heatsink designs.

Figure 45: 6021 (HH8504) [19] & T0-3 (HH8510) [20] Heatsink

Thermal resistance are 12°C/W [19] and 5°C/W [20]

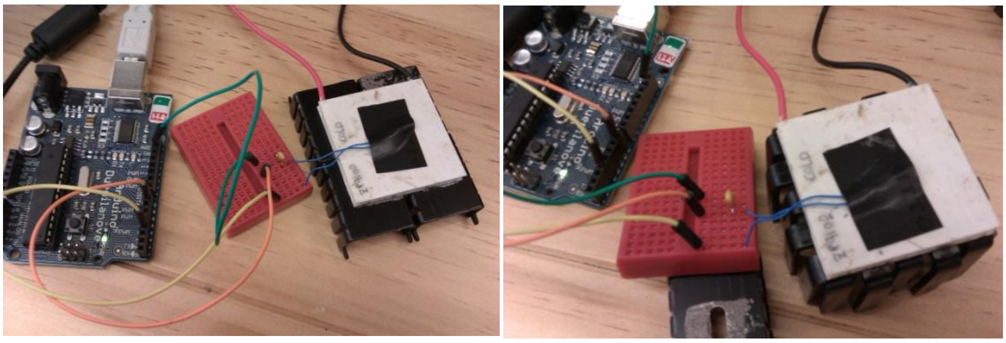

Figure 46: Experiment Setup for Heatsinks in Figure 45

This follows the same wiring as previous heatsink experiment, the only difference being the choice of heatsink.

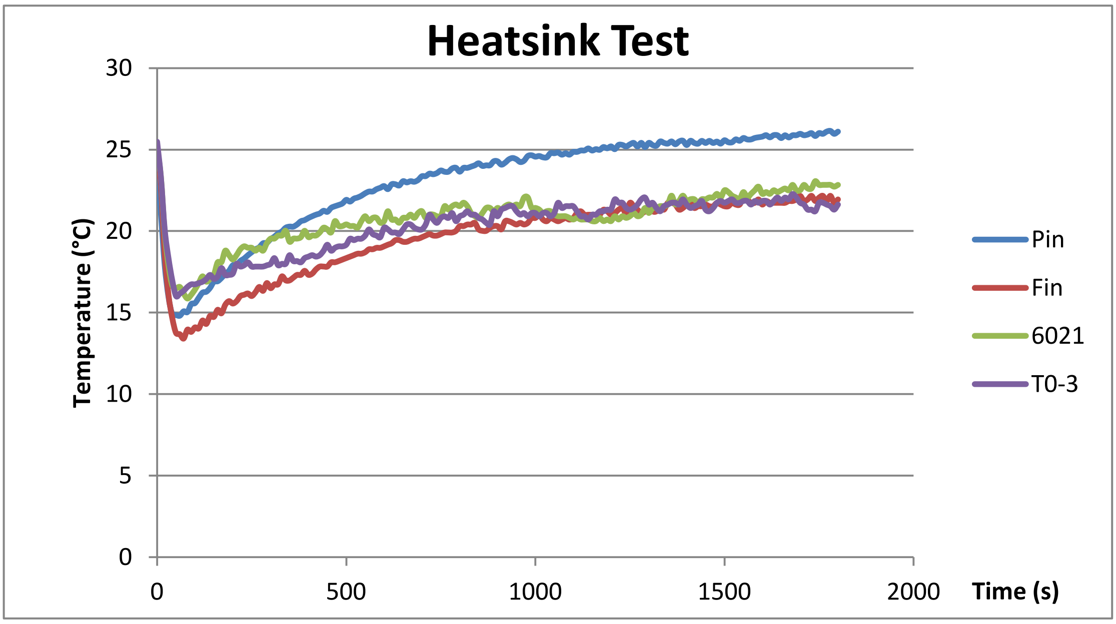

Figure 47: Comparison of Heatsink Temperature Over Time

The result shows that the fin and T0-3 heatsink achieves around 22°C temperature limit while 6021 heatsink is around 1°C above this point. As the size of the T0-3 is too big, it is not practical to use it in the jacket, thus fin heatsink is chosen as it also has lower minimum temperature than the 6021 heatsink. Fin heatsinks satisfies the project aim of 20°C.

6. Power

6.1 Selecting Power Source

For the jacket to be practical it needs to be light and be able to function as long as possible. A jacket that is connected to a bench top power supply or main power supply is neither portable nor practical. A viable solution for power source for the jacket is by using battery. Below is comparison of different type of batteries.

Technology	Energy density	
	Wh/kg	**Wh/l**
Advanced lead acid	35	71
Nickel Cadmium	50	150
Nickel Metal Hydride	80	200
Nickel Zinc	60	100
Lithium Ion	100	300
Lithium Polymer (3M)	155	220
Lithium Polymer (Electrofuel)	183	470
Lithium Polymer Potential	400	500
Sodium Nickel Chloride	90	150
Zinc Air	200	200
Ultra Capacitor	12	5

Table 11: Comparison of Different Battery Technologies [21]

As one can see from the comparison, Lithium Polymer has the highest energy density which means it has high capacity while still being light weight. Therefore Lithium Polymer is the most suitable battery for our project.

The results from the heating and cooling of Peltier plates will be used to calculate battery capacity. The aim is to have a battery and configuration that will last 6 hours. Below is the calculation.

To be conservative, 45°C will be used in the calculation.

$$V = 2V$$

$$I = 0.53\ A$$

$$Capacity = time \times P = 6.36W/h$$

After looking for batteries available on the market, it is deduced that a 3.7V with 2000mAH is suitable for project requirement as it has capacity of 7.4 W/h (datasheet) which satisfies project requirement.

Figure 48: Lithium Polymer Battery [22]

Cell Dimension (Thickness×Width×Length in mm) 5.8 × 54 × 60 and it weighs 36g [A4] which is small and light so it will be suitable to be put on the jacket.

6.2 Battery Life Experiment

The battery is then tested by two methods, first is the worst case scenario of not using any power control by just connecting the battery with the Peltier plate and measures its voltage over time using Arduino [B1].

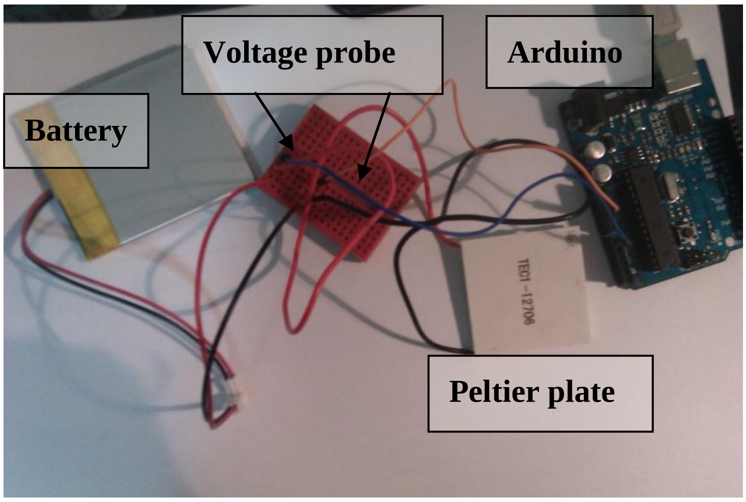

Figure 49: Battery Life Experiment Set Up

The Arduino records the voltage of the battery every 5 seconds and sends the data to the computer.

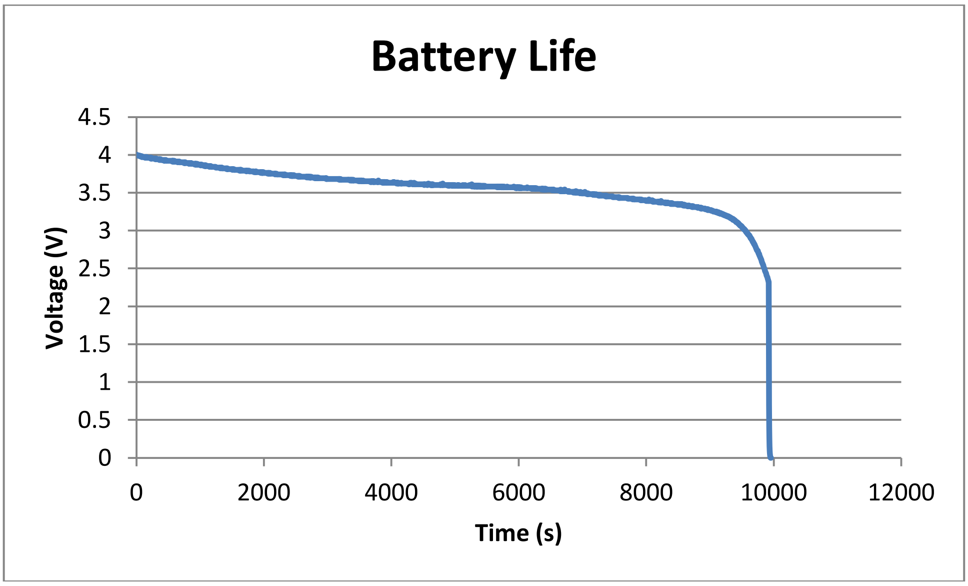

Figure 50: Battery Voltage Over Time

As can be seen from the result the battery is depleted at around 10000 seconds which amounts to 2 hours and 47 minutes. From the result, there is a need for a power management module and PID will be useful for this purpose.

Theoretically, battery life for proposed maximum temperature of 45°C can be calculated as follows,

$$V = 2V$$

$$I = 0.53A$$

$$P = V \times I = 1.06W$$

$$Battery\ capacity = 7.4W/h$$

$$\therefore Battery\ life = \frac{7.4}{1.06} = 6.98\ hours$$

6.98 hours is above the project aim thus in theory, the battery should have enough capacity for the project. Now the battery capacity is tested using PID controller to manage power requirements for the Peltier plate.

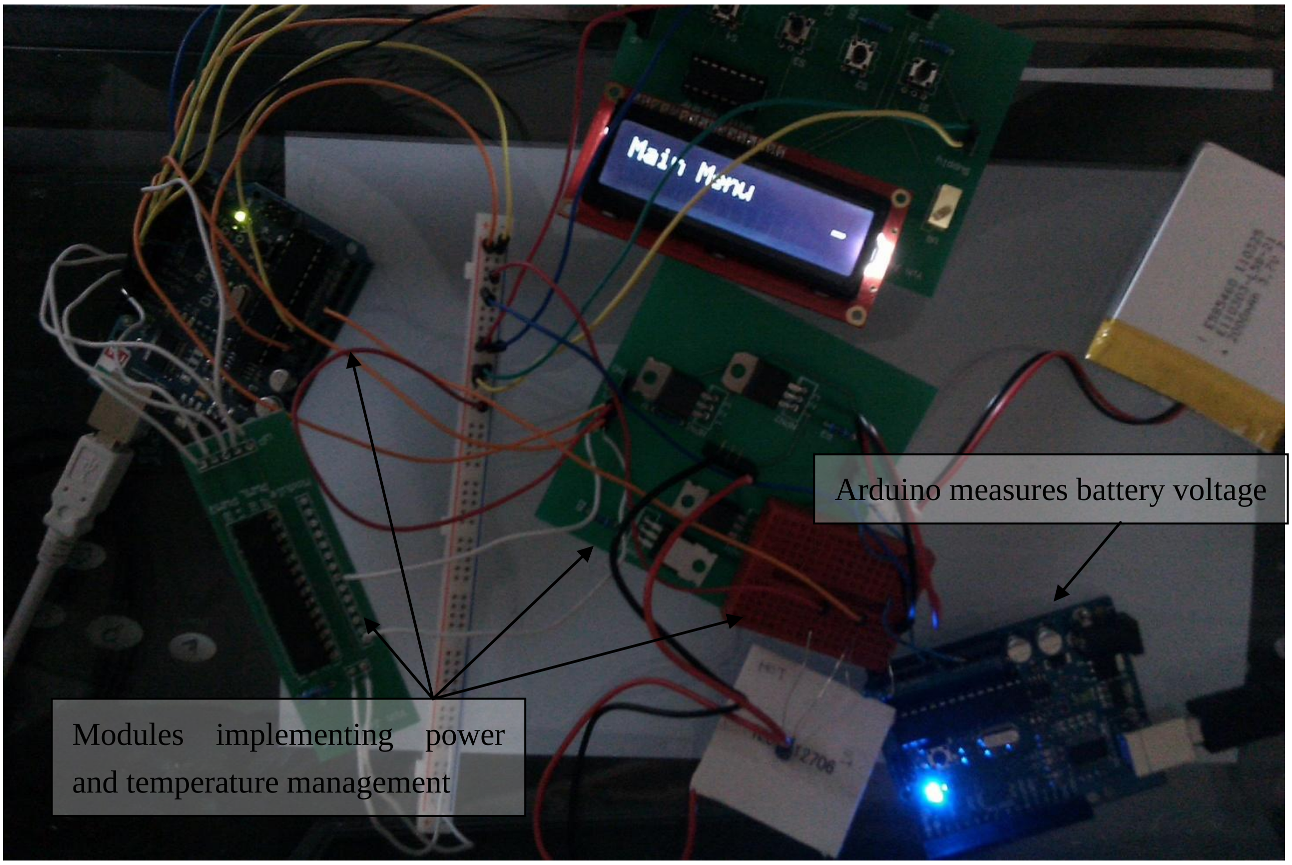

Figure 51: Battery Experiment with Power Management

Temperature is set to be 45°C as this is the maximum temperature of heating module. The experiment is used to see whether chosen battery can satisfy project requirement under the most conservative situation.

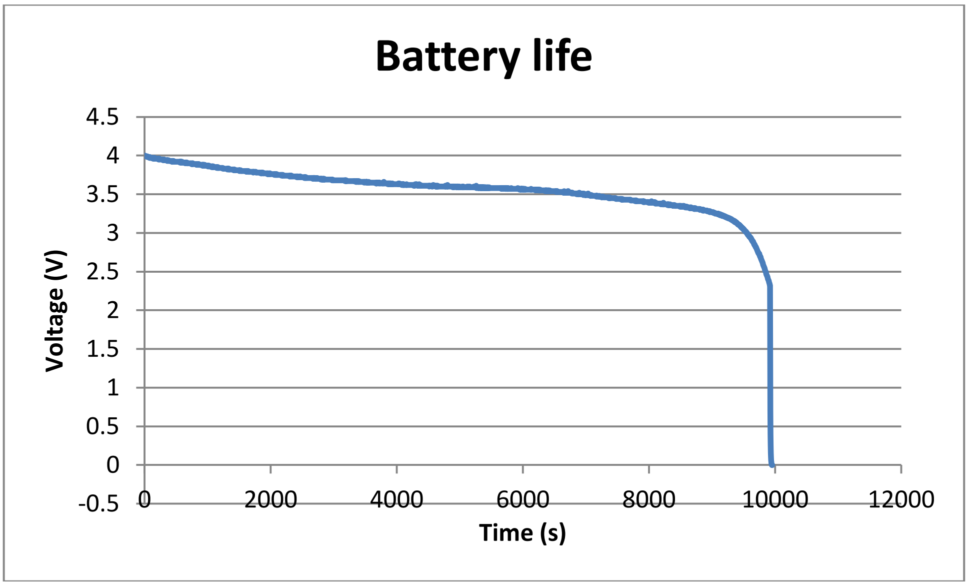

Figure 52: Plot of Battery Life with Power Management

From the figure above, we can see that even with power management enabled (PID control) and temperature controlled at 45ºC, only 3.6 hours of battery life was achieved. This is still far below the aim of 6 hours. The cause of this power loss may be due to the voltage drop of 0.6V [A5] across each transistor used in the H-bridge. The equation above does not consider power lost in the transistor, it is only considering the situation when the battery is directly connected with the Peltier plate.

6.3 Heat Trap

To extend battery life, heat trap mechanism is investigated. Consider a house with perfect heat trap or heat isolation. 1 heat source is used to heat 4 different section of the house. As there is no heat escaping from the house, one could start heating room 1 until desirable temperature, then continue with the same method to heat room 2, 3 and 4. Using this method the whole house could be heated with just one heat source. The same analogy applies to this project in which one battery could be used to heat the whole area of the body by heating each area to certain level. As there will be heat loss in the jacket, this method may be not viable depending on the performance of the fabric material trapping the heat.

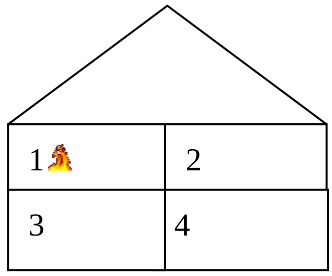

Figure 53: House Diagram

Using the idea of the heat trap explained above, it is possible to use a single battery to heat up all 6 modules. Since the Peltier plate will heat up to 45 ºC in about 40s, to heat 6 modules to maximum temperature, 240s of time is needed. The worst case scenario is when the first module drops to ambient temperature after this 240s. This requires the heat to be trapped for a minimum of 240s to satisfy worst case scenario. Ideally, the heat trap needs to be much longer than 240s if only one battery is used. The jacket needs to make the user feel consistent heat so the material should trap the heat for 240s and the temperature should not drop more than 3 ºC so that the user does not feel the difference. If more batteries are used, the time required for the heat trap needed will decrease, for example, 2 batteries will require only 120s heat trap time, and 3 batteries will require 60s.

An experiment is conducted to see whether heat stays under the fabric for enough time to implement power saving system.

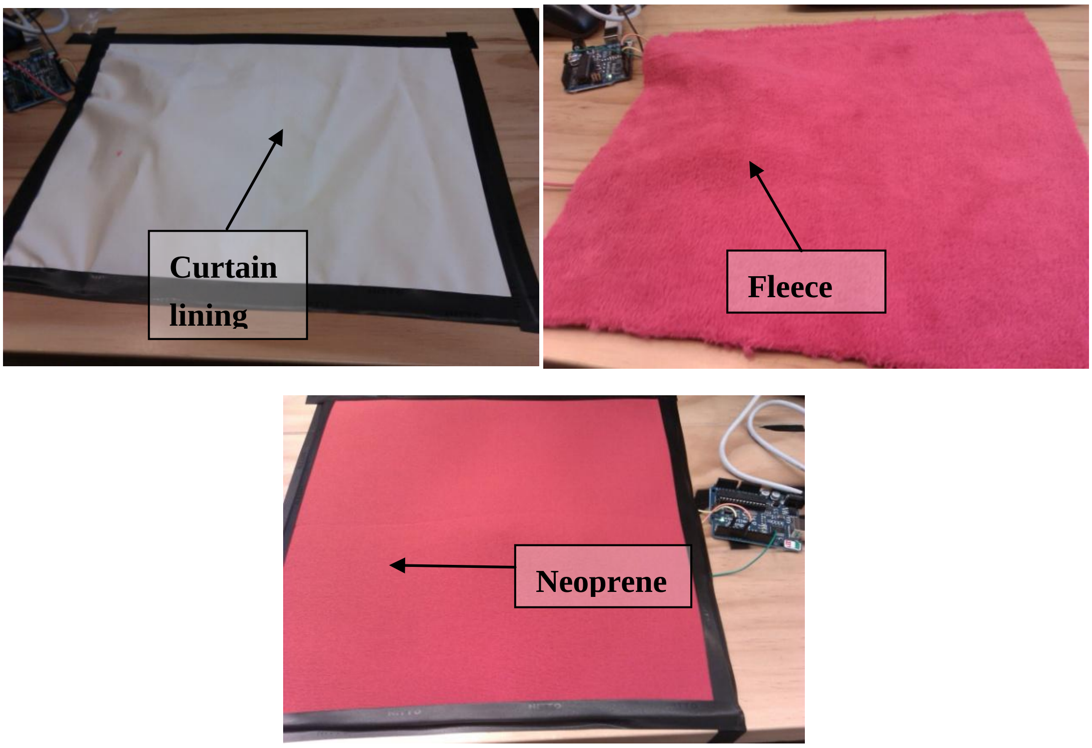

Figure 54: Heat Trap Experiment with Different Fabrics

Three different fabrics are chosen for its quality of trapping heat. The first is curtain lining, which usually used behind a curtain in the house to keep away heat from the sun by blocking light from entering the room. This means that the material is a good heat isolator and thus should not let heat produced by the plate underneath to escape to ambient air.

The second material is fleece which commonly used as material on a jacket to keep a person body warm during winter period. The drawback of using fleece near an electronic circuit is that fleece easily produces electrostatic when rubbed which may cause damage to sensitive electronic devices.

The third material is neoprene which is a waterproof material and also a good insulator as it is made from rubber. Experiment is conducted to see the resistance of Neoprene and the result is the same with electrical tape insulator resistance measured before in which multimeter failed to show resistance. This means that resistance of the Neoprene is above 200MΩ thus it is a suitable choice for this project.

The same setup as the previous heating experiment with the Peltier plate is used to measure temperature. But this time we cover the entire plate and the surrounding area with the fabric to trap the heat. There is a gap between the thermistor and the plate to measure the environment temperature as opposed to plate temperature. The gap between the thermistor and plate is approximately 1cm. The current running through the plate is set to be 0.5A, the plate is allowed to heat up for 300 seconds before the power is switch off.

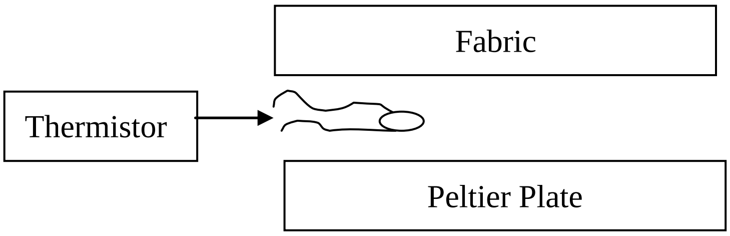

Figure 55: Thermistor Setup

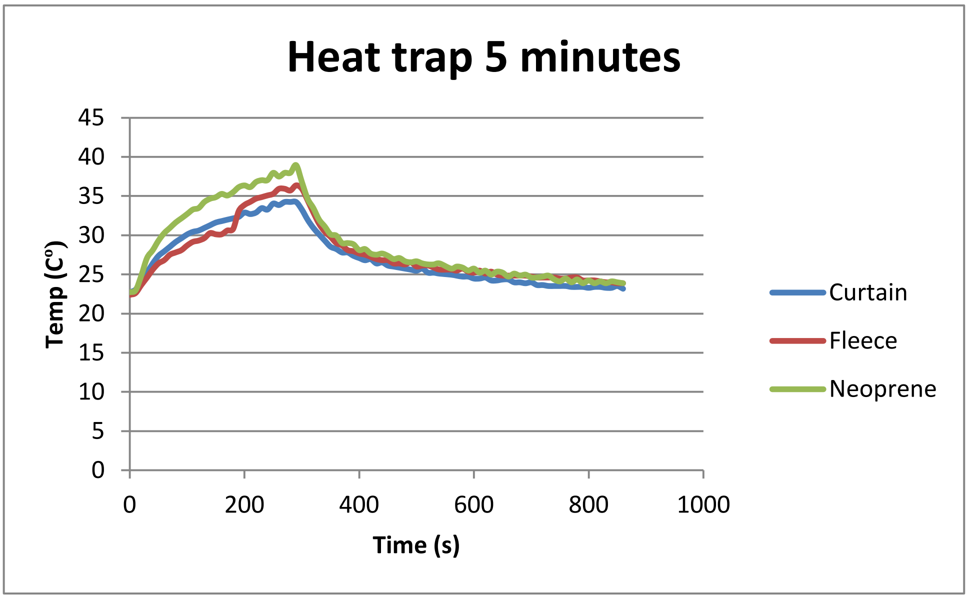

Figure 56: Temperature Plot for 5 Minutes

All materials considered for the heat trap have a temperature drop of about 10ºC after 60s of turning the heating off. This means if 6 batteries are used and the plates are heated in 60 seconds interval, 7.2 hours of battery life will be reached. Unfortunately, the drop of 10 ºC will be noticeable by the user thus negating the heating effect. Therefore the jacket will still need to use constant heating although it sacrifices battery life to only 3.6 hours.

6.4 LCD Power Requirements

The LCD used in the jacket could use power from the Arduino's 5V pin. Unfortunately, when all modules are turned on, the LCD becomes really dim.

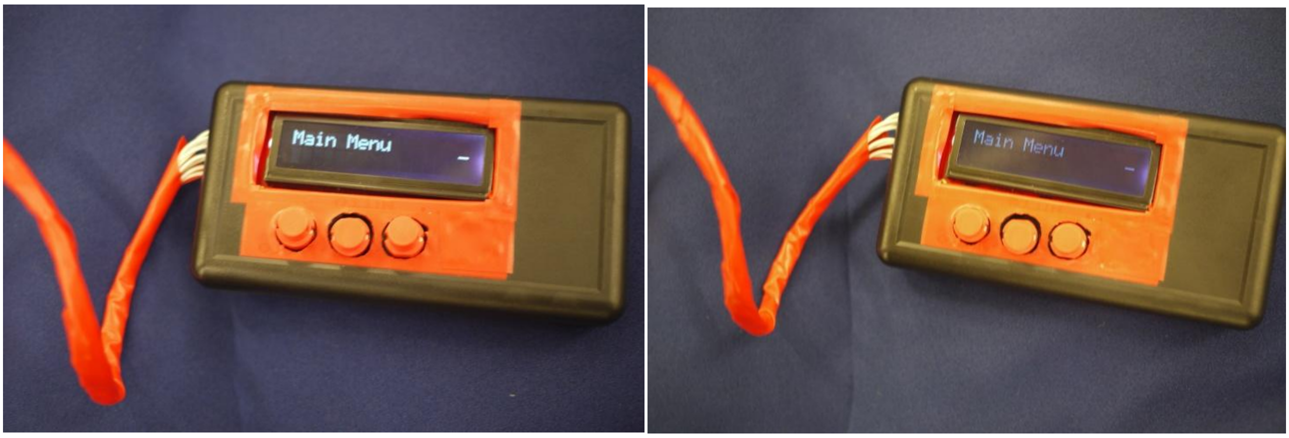

Figure 57: LCD without Any Heating Module On and with All Heating Modules On

This is because the Arduino supplies the current for all the transistors as well as providing logic signals for the LCD and PWM chip. As all these components drain away power and current from the Arduino, there will be less current in the LCD therefore making it dim.

This problem could be solved by using a standalone battery for the LCD. From the datasheet [23], the LCD can take a maximum voltage of 5.5V while maximum current is 4mA. This gives power a consumption value of 0.022W. Using a LiPo battery with 3.7V and 1000mAh, the LCD could turn on for around 168 hours. This will be used in the jacket remote to power the LCD. The remote can run much longer than the required project aim of 6 hours.

6.5 Arduino Power

From the datasheet of the CPU [24], typical power consumption is 12 mA at 5V while FTDI(a chip on the Arduino) may draw about 13mA. Therefore the total is about 35mA at 5V which totals to 0.175W of power consumed.

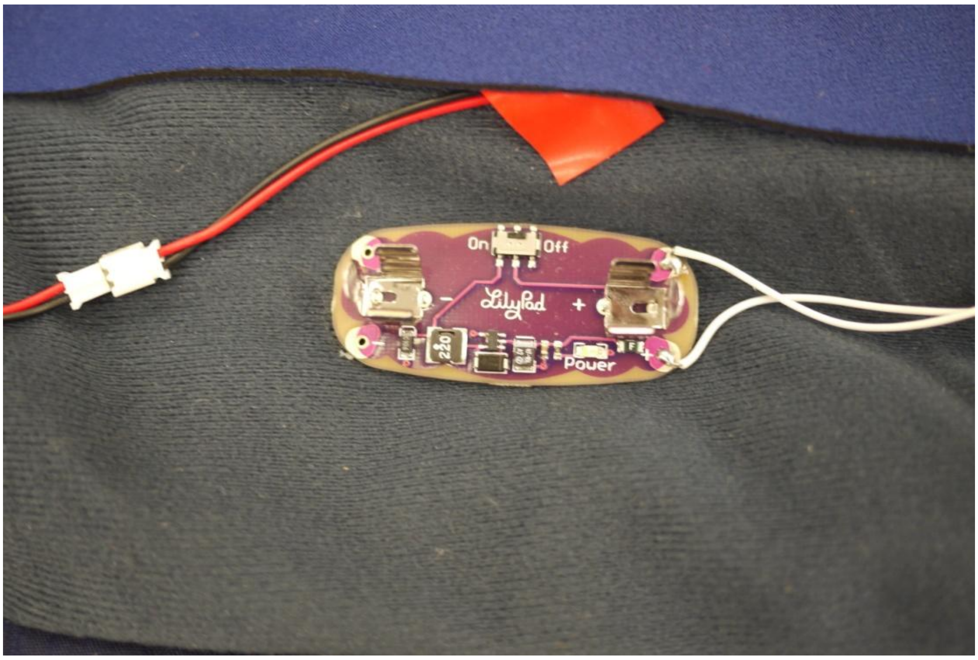

Figure 58: Lilypad Power Source Module

The Lilypad could use a AAA battery using a boost converter module in figure above. Typical AAA battery has around 1.5W/h [25] which will make minimum CPU life of 8.574 hours.

7. H-Bridge

7.1 Introduction

The thermoelectric plate introduced in the previous section requires a controlled current to flow through it. It also needs to have a controller that can permit current to flow in both directions to allow heating and cooling of the thermoelectric plates.

This can be done by connecting the thermoelectric plate to an H-bridge. H-bridge is a circuit that controls the direction of input current to a device. It is often used in motor circuits to control the motor to run forward or backwards [26].

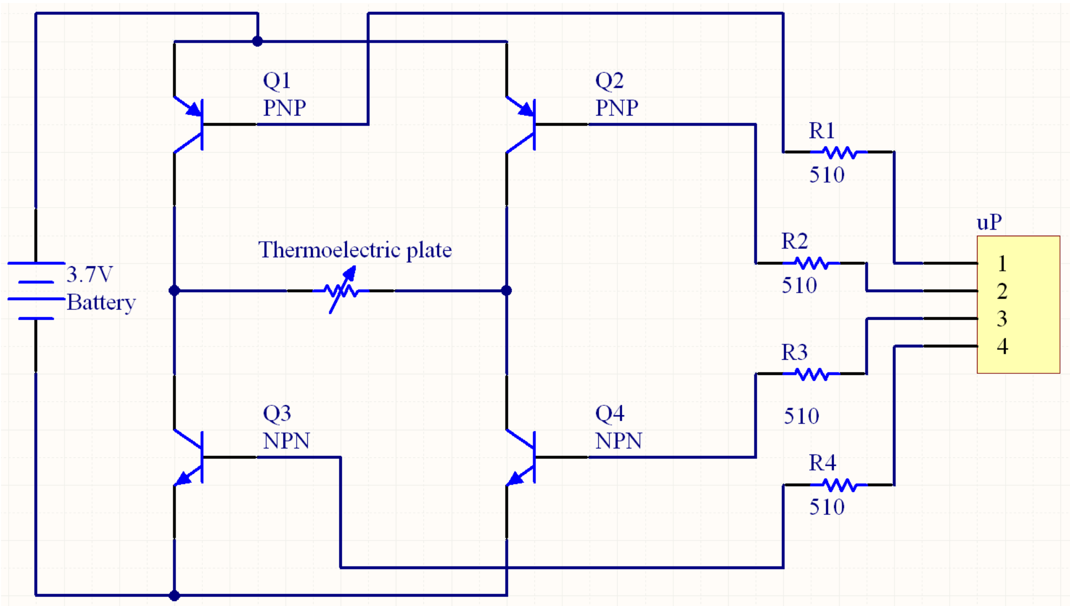

Figure 59: Schematic for H-bridge

An H-bridge consists of 4 transistors, acting as switches to control the direction of current flow through the plate. The bases of the transistors are connected to the micro-controller, to enable control of which transistors turn on/off.

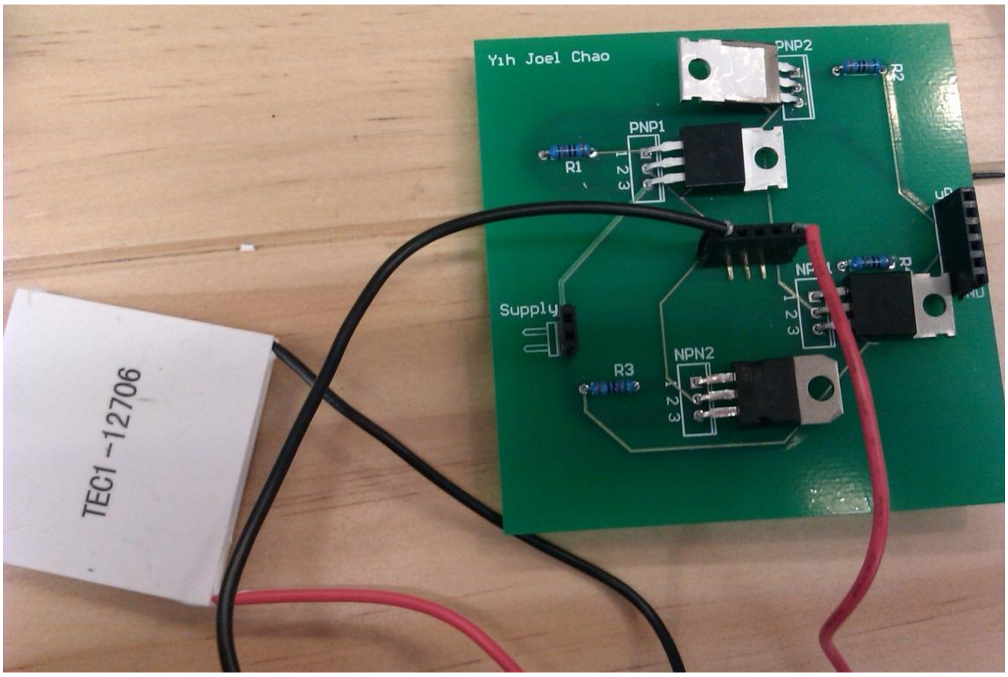

Figure 60: Actual PCB H-bridge Used in the Project

The basic principle of how transistors act as a switch is when there is a current going through the base of an NPN transistor, current will flow from the collector of the NPN to the emitter, which means the transistor is turned ON. On the contrary, if there is no current flowing through the base, NPN will be considered as OFF and current does not flow from collector to emitter. The property of PNP is exactly opposite to NPN. Transistor is ON when the base of the PNP has no current; transistor is OFF when current inputs (how much) to the base. [26]

Pulse Width Modulation (PWM), which will be described in section 7, is used in the base of PNP transistor. PWM allows control for average current through PNP and NPN by varying the current pulse to the base of PNP transistors.

However, there is a limit to the base current. If the current exceeds the maximum base intake current, the transistor will not function properly. The relatively high electric current may cause transistors to heat up which can damage transistors permanently. In addition, driving excess amount of current from the micro-controller can break the inner circuit of the micro-controller since there is a limit to the current that micro-controller can output. Therefore, resistors are needed in series with the base of the transistors to diminish the amount of current flowing to transistors.

$$V_s = I_s * R$$

V_s *is the supply voltage*

I_s is the supply current

R is the resistor in series with the base of the transistor.

V_s is constant, which means I_s is inversely proportional to R. If R increases, I_s will decreases. From this relationship it can be deduced that the greater the resistance in series with the base of the transistors, the less current will supply from micro-controller, meaning less current will flow to the base of the transistors. Therefore the greater the resistance, the less risky it is for the transistor to result in error.

Considering the H-bridge shown in figure 2 below, if Q1 and Q4 are ON while Q2 and Q3 are OFF, current will flow through thermoelectric plate from left terminal to right terminal (shown by red arrows). Similarly, if Q1 and Q4 are OFF while Q2 and Q3 are ON, current will flow from through the plate from right terminal to left terminal (shown by green arrows).

Transistor	Q1	Q2	Q3	Q4	Description
Mode1	ON	OFF	OFF	ON	Left to Right (RED arrow)
Mode2	OFF	ON	ON	OFF	Right to Left(GREEN arrow)
Mode3	ON	ON	OFF	OFF	No current
Mode4	OFF	OFF	ON	ON	No current
Q1 and Q3 or Q2 and Q4 cannot be turned on at the same time as the current will just flow from the collector of PNP transistors to collector of NPN transistors which leads to short-circuit.					

Table 12: Response of Current Flowing through Thermoelectric Plate with Different Switch's States Implemented.

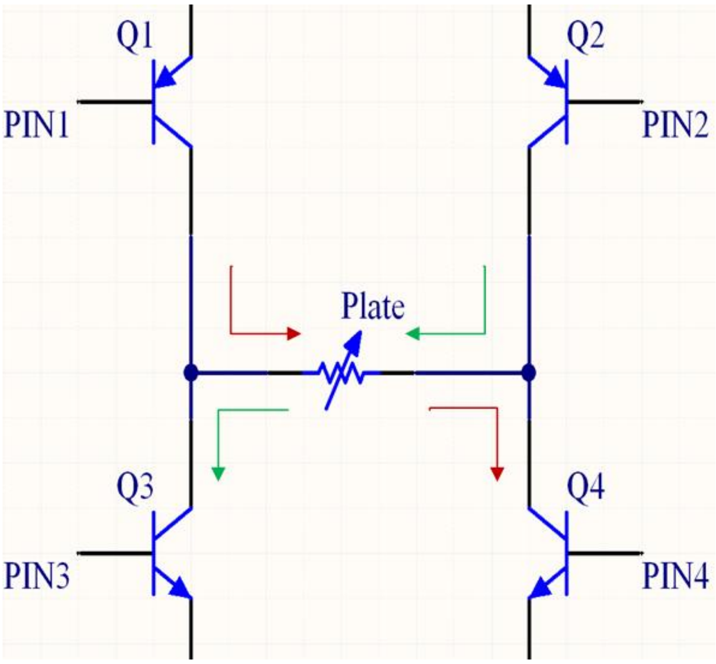

Figure 61: Direction of Current Flow Inside the H-bridge Circuit

7.2 Transistor Selection

In order to achieve high an output current, different types of transistors and FET are used and compared. In the experiment, the supply voltage (V_s) is constant and the input (I_s) and output current (I_o) are measured. The greater the output current, the greater the output power (voltage and resistance constant) thus a higher heating and cooling rate can be achieved.

MOSFET configuration V_s = 3.7V

	N-channel BS170	P-channel BS250
R/Ω	I_s/A	I_o/A
1000	0.03	0.029
510	0.03	0.029
210	0.03	0.029
100	0.03	0.029

Table 13: Response of MOSFET Configuration

BJT configuration1 V_s = 3.7V

	NPN 2N2905	PNP 2N2219
R/Ω	I_s/A	I_o/A
1000	0.26	0.257
510	0.31	0.3
210	0.56	0.544
100	0.49	0.433

Table 14: Response of BJT Configuration1

BJT configuration2 V_s = 3.7V

	NPN 2N2222A	PNP 2N2907A
R/Ω	I_s/A	I_o/A
1000	0.01	0.0075
510	0.02	0.0151
210	0.04	0.03
100	0.08	0.0587

Table 15: Response of BJT Configuration2

BJT configuration3 V_s = 3.7V

	NPN TIP41C	PNP TIP42C
R/Ω	I_s/A	I_o/A
1000	0.43	0.426
510	0.55	0.54
210	0.53	0.52
100	0.57	0.55

Table 16: Response of BJT Configuration3

BJT configuration4 V_s = 3.7V

	NPN BD139	PNP BD140
R/Ω	I_s/A	I_o/A
1000	0.29	0.29
510	0.38	0.379
210	0.45	0.44
100	0.54	0.514

Table 17: Response of BJT Configuration4

BJT configuration5 V_s = 3.7V

	NPN MJE3055T	PNP MJE2955T
R/Ω	I_s/A	I_o/A
1000	0.42	0.416
510	0.53	0.527
210	0.56	0.553
100	0.59	0.561

Table 18: Response of BJT Configuration5

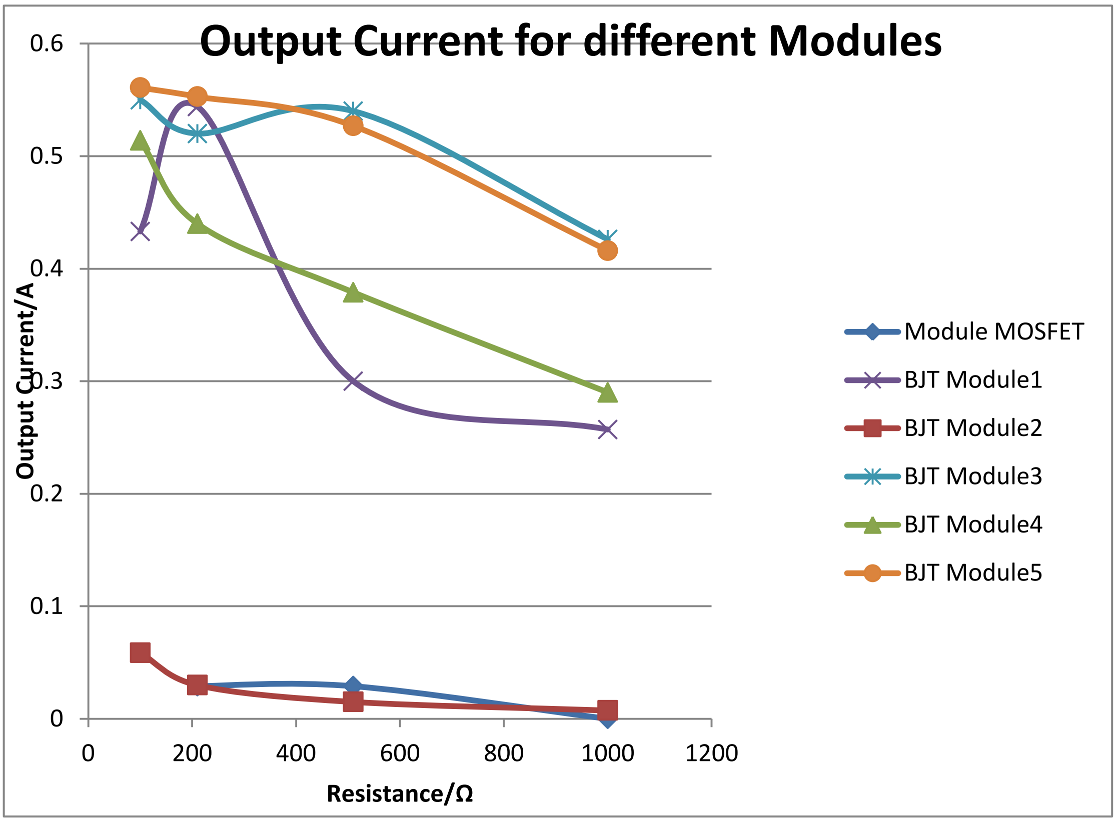

Figure 62: Output Current for Different Transistor Modules

Comparing the results, MOSFET and BJT configuration 2 do not give out enough output current to drive the Peltier Plate. BJT configurations 1 and 4 provide satisfactory outputs but results produced by configurations 3 and 5 are more applicable. From the previous sections, I_o needs to be around 0.5A to achieve the project aim of 45°C maximum temperature. By applying the relationship between I_s and R deduced previously, R = 510Ω is the most suitable solution to give around 0.5A I_o.

Viewing from the graph it can be seen that configuration 3 produces largest amount of I_o at R = 510Ω. The other advantage of using configuration 3 is that the maximum collector current for the transistors (NPN TIP41C and PNP TIP42C) is 6A which is relatively large compare to other transistors [A5]. Maximum I_c for some transistors such as configurations 1 and 2 is only 0.5 to 0.8A [A6]. The current required to perform heating and cooling mechanism is 0.5A which is at the edge of maximum I_c of configurations 1 and 2. With maximum I_c of 6A, configuration 3 provides large amount of tolerance for I_c.

Thus, considering highest resistance needed to use to limit base current and high output current to satisfy maximum temperature in project aim, configuration 3 with 510Ω is the most appropriate module of all.

7.3 H-Bridge chips

The other approach to implement an H-bridge circuit is to use H-bridge microchip. There are two chips that are most suitable, most reliable, and widely available on the market- L293E and L298N.

L293E

The chip is applied by implementing the circuit as shown in its datasheet. [27] However the results are disappointing. For $V_s = 5V$, the voltage difference between thermoelectric plates is approximately 0.1V. This means I_o is too small to perform heating and cooling mechanism. The small voltage drop across the plate is due to large drain of power inside the chip.

L298N

The chip is applied by following the circuit diagram shown in the datasheet [28]. The simplified circuit diagram is shown below. An ammeter is placed in series with Peltier plate to measure current outputted from the microchip.

V_s= 3.7V

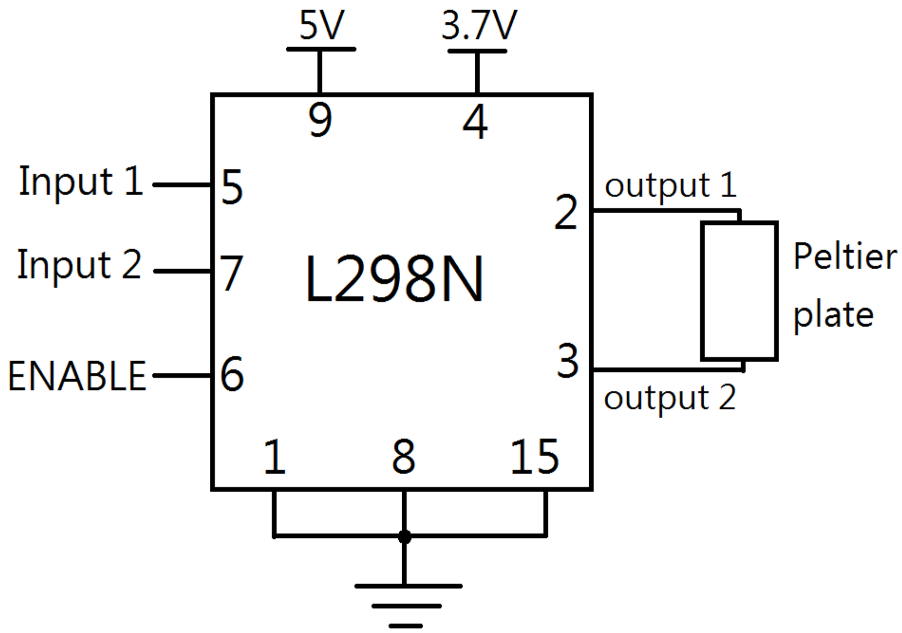

Figure 63: Circuit Diagram of L298N

I_o = 0.36A ~ 0.4A (not stable)

The output current fluctuates between 0.36A to 0.4A. The variation shows the lack in stability of the microchip. However, despite the stability factor, L298D still produces larger output current than L293E. Even with the lowest current measured, the value is still sufficient for desirable heating and cooling to take place.

7.4 Conclusion

In conclusion, by comparing the results for all the experiments, output current produced by BJT configuration 3 with R = 510Ω provides the highest efficiency, stability and output current. At V_s = 3.7V, the module produces highest output current. Resistance in series with the base of the transistor is also sufficient for transistor protection. Therefore configuration 3 with R = 510Ω is used for implemented the H-bridge.

8. Control and Software

8.1 PWM

PWM stands for Pulse Width Modulation, it is a technique used in digital systems to allow an approximate Analog output. In digital systems, a signal can only be either 'high' or 'low'(0V and 5V in the case of Arduino micro controller). The basic idea of PWM is using binary levels of voltages to approximate any voltage in between 'high' and 'low' by adjusting the proportion of time the signal spends on being 'high' and 'low'. The 'pulse width' is the time duration of when signal is 'high'. By modulating this pulse width we can approximate varying voltages between 0 and 5V. If the switching time between 'high' and 'low' is quick enough, the result is a steady voltage. The function analogWrite() available in the Arduino is used to enable PWM usage in the digital pins that have PWM ability. analogWrite() takes in an integer argument between 0 and 255 that indicates how long the pulse width will be. Another term used is the ‘Duty Cycle’, which is essentially the pulse width expressed as a percentage. Figure x shows a graph to illustrate Pulse Width Modulation in terms of the analogWrite() function.

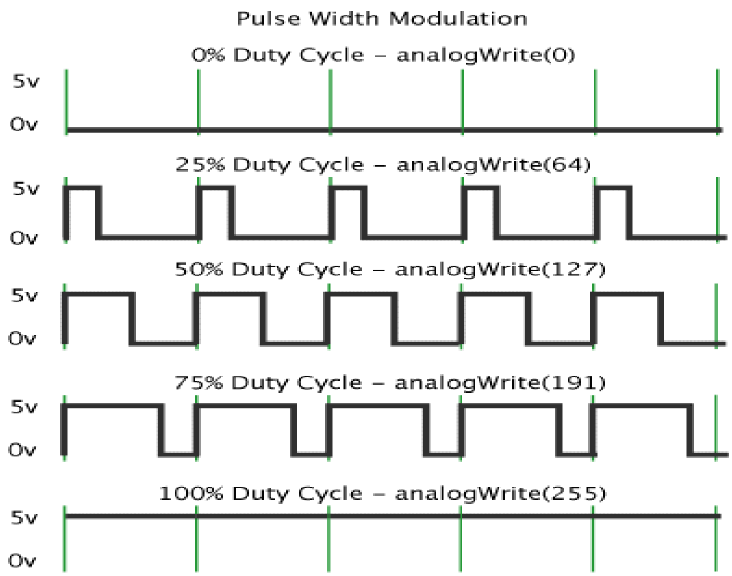

Figure 64: Pulse Width Modulation [29]

8.1.1 Advantages of using PWM in the Jacket

PWM is needed in our application to control the current that will run though the Peltier plate which in turn will heat or cool our jacket. Without PWM we will only have access to a digital on and off which means we cannot vary the current, there will be either no current or maximum current. This results in the inability to use gradual heating/cooling, just like the case with simple thermostats which can only turn on and off depending on current temperature. This is undesirable since the heating and cooling rate cannot be controlled and PID feedback cannot be used (covered in next section). With the ability to vary the voltage between 0 and 5V we can control the rate of heating/cooling, which is highly desirable in our jacket to improve power efficiency and comfort by not having sudden heating/cooling.

8.1.2 Lack of PWM enabled pins in the Arduino Duemilanove

The Arduino Duemilanove provides 6 digital pins that are capable of PWM outputs. 12 PWM enabled pins in this application is needed: 6 to control the currents running one direction (heating), another 6 for current flowing the opposite direction (cooling) through the Peltier plates. Either an upgrade to another Micro Controller such as the Arduino Mega (which has much more PWM ports) is required or another solution is needed. The Arduino Mega's dimensions are much too large to be used in a jacket, therefore additional components must be added to increase the PWM outputs.

8.1.3 TLC5940NT Chip

In order to increase the number of PWM enabled output ports available to the micro controller, the TLC5940NT chip was introduced. This chip is an LED driver normally used to control the brightness of LEDs with PWM output. Driving LEDs is similar to what is needed in our application, they both involve controlling the flow of current in a channel, so this chip was used to extend the number of PWM pins available.

Below is a brief snippet describing the LED driver from the datasheet [30]:

The TLC5940 is a 16-channel, constant-current sink

LED driver. Each channel has an individually

adjustable 4096-step grayscale PWM brightness

control and a 64-step, constant-current sink...

Care must be taken in wiring the circuit due to the fact that the channels are current sinks and not sources. This is why the chip is connected to base of PNP, as the chip is controlling the lower level of voltage pulse. If chip is a current source, it will be wired to the base of NPN transistor.

The Tlc5940 library for the Arduino is used in conjunction with the TLC5940NT chip to add 16 extra PWM enabled pins by using only 5 Arduino PWM pins to control the chip. The library abstracts all the lower level logic from the programmer and allows quick and easy to read code to be written.

Below is the wiring diagram of the PWM chip. All the pins on the left hand side of the chip are output channels. The header to the left will connect to the Arduino. Header pins 1, 2, 3, 4 and 5 will correspond to pins 11, 13, 9, 10 and 3 on the Arduino respectively.

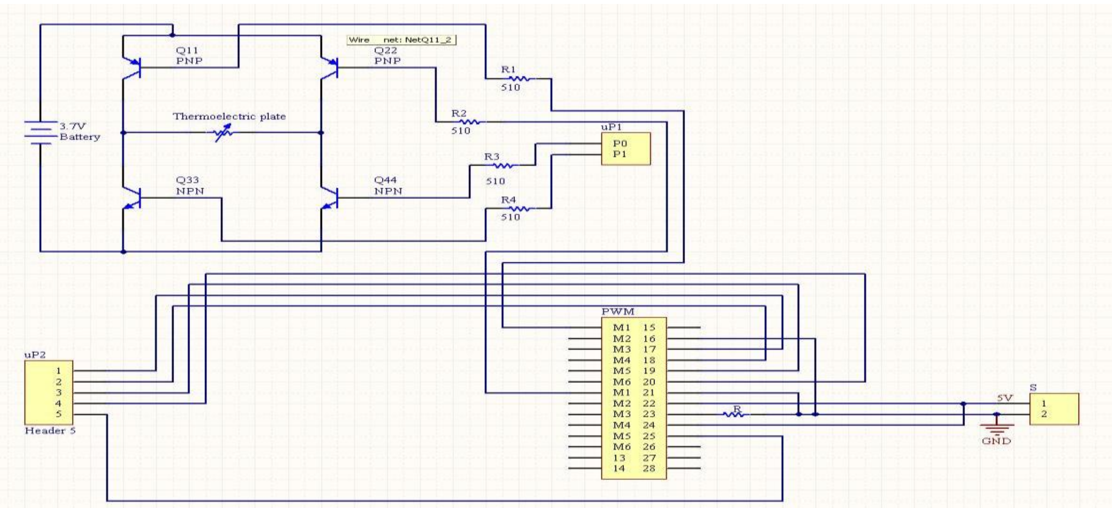

Figure 65: Wiring Diagram of PWM with Hbridge and Microprocessor

8.2 PID Controller

Proportional Integral Derivative Controller(PID Controller) is the most common feedback controller used in industrial control systems. Feedback control systems are used in systems that involve an input, output and a desired set point. A feedback mechanism is needed for the temperature control in order to heat/cool a module to the desired temperature. The most basic way is to use the ON/OFF controller. This is how most thermostats work, the heater will turn on when the detected temperature is below the target temperature and turn off when the temperature is above the target. This causes the heater to be constantly switched on and off which is undesirable in this application due to inefficiency. Another problem associated with on/off controllers is oscillation. A way to gradually increase or decrease the temperature to the desired value and to avoid oscillation is to use PID controllers. PID is made of three separate components: Proportional Control, Integral Control and Derivative Control. The final PID system is a summation of all three components factored in [31].

8.2.1 Proportional Control

Proportional Control is a simple feedback control system where the input to the system is linearly proportional to the instantaneous error (set point – output). A good analogy is the way vehicle drivers accelerate quickly from a complete stop, but will then use less acceleration (smaller input) as the vehicle approaches the desired speed (set point). This is useful because overshoots will be minimised since input is decreased as the output reaches the set point.

8.2.2 Integral Control

Integral Control takes into account all the past errors by summing up all of the past errors in a given interval. This allows the system to adjust accordingly to try and correct errors that have happened in the past.

8.2.3 Derivative Control

Derivative Control looks at the rate of change in error, the higher the rate of change, the larger the derivative factor becomes. This component can help offset the error that will happen in the future. The main function of the derivative control is to counteract the Proportion and the Integral component [32].

8.2.4 PID Library

In order to implement PID control in the project the library PID_Beta6.h (Written by Brett Beauregard) was introduced. The library allows PID objects to be declared which represents a PID calculation. The PID object has 6 attributes; input, output, target and three constants that influence the Proportional, Integral and Derivative components of the calculation. The function PID.compute() can be called anytime to calculate the output of this PID controlled system. The library takes away the use of unnecessary complexity of programming an algorithm and makes code much more readable.

8.3 LCD

The LCD used in our temperature remote is Hitachi HD44780 compatible. HD44780 is the de-facto industry standard for character LCDs. These type of LCDs are text only, therefore they are relatively simple and can save memory in the microcontroller, especially when the Arduino Duemilanove has very limited memory (32KB). They are also well documented, the size is also suitable for our purpose therefore it is perfect for our application. The LCD has a 16 pin interface and has various configurations to connect to the Arduino including four-bit parallel, eight-bit parallel and three-wire. The Arduino Duemilanove only has 14 digital input/output pins, therefore they must be conserved to prevent it from running out of pins. The three-wire configuration was chosen because of this fact, but using this configuration also meant that the 4094 shift register [33] had to be introduced in order to use only three digital output pins from the Arduino to control the LCD.

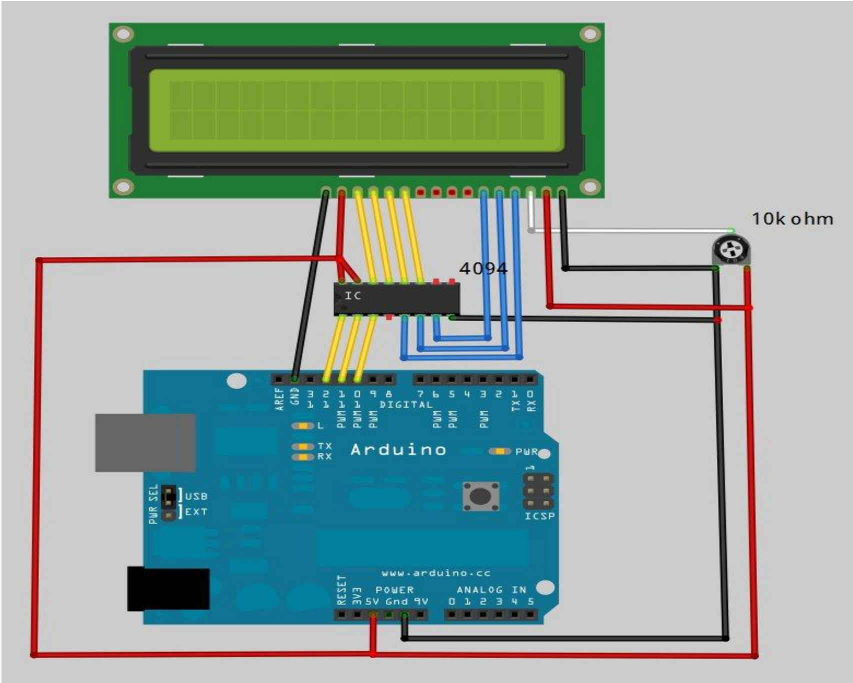

Figure 66: Wiring Diagram of LCD with Arduino [34]

This configuration is used in conjunction with the LCD3wires library available to public for use and modification. The library provides abstractions and allows functions such as printIn() that simply lets the programmer print characters on the LCD without worrying about the complicated lower level logic such as the shift register.

8.4 MenuBackEnd

For the menu system used in the remote controller, a library called MenuBackEnd was used to avoid complicated and messy code for the user interface. MenuBackEnd abstracts the idea of menus, submenus, items and button pressing and allows highly usable menus to be created for the Arduino with a LCD display. It allows creation of menu objects that can be placed left, right and under one another to create a logical structure. This menu structure can then be navigated using directional buttons and functions can be invoked when a menu is selected. The structure of the menu used in the user interface is shown in figure 67. A detailed discussion of the functions of the submenus is discussed in the next subsection.

8.5 User Interface

A part of the project specification is to create a simple to use User Interface. This will involve combining the LCD, the MenuBackEnd library, the Arduino microprocessor and buttons together. In this section the main components or the User Interface is discussed.

8.5.1 Traversing the Menu

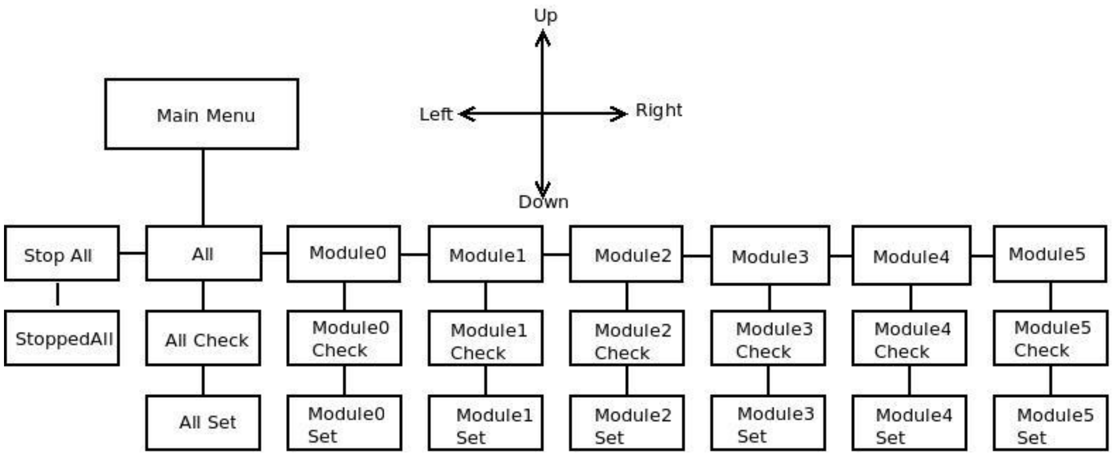

Figure 67: Structure of User Interface

There are four buttons available for the user: Left, Right, Enter and Return. The Left, Right and Enter buttons are used to traverse the tree of submenus in figure 67, travelling along the edges to arrive at a different submenu. Left and Right buttons will take the user to either the immediate Left or Right submenu of the one currently used. The Enter Button will take the user to the submenu under the currently selected one. The Return button will take the user back to the Main Menu.

8.5.2 Modules

The Modules in figure 67 refer to the heating/cooling and temperature sensors that are placed in different parts in the jacket. The modules are named with the generic names as 'Module1', 'Module2' etc. within the code to allow flexibility and readability while writing the program and makes it easier for further modification. Table 19 shows the module names and the corresponding position of the module inside the jacket.

Name	Location in the Jacket
Module0	Chest (Left)
Module1	Chest(Right)
Module2	Stomach(Left)
Module3	Stomach(Right)
Module4	Upper back(Left)
Module5	Upper back(Right)

Table 19: Corresponding Module Number and Heating Module

8.5.3 Functions of Submenus

Upon entering the main menu, the user is presented with the options of choosing to stop all current heating/cooling, selecting individual modules to focus on or choose to treat all the modules as one big module to check and set the average temperature. Choosing a module will result in a ModuleX Check, and this will display the current temperature of the module as shown in an example in figure 68. If 'Enter' in pressed again from the 'ModuleX Check' level, the user can then set the target temperature for the module. From this set of submenus the user can use the left and right button to decrease and increase the desired temperature. When the user presses 'Enter' one more time, the LCD will display a message of confirmation of the name of the module to be heated or cooled and also display the target temperature, the display will then return to the main menu. Below is a demonstration usage of the menu to cool down the left chest module. A step by step explanation of figure 68 in provided in table 20.

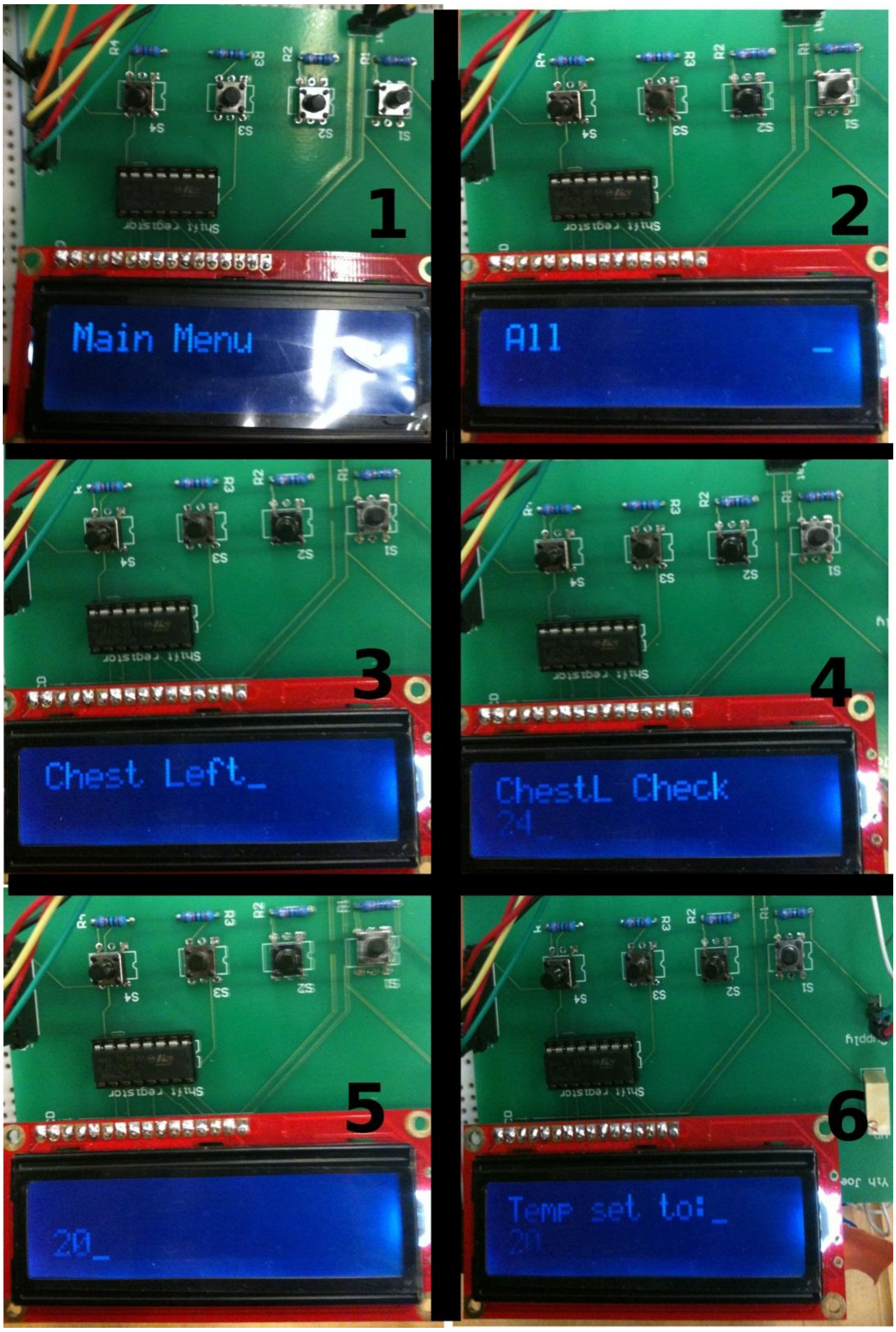

Figure 68: Demonstration of Operating the Menu

Picture	Name of Menu	Description	Next Button Pressed
1	Main Menu	Start-up screen	Enter
2	All	Selection of modules to focus on. The default is ‘All’ which will allow measuring and setting the average of temperature of all modules. Using The left and right buttons will allow choosing the different modules	Right
3	Module0	The submenu to the immediate right to ‘All’ is Chest Left which corresponds to the module located on the left hand side at the chest in the jacket.	Enter
4	Module0 Check	The system will then calculate the current temperature at the left chest module and display it back on the LCD.	Enter
5	Module0 Set	At this point, the user can use the left and right buttons to decrease and increase to the desired temperature. The temperature in this example has been lowered to 20 to cool down the module	Left(4times)
6	Confirmation (not actually a menu, only a display)	This screen confirms that the temperature has been set to 20, and the display will return to the Main Menu after 2 seconds	

Table 20: Demonstration: Using the Menu to Cool down the Left Chest Module to 20 Degrees Celsius.

8.6 Brief Walkthrough of the code

8.6.1 Declarations:

Many variables are declared in this section, mainly for house keeping use, but a few are of interest worthy of discussion:

Code	`double beta = 4100;`
Explanation	beta is a parameter of the thermistors used to measure the temperature in the modules, it is determined by the materials, dimensions and geometric of the thermistor.

Code	`double curTemp[6] = {0,0,0,0,0,0};`
Explanation	curTemp is an array to store the most current recorded temperature in all the modules, curTemp[X] is the temperature of moduleX.

Code	`double setTemp[6] = {0,0,0,0,0,0};` `double setCool[6] = {100,100,100,100,100,100};` `double output[6] = {0,0,0,0,0,0};` `double outputCool[6] = {0,0,0,0,0,0};`
Explanation	The first two arrays above are used to store the desired temperatures on the individual modules, one used when heating is required and the other for cooling. The last two arrays are used to store the output power required for each module, for example, the output determined by the PID calculations in order to achieve the desired temperature for the module.

8.6.2 The Main Loop

Below is a brief outline of the processes the micro controller loops through

1. Detect if buttons were pressed
2. Navigate the menus if buttons were pressed
3. Read temperatures of all the modules
4. Check if heating and cooling is set, if it is, then calculate the correct output for the modules and set the output. If it is not set then ensure all the output is set to 0, so that no current flows through the Peltier plates.

8.6.3 Breakdown of main functions:

Code	`void readTemp(double *curTemp){` `  for(int i = 0; i < 6; i++){` `    //read the normalised voltage across the thermistor network` `    valTemp = analogRead(i);` `    //calculate the resistance of the thermistor` `    Rt = 553.684711*exp(0.874921 * valTemp * 0.0049);` `    //calculate the temperature from the resistance value` `    curTemp[i] = (beta/(log(Rt/10000)+(beta/298.15))) - 273.15;` `  }` `  delay(250);` `}`
Explanation	This function reads the temperature of all the modules and puts it into an array. A for loop is used to repeat the code for all 6 modules. The analogRead(i) function will read the analog pin number i and return a value between 0 and 1023, where 0 indicates the voltage at the pin is 0

	Volts and 1023 will indicate 5V. Multiplying this normalised voltage reading by 0.0049 will give us a voltage given in units of Volts. The resistance of the thermistor can then be calculated and in turn the Temperature can be calculated. A delay of 250 milliseconds was introduced to conserve power, since temperatures generally do not change sharply enough to require the microprocessor to calculate as quick as possible.

Code	`void checkCool(double *curTemp, double *setCool, double *outputCool){` `  for(int i = 0; i < 6; i++){` `    if(curTemp[i] > setCool[i]){` `      //determine how much effort we want to put into cooling the module` `      double factor = coolPower(curTemp[i], setCool[i]);` `      Tlc.set(i + 7, factor * 4094);` `    }` `    else Tlc.set(i+7, 0);` `  }` `  Tlc.update();` `}`
Explanation	This function is used for the cooling application of the jacket. It takes in the array curTemp and setCool to know the current temperature and also the target temperature of the modules in order to determine how much current to output through the Peltier plates. A ‘for’ loop is used to repeat code for all 6 modules. If the current temperature of the module is higher than the desired temperature, then cooling is required. An auxiliary function coolPower() is used to determine how much power needs to be output. Tlc.set() is a function from the Tlc5940.h library, used to set the channel to output at a certain PWM factor between the

	values 0 and 4094. Tlc.update() is also a function from the library. It is used to output through the channels of the TLC5940 chip whatever was set by the Tlc.set().

Code	`double coolPower(double curTemp, double setCool){` `  double diff = curTemp - setCool;` `  if (diff >= 5) return 1;` `  else if(diff > 2.5) return 0.5;` `  else if(diff > 1.5) return 0.3;` `  else if(diff > 0) return 0.1;` `  else return 0;` `}`
Explanation	This function is an auxiliary function used to determine how much ‘effort’ the PWM chip needs to push a current. This is analogous to how much pressure a driver would apply to the accelerator to control the acceleration and speed of the vehicle. The function is equivalent to the idea of PID in that an output is determined by how much the difference is between the target and input. Unfortunately the PID library used in this program is not suitable for cooling calculations. When the PID library function finds a target that is lower than the current sampled value, the PID function does not return a negative value to decrease the value which is what we need for cooling. Because of this reason a separate function was written to fulfil this need. This function looks at the current temperature and the target temperature set for a module. If the difference between the temperatures is greater or equal to 5 degrees then use full throttle, return a factor of 1. If the difference is between 2.5 and 5 degrees then only half on the full power is needed and so on for the rest of the temperature differences.

Code	<pre>void settingTemp(int i){ readTemp(curTemp); lcd.clear(); set = curTemp[i]; lcd.clear(); switch (i) { case 0: lcd.printIn("ChestL Set"); break; case 1: lcd.printIn("ChestR Set"); break; case 2: lcd.printIn("StomachL Set"); break; case 3: lcd.printIn("StomachR Set"); break; case 4: lcd.printIn("UpperbackL Set"); break; case 5: lcd.printIn("UpperbackR Set"); break; } lcd.cursorTo(2,0); itoa(set, temp, 10); lcd.printIn(temp); lastButtonPushed = 0; while(lastButtonPushed != buttonPinEnter){ readButtons(); if (lastButtonPushed == buttonPinLeft){ set++; itoa(set, temp, 10); lcd.clear(); lcd.cursorTo(2,0); lcd.printIn(temp); } if (lastButtonPushed == buttonPinRight){ set--; itoa(set, temp, 10); lcd.clear(); lcd.cursorTo(2,0); lcd.printIn(temp);</pre>

	`` } } lcd.cursorTo(1,0); lcd.printIn("Temp set to:"); delay(2000); if (set < curTemp[i]){ setCool[i] = set; cool = 1; } else{ setTemp[i] = set; cool = 0; } onoff = 1; menu.toRoot(); } ```
Explanation	This function is used to set the target temperature arrays(one each for heating and cooling) to the desired value. The function also deals with displaying on the LCD to provide feedback to the user. settingTemp() takes in an integer value to indicate which module's temperature is to be set(between 0-5 inclusive). The function will determine what to display on the LCD depending on which module is chosen to provide a user friendly interface i.e. Displaying "ChestL Set" instead of "module0 Set". The function will then provide the option to change the temperature using the "Left" and "Right" buttons to set the desired temperature while the display continuously updates itself to display the new number until the 'Enter' button is pressed. The heat or cooling 'set' array is then updated depending on the whether the new value is higher or lower than the current temperature(to determine heating or cooling) .

9. Conclusion

From the experiments conducted, the heating module has the capacity to heat to over 45°C which satisfies the project aim for the heating function. The module is also able to maintain a temperature of 20°C after a period of time which also satisfies the target set out in the first place. Even though the minimum temperature from the Peltier plate can go to 17°C the module will warm up to 20°C because of the heat from the hot side of the Peltier plate travels back to the cold side. The amount of heat that comes back to the cold side depends on how much the heatsink can dissipate the heat. Although it is possible to achieve longer battery life than aim, 3.6 hours battery life is chosen for comfortable constant heating. Visual feedback for the user via LCD gives a simple, easy to use interface while allowing user to control temperature to by using 1°C increments. The jacket is also safe as the Neoprene layer insulates any possible electrical hazard. In conclusion the project was a success and shows that a heating and cooling jacket with electronic control can be made and possibly be a profitable technology.

10. Future Work

Suggestions for future improvements include finding better heatsinks to improve the cooling module. The heatsink must also be smaller and shorter in height so that it does not protrude through the jacket while also reducing weight. The heatsinks used in the jacket satisfies the dimension required, but does not give effective cooling performance.

Battery charging methods could also be considered. The traditional method of disconnecting batteries and charging them individually via mains power or using USB port is not efficient and inconvenient for the user. Thus in the future parallel charging is suggested. Also, The ability to use the jacket while charging the battery is desirable. Alternative charging methods can also be considered such as solar power or piezoelectric modules that can charge the battery by converting the user's kinetic movement energy into electrical energy.

The circuit can also be coated with water proof material so that the jacket can easily be washed in the washing machine. Better heat trapping material may be useful to reduce power consumption as discussed in the power section. Better heat flow mechanism could be devised to make radiating heat from heatsinks more effective.

Since rigid PCB and heating/cooling material are used in the jacket, the jacket will definitely be less comfortable. Thus in the future, the use of flexible PCB and flexible heating/cooling materials can be investigated. Flexible materials mean the jacket will be more comfortable and may even weigh less.

There is power loss in the H-bridge. This may due to the property of the TIP41C and TIP42C transistors. Thus for future research, better transistor can be examined to increase the operation time of the jacket.

Last but not least, is the distribution of the heat. In the jacket only neoprene provides heat trap to the jacket. This helps distributing the heat around the jacket. However, when the jacket is being worn, only the 6 heating/cooling spots are noticeable to the users. Thus a heat distributing material should be further investigated to distribute heat and cool inside the jacket more evenly.

11. Contributions of Each Student

Boby Mina Contribution

- Together with Joel and Cheuk Man contributes in initial research for the design of the jacket, essential modules and theory behind heating and cooling functions.
- Design circuit for temperature sensors along with which resistance and type of thermistor chosen while together with the team did the experiment to test the design.
- Together with the team, decides on which temperature sensor design used by comparing their standard deviation.
- Helps initial research of different types of heating and cooling module and researching theory behind each module.
- Along with Joel, order the necessary parts to build heating and cooling module.
- Tested effectiveness of heating and cooling from whole range of modules which includes Peltier plate, Nichrome wire and heating fabric.
- Together with Joel research on which heatsink to be used along with Peltier plate.
- Conducted experiment of cooling with different type of heatsinks.
- Together with the team, by looking at specific project aims, decide on which heating and cooling module to be used in the jacket.
- Research on suitable power supply for the project.
- Design heat trap mechanism to help prolong battery life.
- Did experiment on battery life with and without temperature and power management.
- Together with the team, did experiment on heat trap mechanism.
- Helps Joel design PCB in the Altium software.
- Together with the team, solder all modules together and attach it to the jacket along with the neoprene layer on top.
- Author of section 3, 4, 5, and 6 of the report

Yih Joel Chao: Mainly focused on the hardware part of the project.

- Researched and tested different heating and cooling module with Boby.
- Researched and tested battery with Boby.
- Examined the properties of transistors and constructed H-bridge.
- Designed PCB in the project via Altium Designer.
- Soldered components on the PCB.
- Investigated and constructed different kind of temperature sensor with Boby.
- Poster and Presentation slide design.
- Helped with Neoprene heat trap experiment.
- Putting together the jacket.
- Conducted survey online and analysed responses from volunteers.
- Main author of H-bridge and Jacket customisation (Section 2 and section 7).

Cheuk Man Mong focused mainly on:

- Programming of Microprocessor
- Implementation of algorithms used in the Arduino
- Research and implementation of PWM (including finding a suitable chip)
- Research and implementation of the menu system and LCD display
- Research and implementation of PID controller
- Prototyping of the remote controller
- Testing and debugging of the user interface
- main author of section 8

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