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Self-Charging Heated Gloves: Physics of Mechanical Motion towards Energy Generation

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Self-Charging Heated Gloves:
Physics of Mechanical Motion towards Energy Generation

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Abstract

It is more challenging to maneuver and perform your daily chores and activities during the wintertime. Working in a cold environment can cause several adverse effects on human performance and health. Workers suffering from exposure to the cold can experience thermal discomfort, increased strain, decreased performance, and cold-related diseases and injuries such as frostbite and hypothermia. The winter season makes it challenging to go outside and perform outdoor chores and activities without the proper attire. Keeping your hands warm is especially crucial because they lose heat very fast if exposed directly to the elements. There is only so much warmth that a thin layer of fabric can provide. On those extra chilly days, the freezing temperatures and blistering winds can seemingly cut right through your gloves and leave your fingers numb. In this paper, we develop a self-heated glove with power generated from the movement of your hand. Like a squeeze flashlight, the depression of a handle will power a motor and create an electrical current. As the current flows through the heating plates woven into the glove's fabric, the plate will release heat to the glove. By using the power of your hands, you will stay comfortable and warm while enjoying outdoor winter activities. The paper also describes the prototype, data, and future applications of the system. What's more, this work teaches students to master various skills, such as research, collaboration, design, construction, and technical writing.

Introduction

It is more challenging to maneuver and perform your daily chores and activities during the wintertime. Working in a cold environment can involve several adverse effects on human performance and health [1]. Workers suffering from exposure to the cold can experience thermal discomfort, increased strain, decreased performance, and cold-related diseases and injuries such as frostbite and hypothermia. It affects people in a long list of industries. In -20°F temperatures, a strong wind can make it feel closer to -55°F, and frostbite can happen within 5 minutes [2]. In cold weather, our bodies constrict the blood vessels that keep our extremities warm and redirect that blood flow to the core to keep our vital organs warm. As a result, our hands and feet get cold more easily and are more susceptible to frostbite, which results in the hardening of the skin.

One common reason for cold hands is inadequate fitting gloves [3]. In particular, gloves that are too large for your hands are a culprit in creating many cold fingers during the winter months. There is only so much warmth that a thin layer of fabric can provide. Unless you have hand warmers, gloves don't make heat. They only retain heat. So, if your hands are cold when you put your gloves on, they'll usually get colder unless you can stimulate some blood flow to your fingers. Heat increases blood flow by expanding blood vessels.

As a team, we decided to tackle these problems by devising a glove that would ease the discomfort. Our proposed self-charging heated glove can generate heat from batteries and the movement of your hand. The glove liner consists of four rechargeable batteries, heating plates, wires, and a hand pump. When the battery dies or its voltage diminishes, the depression of the squeeze handle will power a small generator (dynamo) and create an electrical current that will recharge the batteries and flow through the heating plate weaved into the glove's fabric. The plate will release heat to the glove.

Methodology

Our approach follows the engineering design cycle. After finding the problem, we described what our solution should exhibit, which is a rechargeable heated glove. Before arriving at the decision to create a hand pump generator, we first considered the possible parts of the body that could generate electricity to be in harmony with the glove design. It was decided that the focus would be on the hands because their simple movements will increase the blood flow to your fingers.

With that in mind, we brainstormed possible ways of converting hand movements into energy that could transform into electricity through the use of a DC generator. We decided to design a hand crank to produce electricity and flow through the carbon tape, which will heat the glove. We came up with four designs. The first design consists of the battery pack, hand crank, stitched carbon tape, thermal switch, and wires. The second design includes detachable carbon tape using Velcro, which proved inefficient because it limits the thermal output. The third design uses Teflon wire instead of carbon tape. The fourth design includes a flywheel mechanism to the hand crank. Our decision matrix determined that the first design was the better option because carbon tape is a better conductor and generates greater thermal output. However, in our final design, we used heating plates because we could not purchase the carbon tape. Also, we used a squeeze flashlight because we could not manufacture our hand crank design.

Preliminary Research

Before we were able to start deciding on some of the finer details of our product we first looked into a few things, how we could convert mechanical energy to electrical energy and if there was a product that was similar to ours that already existed in order to find the best way to make our product.

We decided early on that our product would revolve around turning mechanical energy into electrical energy. Since we wanted to keep our product small, compact, and easy to use we looked into different products that convert mechanical energy into electrical energy while being small and user friendly [4]-[9]. The idea of using a dynamo, which created electricity by moving a magnet in a coil of wires, seemed like a good idea to us. We discovered that squeeze flashlights are quite simple, yet effective, by squeezing the trigger, a flywheel, attached to a small dynamo, spins which produces an electrical current which powers an LED or bulb. We thought this would be an ideal way to provide the electricity necessary for our gloves, but instead of powering a light, the squeezing of the trigger would heat the gloves and charge the attached battery pack.

After deciding on using a hand crank to generate the electricity needed, we then needed to decide on a heating element, this element ideally being thin and flexible so as to not make the gloves lose functionality. After some searching, we found an article about a pair of homemade heated gloves, in which carbon tape was used as the heating element [10]. We found that the carbon tape checked all the boxes that we were looking for in a heating element. Unfortunately, we ended up having to use a different heating element as we were unable to get carbon tape in time. The replacement heating element was similar to carbon tape, as it was flexible and put out enough heat.

The one of the final elements we needed to decide on was what kind of battery would be best, we wanted the battery to be small and lightweight and still be able to store as much energy as possible. We compared 2 AA batteries vs 9 V and we decided to use 2 AA batteries.

Design Implementation

Now that we were able to begin designing our product, we began by splitting the design into two parts: the hand pump generator and the glove. By doing this we were able to allocate the design of these parts among ourselves and increase collective knowledge and understanding of the product. Each of us were able to reach levels of understanding of our particular piece of the whole at a level that would have been otherwise impossible if we collaborated on each and every step of the process. However, this did not prevent us from working as a collective to brainstorm ideas or mechanisms that could benefit our product.

Creating and designing a hand powered generator to charge the batteries on our glove was not an easy task. After researching a multitude of different methods of generating this power we got to work designing the most effective version. Our first challenge was finding a way in which we could translate a squeeze motion into rotational motion as dynamos are reliant on rotational motion to output a voltage. We were able to accomplish this by utilizing a rack and pinion to drive a small gear to optimize its mechanical advantage. We also included a number of gear transfers to further decrease the mechanical advantage of the system. By doing this we were able to get the flywheel and clutch mechanism spinning at high velocities in our 3D simulations. However, by getting the flywheel to spin so fast, we needed to alter our original mechanism for the clutch and flywheel. Doing this, we found a number of different options that would be helpful to us, however these were severely limited by 3D printing capabilities (an issue that would pose our biggest challenge throughout the design stage).

Unfortunately, most of this design work came to no avail as the 3D printers available to us were incapable of printing our gears with enough precision to render them useful. Small imperfections in gears are normally tolerable in slowly driven machines with high torque, but for our mechanism utilizing 3D printed gears and parts would have resulted in high amounts of friction, an overly loud and obnoxious mechanism, and catastrophic failure after extended use as they would have worn and degraded much quicker than a normal system. So, as a result, we decided to make use of pre-existing technologies and modify a squeeze flashlight that works on the same fundamental principles that our hand generator would have functioned on. However, it had to first be modified to be able to get an output voltage. The assembly had to be taken apart and the LEDs removed so that the power could be diverted out of the device. In addition, the generated power from the squeeze flashlight is an AC voltage, thus, the two lead wires were first passed through a bridge rectifier circuit which converted that voltage to DC and then could be used. We decided to house all the components for this within the hand generator to minimize the weight of the gloves and increase their durability by removing breakable components. The finished modifications are shown in Figure 1.

The other main aspect of our project was the glove itself. We needed to attach the heating elements, battery pack, and all necessary wiring on the glove. The main difficulty in this process was ensuring that our design would still be comfortable to wear and also the user to have a full range of motion and dexterity.

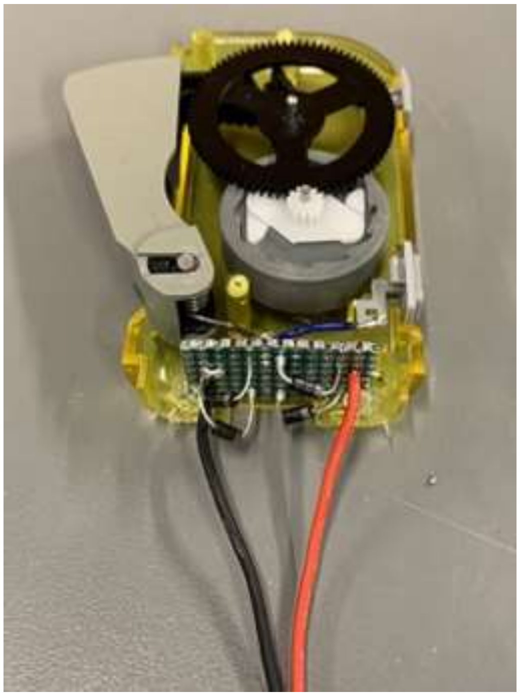

Figure 1: Modified hand crank generator

It would undermine our entire project if the glove heated up but was stiff as a cast. Our initial design was to implement carbon fiber tape technology which could be woven into the fabric. This would allow the glove to be extremely flexible and provide a good surface area coverage for heat distribution. Unfortunately, we were unable to source this material in a timely manner and substituted it for some heating pads with similar properties. Using the heating pads allowed our design to be simplified. We no longer needed stitching because the pads had an adhesive 3M backing, we didn't need silver glue because they already had lead wires, and we didn't need a thermal switch to regulate the temperature because they had a maximum operating temperature of 40 ℃ (104 ℉). Now the bulk of the work for the glove became building the circuitry. The final design is shown in Figure 2.

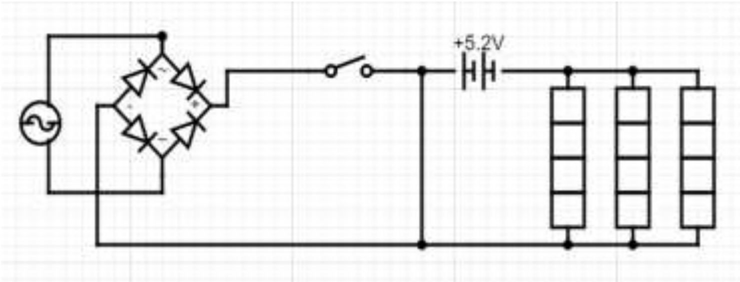

Figure 2: Project circuitry

The left-hand side of the two-part circuit represents the crank and the AC voltage it produces going through a rectifier. The other side is the battery pack wired in parallel with three heating pads. These could have been wired in series to make the battery last longer, however we found that not enough heat was produced when the voltage source was split three different ways. Thus, our final design for the glove and the crank together is shown in Figure 3. The final prototype ended up being bulkier than anticipated, but we determined that it wasn't bothersome enough to negate the warmth it provides.

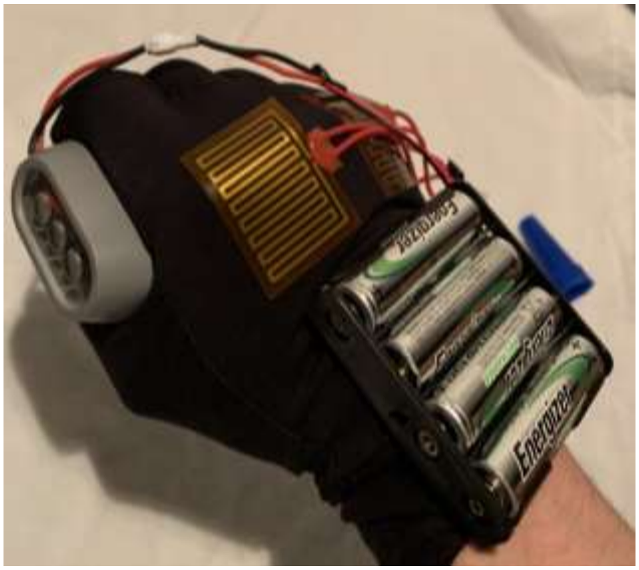

Figure 3: Complete prototype

Data Analysis

To evaluate our success on this project, there were two goals our team set out to achieve. The first was to design a crank generator that would output a sufficient voltage to power our circuitry. The second was to have a working prototype which would heat up to a desirable temperature for warmth.

Although we were unable to manufacture our crank design due to limited access to 3D printing at Northeastern, we were able to make use of pre-existing technology to meet our goals. We were able to use exnovation to overcome the difficulties in obtaining the materials to build our own design. To test the output of the crank, we used the Sparkfun Redboard and a pre-built circuit that they designed to be used as a voltmeter [11]-[12]. This circuit takes in a voltage load and outputs the value on a lcd screen. To be able to capture the data being processed by the serial monitor of the Arduino, the code had to be modified. In doing so, the software was then able to use the serial plotter to record the values and display them with little hassle. This was then wired to the Sparkfun Redboard and the crank output voltage could be measured. For three single pulses (lever depressions), the output is shown in Figure 4.

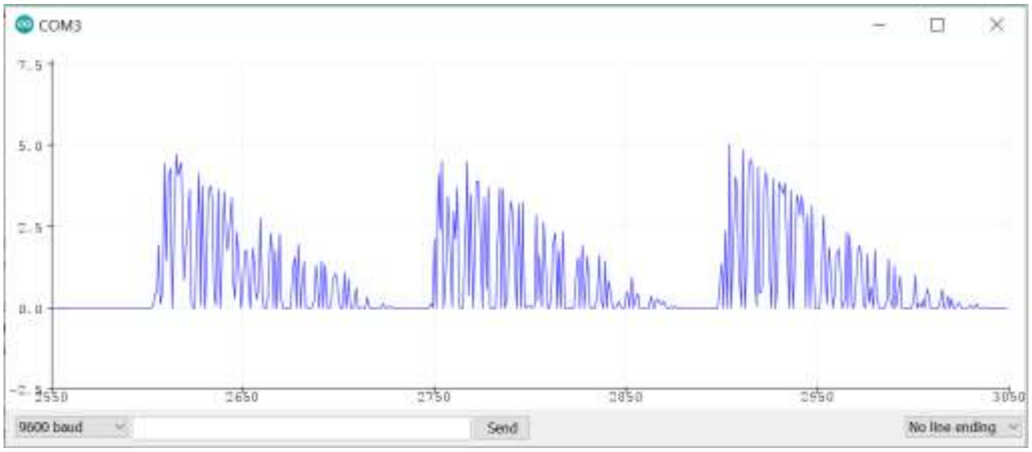

Figure 4: Three pulse output voltage

The peak-to-peak voltage is roughly 4.8V, which is only marginally smaller than the output voltage of the battery pack which supplies the heating elements on the glove. Each pulse lasts around 1300ms. In a similar fashion, the crank was tested by rapidly depressing the crank in a short time interval. The output is shown in Figure 5.

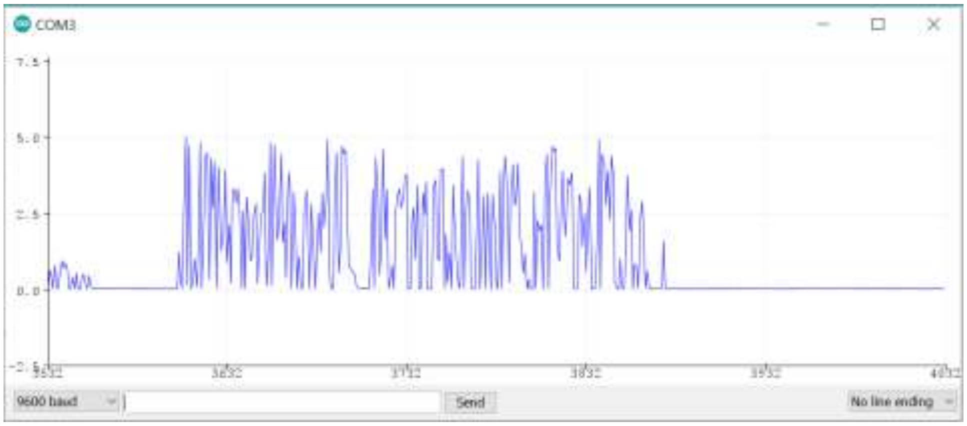

Figure 5: Rapid output voltage

This graph is very similar to the previous graph, with the only difference being the gap between peak voltages, or the frequency. Both of these tests confirmed that the crank would be suitable for our project. Not to mention the crank we designed would have an even higher output because of the increased gear ratio and larger scaling.

To test the thermal output of the glove, originally the plan was to use a similar set up to the data collection described above but utilizing the Sparkfun Redbord’s temperature sensor. However, initial testing led us to believe this wouldn’t be the most accurate result, as the numbers were very inconsistent across several trials. We suspect this was due to the inconsistency in the contact between the glove and the temperature sensor. It is a very small component with only a small flat face to work with. The solution we decided on was to use a digital meat thermometer and manually record the values displayed. Although this method reduced the number of data points we got, we found the data to be far more consistent and reliable. Using video software, we were able to record the digital display of the thermometer and plot the data using time stamps on the video footage. The testing setup can be seen in Figure 6.

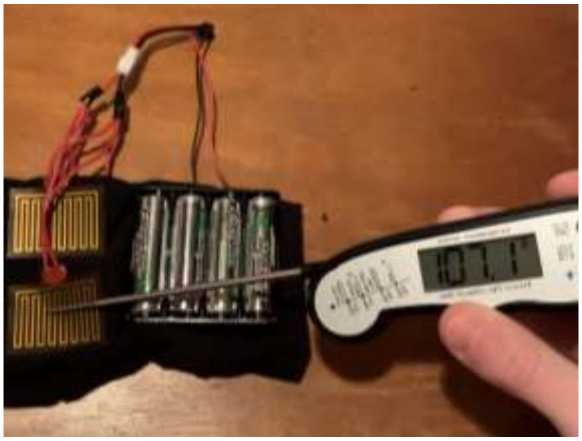

Figure 6: Set up for testing thermal output

A sample trial is shown below in Figure 7.

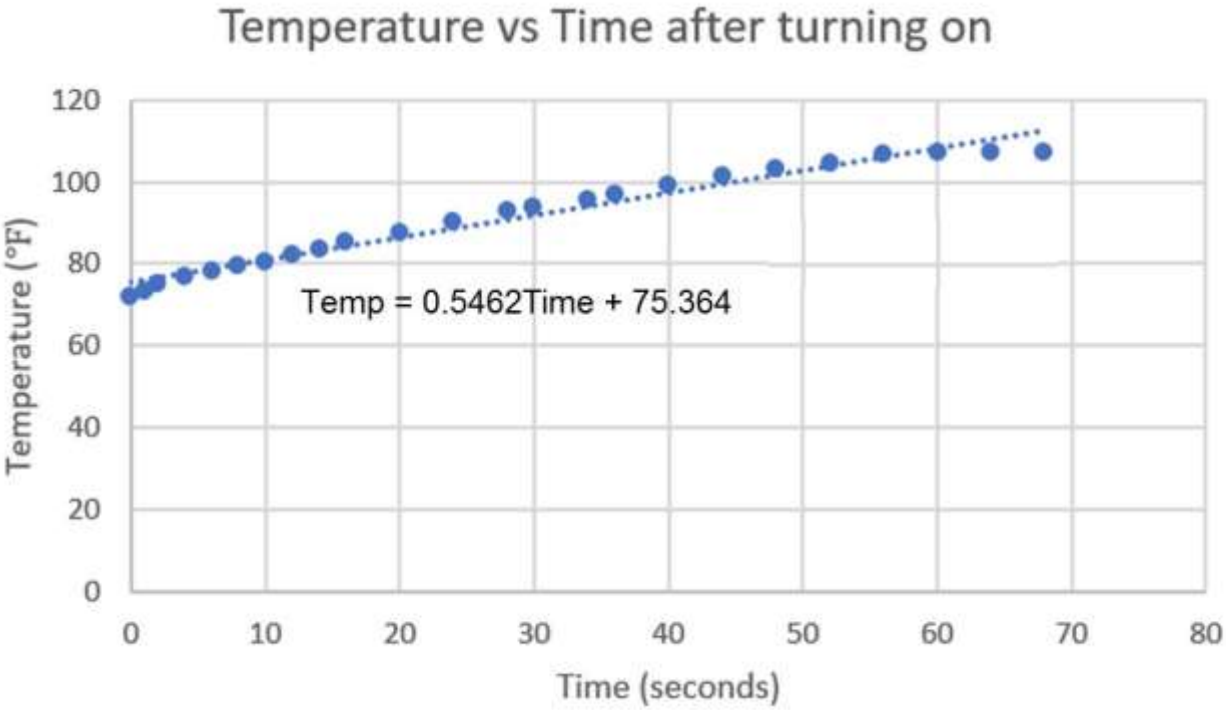

Figure 7: Thermal output of glove

As can be seen in the graph, over a span of 60 seconds the gloves were able to heat up over 40 °F. The gloves heated up at a relatively constant rate of 0.5 °F/second over that interval, until the gloves reached around 107 °F, at which they remained at a constant temperature. This perfectly met our goals without requiring the current to be limited. This is because the heating elements we used had a maximum working temperature of 100 °F and would not get any hotter than that. A temperature of 107 °F is warmer than most hot tubs and will definitely help to combat those frigid winter temperatures.

Ideally, if we had access to infrared video technology equipment, we could have created heat maps for the prototype of the glove. This would have allowed us to get a more accurate measure of the temperatures the glove was reaching and allow us to see how well the heat was distributed across the surface of the glove. This is testing that could definitely be done if this project were to move forward in the future.

Results and Discussion

With our prototype finished and testing concluded, we can effectively say that our product was a success and met all of the design goals that we set out for it. Our highest value goal had to deal with the safety of the product and due to the nature of the heating pads, the glove is extremely safe and could not hurt the user unless they deliberately meddled with its components. Secondly, we reasoned that the gloves and hand pump would need to be highly durable to weather the wear and tear of everyday use. The prototyped hand generator was quite durable as we were able to recycle the hard plastic shell of the squeeze flashlight. This added a large amount of protection to the device, however, vibrations from the spinning gears and flywheel could potentially break the connection between the thin copper leads from the dynamo and the bridge rectifier. The glove, on the other hand, is highly durable and would be very unlikely to break without tampering. Thirdly, we sought for our glove to have a significant thermal output that could keep hands warm on cold winter days. As is shown in figure 6, the heating pad is able to heat up to a very comfortably warm temperature of 107 degrees within a small timespan, rendering the user's hands warm and increasing blood flow to the hands allowing the gloves to trap and insulate the body's heat.

The hand generator and glove were surprisingly cheap to manufacture considering the number of components that we needed to include. Our final cost for our product ended up being $37, giving us a surprisingly low manufacturing cost. This, in conjunction with lower costs for bulk purchases of materials, would allow us to have an impressively high profit margin while still undercutting the competition.

Conclusion

Overall, our project turned out to be a success, we were able to create a heated glove that's powered by the user through the squeezing of a trigger. The glove allowed for finger dexterity very similar to normal gloves, while having the added bonus of heating the user's hands. That being said, there are still a few areas that we would definitely improve if we had more time and access to more resources.

The main improvement we would make would be swapping our heating plate for carbon tape, which was our first choice for a heating element. While the heating plate we used got the job done, there are a few aspects of it that were lackluster when compared to the carbon tape. The first area in which carbon tape would have been better was in heat output, the heating plates used could only reach a max output of 40 degrees Celsius, which is less than the 50 degrees that we could have gotten if we used the carbon tape. Additionally, the carbon tape would have covered more of the gloves, leading to a more even heating of the user's hand, the heating plates we used were unable to cover the fingers which was an area we were hoping to cover up. The adhesive on the heating plate we used was also a bit of a letdown, as it got worse as the glove heated up, had we used carbon tape, we would have been able to stitch the carbon tape to the glove ensuring it would stay on the glove while not restricting movement. Another area related to heat output that we would improve if we were making the ideal product would be some way to set the temperature of the gloves. This would have been accomplished through the use of a thermal switch, or thermal switches, which would turn on or off the batteries depending on the current temperature of the gloves. Since the output of the heating plates was lower than we had hoped, we didn’t feel it was necessary to add in multiple heat settings as 40 degrees Celsius is the lowest temperature we wanted for the gloves. The final improvement related to the heating of the gloves, would be to find a better way to test the heat output of the gloves. We didn’t have access to the best tool for measuring the heat output of the glove, so we had to settle for a thermometer, which got the job done but was not ideal.

Another area that could have been improved is the battery pack. To get the desired heat output we ended up using 4 AA batteries instead of 2 AA batteries, which made the battery pack larger than we had wanted. In the future we would definitely find a way to make the battery pack smaller and sleeker. We are unsure how many batteries we would have needed to use if our heating element was carbon tape, so swapping carbon tape for the heating plates could have solved this issue as well.

Another area we would improve if we were taking this product to the market would be to stitch the out glove to the glove liner, but since we wanted to show off the actual components of the glove we decided not to stitch the outer glove and liner together for the prototype. This would ensure that the components wouldn’t fall out and it would make the glove easier to remove and put on, as it would be one piece instead of two separate pieces. This would also improve the safety of the glove a bit, the glove is safe as is, but stitching everything together would better protect the components and make it less likely for someone to get hurt using the product.

The least important area that we would improve would just be the cosmetic aspect of the glove. If we were to take this product to the market, we would make it in a number of colors and have color options for the hand crank as well.

The final area we would look to improve in the future would just be the quality of the components, mainly of the squeeze flashlights. Since the crank we designed to have 3D printed turned out to be too intricate, we repurposed a squeeze flashlight to act as our crank, but many of the parts were cheap and very fragile. When we attached the inverted to the wires in the squeeze flashlight, a few of them broke because they were very thin and brittle. In the future we would look for a way to incorporate sturdier wires to ensure that nothing broke after someone had purchased the gloves. Additionally, if we were able to create our own custom flywheel and dynamo, it might have been able to increase the output of the hand crank, allowing for a quicker heating and recharging time. Custom parts may have also decreased the size of the hand crank, which is an added bonus, although the hand crank is a good enough size as is.

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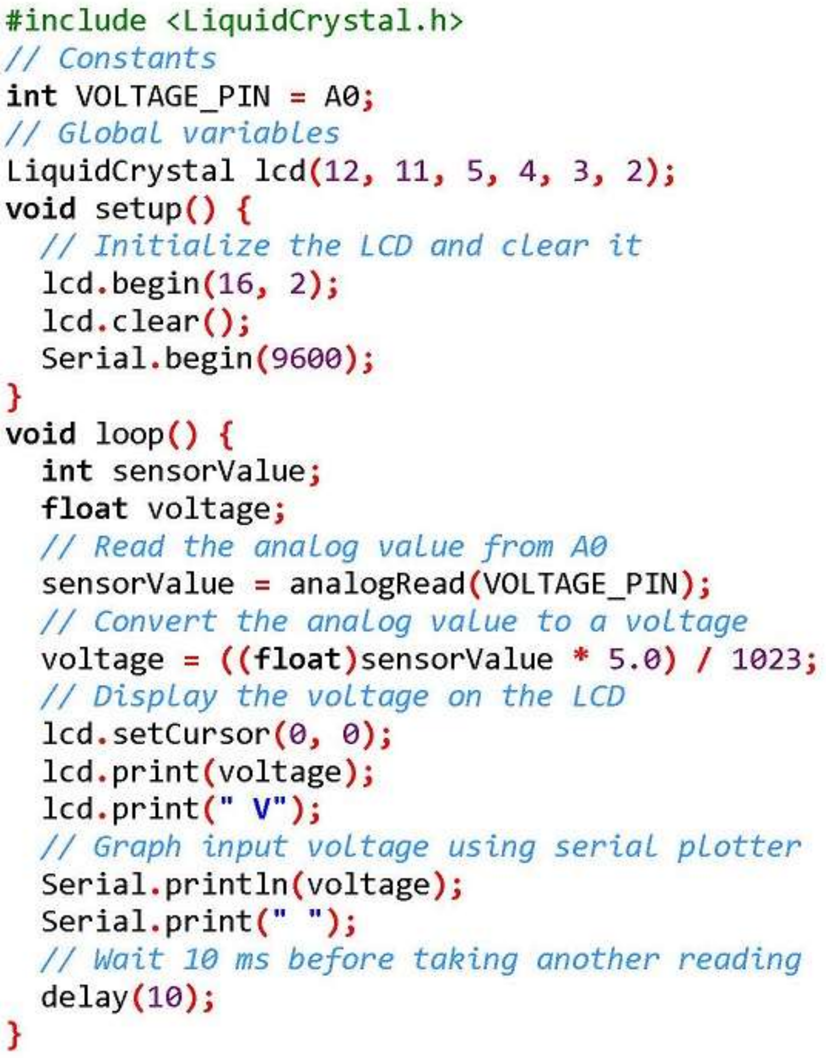
Appendix 1: Code from Sparkfun voltmeter circuit



```
#include <LiquidCrystal.h>
// Constants
int VOLTAGE_PIN = A0;
// Global variables
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
void setup() {
  // Initialize the LCD and clear it
  lcd.begin(16, 2);
  lcd.clear();
  Serial.begin(9600);
}
void loop() {
  int sensorValue;
  float voltage;
  // Read the analog value from A0
  sensorValue = analogRead(VOLTAGE_PIN);
  // Convert the analog value to a voltage
  voltage = ((float)sensorValue * 5.0) / 1023;
  // Display the voltage on the LCD
  lcd.setCursor(0, 0);
  lcd.print(voltage);
  lcd.print(" V");
  // Graph input voltage using serial plotter
  Serial.println(voltage);
  Serial.print(" ");
  // Wait 10 ms before taking another reading
  delay(10);
}
```