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Heart Rate Monitor

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Thermoelectric Heart Rate Monitor (THRM)

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Abstract

It is crucial that humanity produces clean energy from any source possible in order to reduce our reliance on unsustainable power sources like lithium ion batteries and electricity generated by the burning of coal or fossil fuels. Many small devices are powered by batteries, which can only be reused so many times before they are defective. The mining required for their production is also responsible for many environmental and human rights problems. Consequently, our group has decided to produce a heart rate monitor, which is powered by the user's body heat. We used thermoelectric generators, which consist of panels with two metal-semiconductor sides that generate energy through the transfer of electrons. This is a free and clean energy source as it makes use of thermal energy that would otherwise be wasted. Our design consists of a chest strap, which the thermoelectric generators and an Arduino are attached to. The heart rate monitor is also wired to the Arduino, and straps onto the finger of the user. These are wired to the computer where the heart rate and voltage output are displayed.

The thermoelectric heart rate monitor (THRM) serves as a proof of concept that could eventually be modified into a marketable product. Constraints such as time and money limited its wearability and efficiency. These could be improved in the future with better materials, wiring and code. The Thermo-Electric Generator (TEG) do not power the heart rate monitor directly in our final product. The TEGs feed power to the computer which powers the heart rate monitor. Our hope is that eventually our product could be modified to be powered directly from body heat without relying on other power sources. Later designs would also have a more streamlined appearance and would use more efficient TEGs to generate larger amounts of electricity.

Introduction

Our device can provide a green energy alternative. Power sources such as lithium ion batteries are an essential for energy storage, yet the harvesting of their materials comes at a steep cost. To extract the materials children are often exploited and face unsafe conditions. About one third of the world's lithium comes from Argentina and Chile where it is mined using enormous amounts of water. In places like China and Australia it is common to create lithium by exposing the material to very high temperatures which requires a vast amount of energy. Furthermore, lithium ion batteries are not recycled as frequently as they should be. This is demonstrated by the EU's goal to use 4% recycled lithium by 2030. That means, currently less than 4% of the lithium comes from recycled materials [1]. While there are many ways to combat this problem, our group has created a heart rate monitor (normally powered by lithium ion batteries) that is powered by body heat.

Body heat is a clean source of energy as it makes use of thermal energy that is otherwise wasted. However, body heat as an energy source generates little energy compared to sources such as solar, or fossil fuels, it is still important to conserve energy in any way possible as these small changes can add up.

Our device utilizes thermoelectric generators to convert thermal energy into electrical energy. Thomas Johnathan Seebeck first explored this idea in 1821. He found that an electric potential can develop within the difference in dissimilar materials. This is now known as the Seebeck effect.

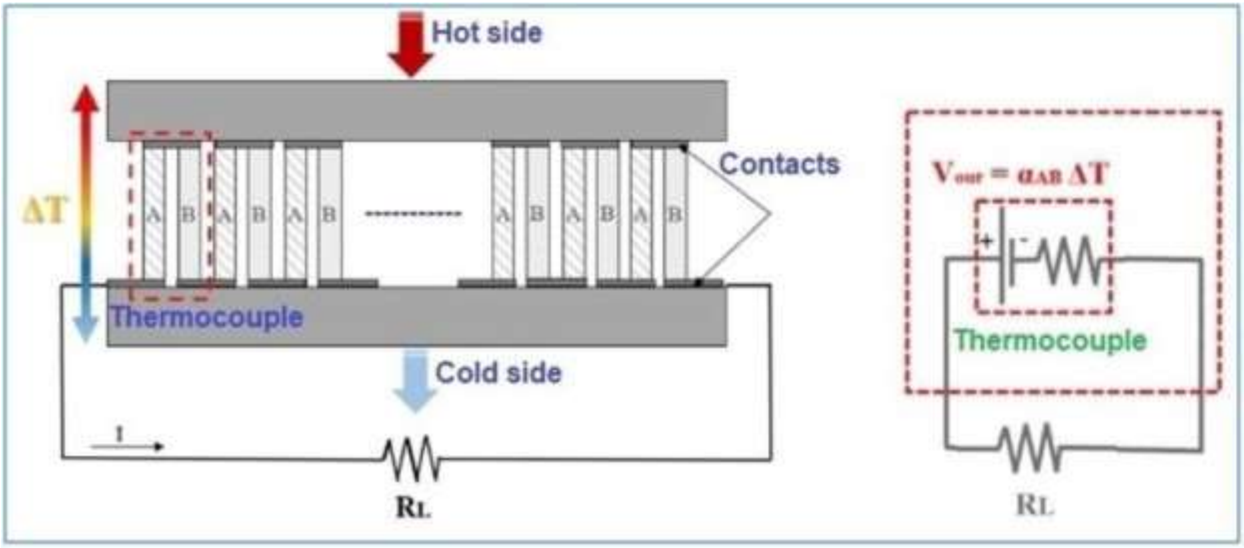

Figure 1. Seebeck Effect

These panels consist of two metal-semiconductor sides, and generate energy through the transfer of electrons. The side that is heated has a higher amount of electrons and therefore a higher amount of energy compared to the cool side. The difference in the amount of electrons causes the electrons to move to the cooler side, and a current is generated. The greater the temperature difference, the more electrons that will flow, and the greater the current generated. The voltage generated is given by the equation $V_{out} = \alpha_{AB}\,\Delta T$, where α_{AB} is the Seebeck coefficients of A and B joined materials, which form one thermo-junction, and ΔT is the temperature difference between the end of the materials. [2]

TEGs have been used to harvest waste heat from pipelines, processors and even hydrothermal vents. [3] Smaller scale examples of this technology include a coffee mug which produces electricity using heat from the coffee and gloves that harness the heat from your hands. We took inspiration from these designs, but chose to use a chest strap since it produces more thermal heat. We also choose to use body heat rather than something like coffee since it is a sustained source of heat compared to the coffee which will eventually cool off. Overall, there are many applications of TEGs, and their technology is rapidly improving. They have enormous potential to convert waste heat into electricity, especially considering their compact size.

Methods and Approach

Our initial design consisted of a jacket covered with thermoelectric panels. These panels were originally intended to power a phone charger so the user could charge their phone on the go. However, the jacket had several issues. A jacket would need to be washable which would be difficult to design because the TEGs would need to be removable. We thought the jacket would also be bulky and uncomfortable considering all the TEGs and other wiring components needed. As a result we switched our design to a running armband that charged a phone because the wiring would be easier in a more compact area. In addition, the product could be marketed towards a more specific audience: runners. However, we discovered the armband had many of the same issues as the jacket such as washability and comfortability. We also found that with our current design we would not generate enough energy to power a phone. Our initial tests with the TEGs showed them to produce around 30-40 mV when the warm side was against a hand and exposed to room temperature. Based on this we concluded that even with seven TEGs we would not produce enough energy to charge a phone, which requires 5 volts to charge. The TEGs also might equilibrate with body heat when worn for long periods therefore reducing the voltage output. A device that does not need to be worn for long periods would be ideal.

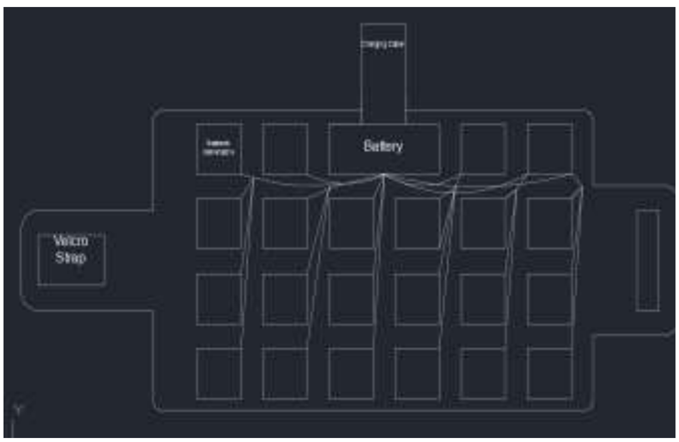

Figure 3. Initial design circuit for armband

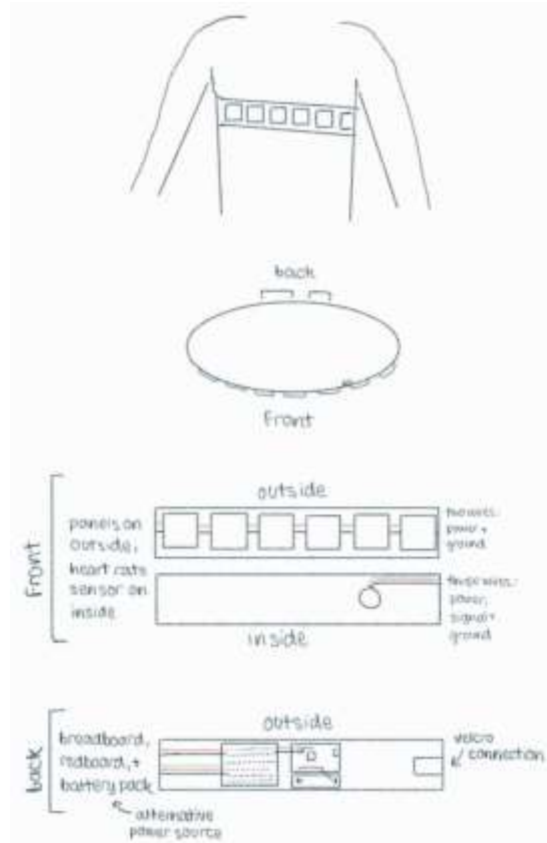

Figure 4. Draft of final product

We shifted our idea a final time and decided upon attaching the TEGs to a chest strap which powers a heart rate monitor. The initial draft of this design is shown in figure 4 and the final product in figure 5. Our initial design required a 3-D printed case for batteries which was designed on Solid Works. Originally, our goal was to display the voltage created and heart rate on an LCD screen. The TEGs did not produce enough electricity to power the LCD so we had to use a battery pack. However, the wiring for the LCD didn't work consistently so we pivoted to displaying the information on the computer instead. In the end we didn't end up needing the battery pack in our final design.

Figure 5. Final product–human testing

Design Details

Our design consists of seven TEC1-12706 thermoelectric generators attached to a chest strap via velcro. The chest strap can be put on and taken off with adjustable straps, so it can fit on many sizes. An Arduino is also attached to it. The heart rate monitor is connected to the Arduino via wiring, and straps around the finger of the user. The Arduino is enclosed in a box that was designed on Autocad and was laser cut using acrylic. The box was made to fit the Ardino's dimensions of 2.7 by 2.1 inches, with cutouts made for the input and output ports. This prevents the user from scratching themselves, or accidentally messing up the wiring.

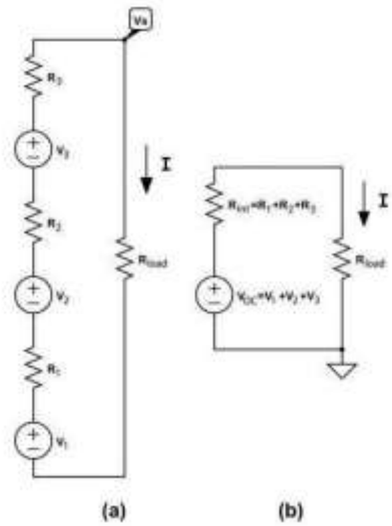

Figure 5. Circuit diagram of TEGs connected in

We decided to use a chest strap specifically because this part of the body has a large surface area. The surface area is important because a greater number of TEGs can be directly against the skin therefore taking in the maximum amount of heat. Furthermore, according to Nakamaura's research article, the trunk of the body, which includes the abdomen, has the least amount of temperature differentiation. [4] This means it is less resistant to changing temperature when exposed to cold weather. This is crucial to maximize the temperature differential and voltage output.

The thermoelectric panels are attached to each other in series. The series arrangement was decided due to the lack of space available for extra wiring between the thermoelectric panels. The first thermoelectric panel in the series has a ground wire that is attached to a ground port; the last thermoelectric panel in the series has a wire containing voltage that is attached to an analog input port. The pulse sensor is attached to the 3.3-volt power port, a ground port and another analog input port. The THRM contains a RedBoard that runs on Arduino code. The pulse sensor has a module in the Arduino IDE called Pulse Sensor Playground, which enabled us to use commands to see when the pulse has been identified and the bpm of the pulse. In the code, the voltage is read in as an analog value and is then converted into a value between zero and five volts. Both the voltage value and the bpm value are printed to the serial monitor located inside the Arduino IDE.

Results and Discussion

Table 1. Shows the voltage output from the TEGs when worn in various temperatures. The room temperature measurement was taken in a dorm room lobby, which was approximately 70 °F. The outside temperature was 31°F according to the apple weather app. We also do not have an exact measurement for the body temperature. We did not have access to a thermometer and the chest strap was worn over a shirt, so it would have been slightly lower than body temperature.

Cold Side	Hot side	Voltage
Room temperature	Body temperature	.378 Volts
Outside (31°F)	Body temperature	.410 Volts

Table 1. Initial testing: voltage output at various temperatures

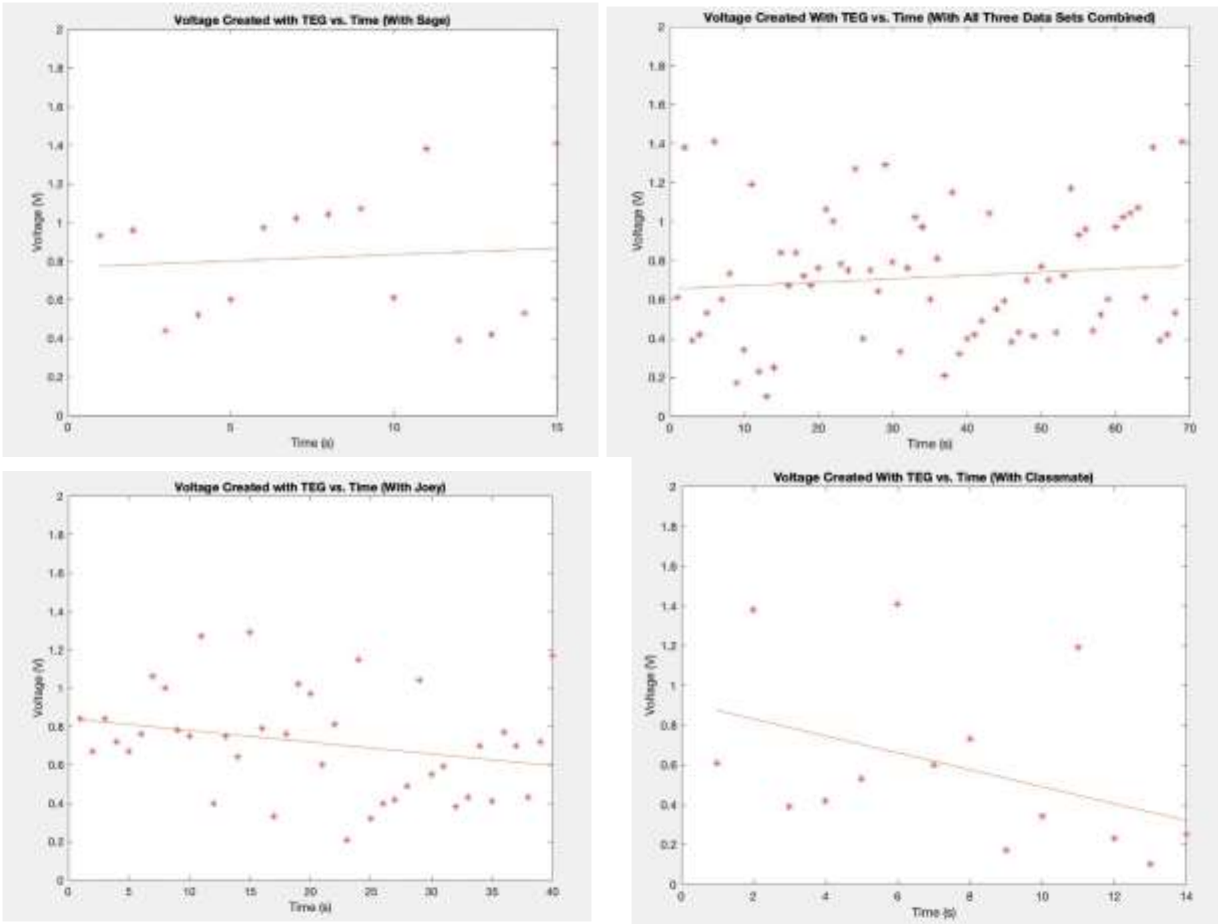

Figure 6. Voltage Created From Various Users

Figure 6, shows the voltage output over time from three users wearing the chest strap. All three of these users wore the chest strap inside heated University buildings. Again, the exact temperature is not known, but we are assuming it was around 70 °F. All users should have similar body temperatures, so the voltage created should remain consistent. However, between the largest and smallest average voltage values as shown in table two; there is a 31.5% difference which is significant. This variation could be mitigated with higher quality materials. Factors such as the user's movement can change the voltage output as well. The chest straps were worn over the clothing of the users, so the thickness of their shirts could alter the temperature differential, which in turn affects voltage output.

Person Testing Device	Average Voltage Created
Person 1	0.715 V
Person 2	0.819 V
Person 3	0.596 V
Average	**0.710 V**

Table 2. Average Voltage Created From Different Users

We hypothesized there would be a downwards slope in voltage output because the TEGs would start to equilibrate with the body heat. However, in the graph with all three datasets combined there is actually an upwards slope in voltage output. This is most likely because the data was only collected for 70 seconds, which is not enough time for the TEGs to start equilibrating. Lastly, despite only getting 0.410 volts when wearing the chest strap outside in 31°F weather, the average voltage output was 0.710 volts when testing the output inside. This is because of improvements made between testing. In our initial tests displayed in table 1, we only collected one data point. The second time around we recorded more data points, so we were able to calculate a more accurate average.

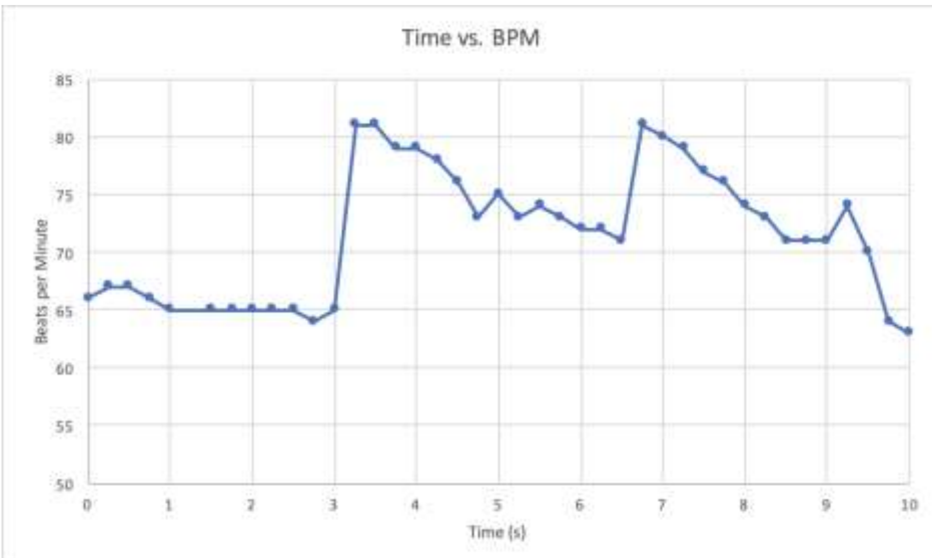

Figure 7. BPM vs. Time

Figure 7. is a scatter plot of beats per minute vs. time. The data looks relatively realistic, which is a good indication the heart rate monitor is working consistently. This data was recorded while the user was sitting still. The average human resting heart rate for adults is 60-100 bpm, and our data falls within that range. However, there are a few erratic jumps. There is a big leap at three seconds and the heart rate jumps from 65 to 82 bpm. Although this jump is not impossible, it is unlikely because at rest the heart rate does not normally fluctuate that much. Therefore, this indicates a potential source of error from our heart rate. With a better quality heart rate monitor there would likely be less jumps in the heart rate over time.

Conclusion

In this project, we were able to successfully create a chest strap that generates power from the user's own body temperature. This demonstrates the potential of thermoelectric panels combined with wearable technology. However, due to time and money constraints the device was not developed as much as we would have liked. Our current model does not produce enough electricity to power the heart rate monitor. However, with a more effective wiring arrangement and higher quality materials that could be possible. The TEGs that we had available to us were made to be CPU coolers, so they were not designed for energy production. TEGs made for producing electricity are made with different materials which have higher Seebeck coefficients; purchasing these would greatly improve the voltage output. A study done by M.S. Sulaiman shows that higher quality TEGs can produce around 0.169 volts per one degree temperature difference. [6] This means 4.732 volts could be made when there is a temperature difference of 28 degrees (70 degree room temperature vs. 98 degree body temp) Based on this, the TEGs he used should be able to power heart rate monitor or even a phone (which needs 5 volts) in any environment colder than room temperature.

Other improvements include connecting the power input from the TEGs directly to the heart rate monitor without the help of the computer. We could do this by adding a rechargeable battery or creating a resistor-capacitor circuit to store and distribute the voltage that the TEG produces. There would also be a display screen to show the user's heart rate, or a Bluetooth connection to show the heart rate on a user's device. To make the device more comfortable and streamlined we could use thinner, flexible thermoelectric generators such as those made with PEDOT:PSS [7]. A thin layer of fabric would also be wrapped around the device.

The skills learned from this project were invaluable, as research, design, trial and error, as well as technical writing are all important experiences within engineering [8]-[9]. This heart rate monitor not only provides scientists and researchers with more valuable information about design, prototyping and proof of concept, but also is also capable of educating the everyday person about the basics of engineering as well as the importance of innovation.

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Appendix 1: Arduino Code

```
//Ardunio code
#include <LiquidCrystal.h>
LiquidCrystal lcd(13, 12, 11, 10, 9, 8);
#define USE_ARDUINO_INTERRUPTS true
#include <PulseSensorPlayground.h>
const int PulseWire = 0;
// PulseSensor PURPLE WIRE connected to ANALOG PIN 0 const int L
// The on-board Arduino LED, close to PIN 13.
int Threshold = 550;
// Determine which Signal to "count as a beat" and which to igno
//PulseSensorPlayground pulseSensor;
void setup() {
    Serial.begin(9600);
    pulseSensor.analogInput(PulseWire);
    pulseSensor.blinkOnPulse(LED13);
    pulseSensor.setThreshold(Threshold);
    if (pulseSensor.begin()) {
    Serial.println("We created a pulseSensor Object !");
    }
}

void loop(){
    int myBPM = pulseSensor.getBeatsPerMinute();
    if (pulseSensor.sawStartOfBeat()) {
        Serial.println("? A HeartBeat Happened ! ");
        Serial.print("BPM: "); // Print phrase "BPM: " Serial.println(m
                                // Print the value inside of myBPM.
        int sensorValue = analogRead(A1);
        // Convert the analog reading (which goes from 0 - 1023) to a v
        //float voltage = sensorValue * 0.004882813;
        Serial.print("Voltage: "); //Prints voltage Serial.println(volt
        }
    delay(1000);
}
```