Energy Harvesting Of Human Kinetic Movement

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ABSTRACT

Development of kinetic energy scavenging applications from the human body necessitates additional research to assist in designating a mounting position for a potential device. A data acquisition system adequately provides a parametric average power comparison among four locations on the body (waist, upper arm, hand, and calf) for both a male and female subject. Experimentally, the hand-held device provided the highest average power. Thus, subsequent investigation at set speeds provides further analysis of the output's characteristically linear behavior. The physical energy-harvesting device features a plastic tube casing wrapped with the stationary coiled wire through which a neodymium magnet oscillates. While the data delivers a practical comparison for a mounting point and angle, size and power output may increase or decrease depending on variable device parameters.

I. INTRODUCTION

The amount of scavengeable energy around us goes largely untapped. The energy scavenging industry has tremendous potential for growth and attracts people from every technical discipline. Every motion the body makes provides an opportunity for acquiring scavenged energy. The unpredictable nature of solar or wind energy sources makes scavenging energy kinetically the most appropriate and effective way to reliably power a battery-less standalone device. This project captures this energy from the running motion of the body, examines the amount of energy that can be harnessed, and explores viability of certain accessories using the collected energy. We examine the energy potential from various parts of the body and with multiple orientations of the scavenging device. The goal is to create a useful set of data that opens the door for others to easily enter the field and create products that can benefit from the use of scavenged energy.

The project originally started to create a device with features that would address this need but the lack of data in this field reveals the need and usefulness for the data that we collect. Data collection in this parametric fashion creates the potential for applications that go well beyond just running. Examining the energy ranges acquired from various parts of the body provides data that others can use for any range of devices, as the different mounting angles greatly varies the resulting current output. Testing the device at the waist, upper arm, hand, and calf provides an overall comparison of the relative force exerted at each point.

II. BACKGROUND

One kinetic energy harvesting method utilizes a permanent magnet moving through insulated copper wire coil of N turns. Also seen in "shake flashlights", this method induces an electromotive force (EMF) as calculated by Faraday's Law. This principle generalizes for kinetic energy harvesting applications characterized by single-axis oscillating sources enabling relative motion between the permanent magnet and coil.

The induced EMF can be calculated by Faraday's Law. In general, Lenz' Law states that the induced current in the coil produces a magnetic field opposite to the change in the magnetic field which produces it. As the N-polarity end of the magnet approaches the solenoid entrance, the current direction follows the direction of one's fingers according to the right hand rule. As the magnet changes direction, the same magnetic field opposes that of the first, reversing the current direction, producing an alternating current with the continual oscillation of the magnet. The induced EMF across the copper wire varies based on the number of turns, length of solenoid, area of loop, etc., while the induced current increases proportionally with the relative speed of the magnet through the coil. A higher magnet velocity moves electrons through the circuit faster, thus resulting in a larger current.

For testing purposes, a simple resistor interfaces the current input with the Arduino DC voltage input.

III. Requirements and Specifications

Marketing Requirements	Engineering Specifications	Justification
1, 2	*Weighs* no more than 8 oz.	Weight does not interfere with regular running stride
1, 2	Less than 4.5” in *width*	Grippable by both test subjects
7	Non-volatile SD memory	Data available after testing for analysis and presentation
5, 6, 7	Parts obtained from public retailers	No customized parts allow for easy reproduction of device and testing method
4	Physical switch	Allows for easy data acquisition control while running
1, 2, 3	Completely contained	No open wires allows for secure handling
Marketing Requirements 1. Ease in handling and carrying 2. Surface mountable 3. Sturdy enough for repetitive motion 4. Intuitive interface with recognizable controls 5. Reproducible 6. Adaptable for energy harvesting applications 7. Acquirable data with common hardware		

Table 2: Summary of Marketing Requirements and Engineering Specifications

IV. DESIGN & FUNCTIONAL DECOMPOSITION

Energy Scavenging & Data Acquisition System

Level 0 Block Diagram

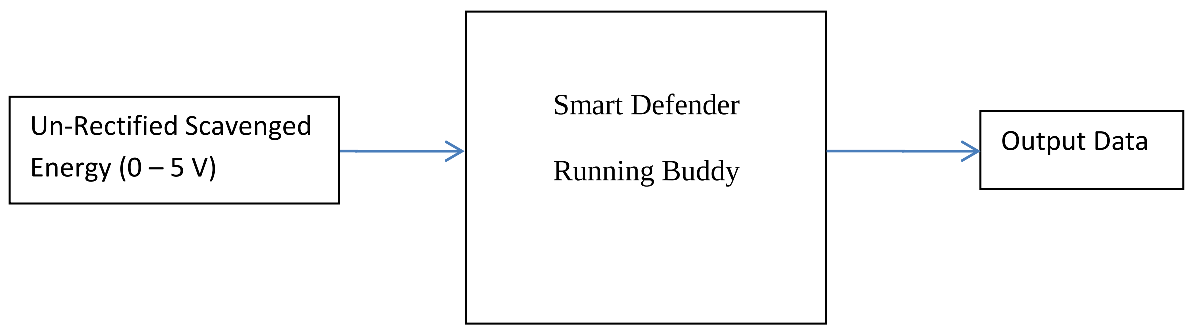

Figure 1: Level 0 Input/Output Block Diagram for the Smart Defender Energy Scavenger

- Inputs
  - Scavenged energy generated from the running motion
- Outputs
  - Output Data used for analysis and calculations

Level 1 Block Diagram

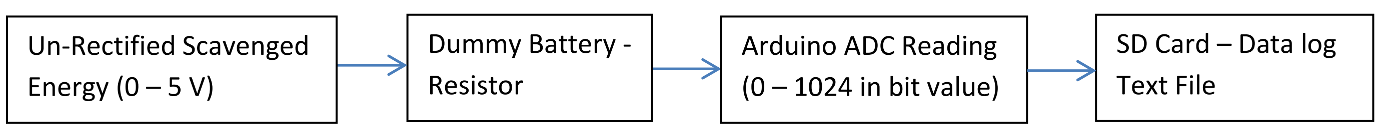

Figure 2: Level 1 Input/Output Block Diagram for the Smart Defender Energy Scavenger

- Stages
  - Scavenged Energy
    - Raw energy created from the dynamic running motion
  - Dummy Battery
    - Allows for calculation of power data based on the generated voltage across it.
    - Controls the scavenged energy voltage and keeps it safely in the readable ADC range.
  - Arduino ADC

        - Reads the voltage on the A0 analog pin – 5V * (Reading / 1024)
    - SD Card
        - 8GB SD Card provides easy to use avenue for logged data

During data acquisition, the device is positioned accordingly and powered up. The Arduino immediately begins appending to the data log starting with a max value write of 1024 to indicate the separation of runs if data is not pulled from the SD card immediately. Data is logged in a large column with each point on its own line for easy exporting to analysis software like Excel.

Original Prototype Design with Added Features

Level 0 Block Diagram describing functional requirements

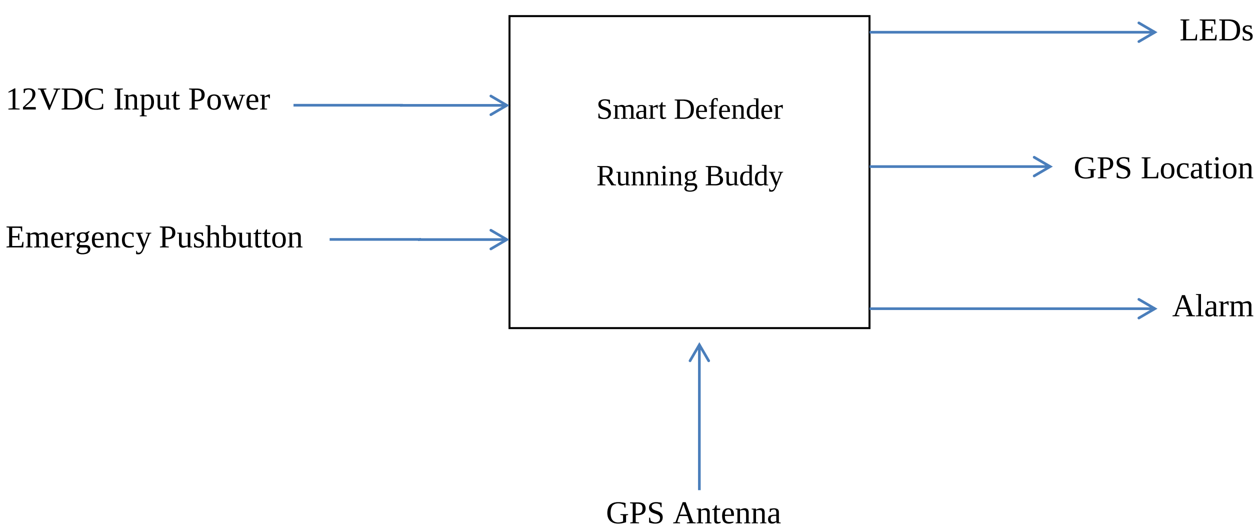

Figure 3: Level 0 Input/Output Block Diagram for the Smart Defender Running Buddy accessory

Functional Requirements

- Inputs
    - 12 VDC Input Power: Power generated from energy-harvesting device
    - Emergency Pushbutton: Located on device to trigger alarm
    - GPS Antenna: Input data from Global Positioning System
- Outputs
    - LEDs: Continuous light emission for visibility
    - GPS Location: Outputs location data to a remote device
    - Alarm: Audible distress signal

During use, the device receives a 12 V input voltage to potentially power LEDs, GPS and an alarm system. An overall system power on/off switch controls the LEDs, while the GPS and alarm require an additional pushbutton trigger to activate, as shown in *Figure 1*.

Level 1 Block Diagram describing System Architecture

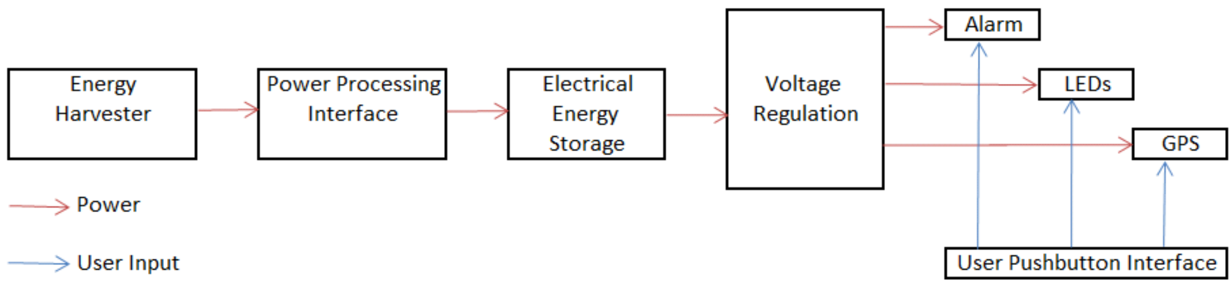

Figure 4: Level 1 Block Diagram for the Smart Defender Running Buddy accessory

Functional Requirements

- Stages
  - Energy Harvester
    - Scavenges energy from running motion
  - Power Processing
    - Takes scavenged energy and converts it into storable energy
  - Energy Storage
    - Stores energy to power device functions
  - Voltage Regulation
    - Converts stored energy into ranges required for output features
  - User Input
    - Controls which outputs are activated
    - Controls outputs
      - LEDs: Continuous light emission for visibility
      - GPS Location: Outputs location data to a remote device
      - Alarm: Audible distress signal

The level 1 Block Diagram shows the system architecture with power and user input controls for the functionality outlined in the engineering requirements. The energy harvester mirrors the kinetic energy from the running motion into linear motion. The power processing interface transforms this into electric energy and outputs through to an energy storage device. The voltage regulator sources the appropriate power output to each function block, where the outputs are controlled by the user.

V. Test Plans

Track Testing:

Track testing includes fastening the device to a specified body limb and running a ¼ mile (400 meters) while logging the generated voltage on the Arduino. The averaged voltages squared and divided by the 100 Ω simulated load resistance yields the average power and thus, the nominal number (in mW) characterizing each of the four positions tested on the body. The time of the run is also recorded to calculate the average speed of a single trial for added perspective on the data. The nominal number indicates a reliable amount of power that can be generated for any period of time, short or long, so that one can determine what features they can power with a similar scavenging system.

Independent variables:

- Limb position and device angle
    - Hand
        - Vertical device orientation
    - Calf
        - Vertical device orientation
    - Waist
        - Vertical device orientation
    - Upper Arm
        - Vertical device orientation
        - Horizontal device orientation

    Device orientation is selected for the largest range of motion of the magnet. Upper arm was tested with both orientations as vertical proves to generate negligible power if any at all.

- Male vs. Female
    - Compare the data generated from both male and female to see if there are any noticeable differences in generated energy and any logical reasons why this is the case.
- Run
    - Distance
        - ¼ Mile
    - Time
        - Measured to give more perspective on the data.
- Device resistance (dummy battery)
    - Simple, effective simulation of battery charging for power calculation.

Dependent variables:

- Voltage
  - Measured on the Arduino across the resistor for power calculation
- Power
  - Calculated and analyzed to find the nominal power that is generated for each bodily limb / device position.

Treadmill Testing:

Treadmill testing is meant to take the best option (most power generated) from the track testing and run with the device at fixed speeds to show how generated power fluctuates as one runs slower or faster.

- Hand
  - 5.0 mph
  - 6.0 mph
  - 7.0 mph
  - 8.0 mph

Data acquisition system: (Arduino code, input/output, circuit diagram

- Program Code: Consult *Appendix D* for data logger code.
  - The Arduino code consistently reads a voltage value on the A0 analog pin and records that value to the attached SD Card following this formula for conversion to voltage:

$$Voltage\ Value\ (V) = 5V * \frac{A0\ Read\ Value}{1024}$$

**Note:* A0 Read Value can vary from 0 to 1024 making the conversion to voltage possible using the binary reading ratio multiplied with the Arduino reference voltage.

Data Modeling

Collected data is graphed according to the time of the run and a nominal power value is calculated for the average energy one could generate with this type of scavenging system. The idea being that one can take this data and apply it to their projects, using it to know what they can power with a similar scavenging system. We present the data to show what types of power can be generated by the motion of the human body. For this data and its corresponding analysis, consult *Section VII* of the report.

VI. Development and Construction

The device includes a main sliding magnet, two repelling magnets, coil, casing, and adhesive material. The construction materials were selected for optimal current generation and minimal weight and size to fit within budget constraints. The engineering specifications outlined in Section III provided the guidelines for each decision.

First, Neodynium magnets provided the highest density magnetic strength available online at an affordable cost. At 0.5” in diameter and 1” in length, the cylindrical magnet provided 5484 surface Gauss rating with 16.68 pound pull strength at 0.845 oz. The two repelling magnets were smaller with a 0.375” inch diameter, 1” in length, 5232 surface Gauss and 8.926 pound pull strength, and weight of 0.478 oz. The device required a size-customizable, transparent, rigid casing to ensure full magnet swing through the coils with little friction. We opted to roll transparent projector paper into ¾ inch tubes to house the magnets. Experimentally, we found a 7” long tube encasing provided a sufficient buffer between the repelling magnets to allow full swing through the 1” long coil system. The 1000-turn coil wrapped around the center of the transparent casing is composed of 40 gauge wire secured between two pieces of electrical tape 1 inch apart. Electrical tape provided sufficient support for the ends of the tube to secure parts. Finally, 6” of wire was left off from each side of the coil to attach to the Arduino input and output pins, adding a 2.5” width by 3” length to the device with the inclusion of the 9V battery.

During the testing phase, a belt and elastic wrap attached the device in the four specified mounting positions during each run.

VII. Integration and Test Results

Integration Notes

- The *scavenged energy* comes into the data logging device *unmodulated* to avoid the voltage drop that would come with signal rectification (~0.7V - 1.4V).
- The ADC on the Arduino only *reads positive* values from 0 - 5V but the device generates *positive and negative* voltages as the magnet slides back and forth.
  - The comparison test shown in *Figure 5* displays the differences between the polarities of the signals. Flipping the leads ended up increasing the power for both runners by a similar amount.
    - This allows an estimation accounting for the *opposite polarity* signal on the other limb positions as well. The scaling factor for this test should nominally hold for the other limb positions given how the magnet moves through the coil.
      - This provides a power range for each of the limb positions and the nominal power average with both sides included would sit in the middle of that range.

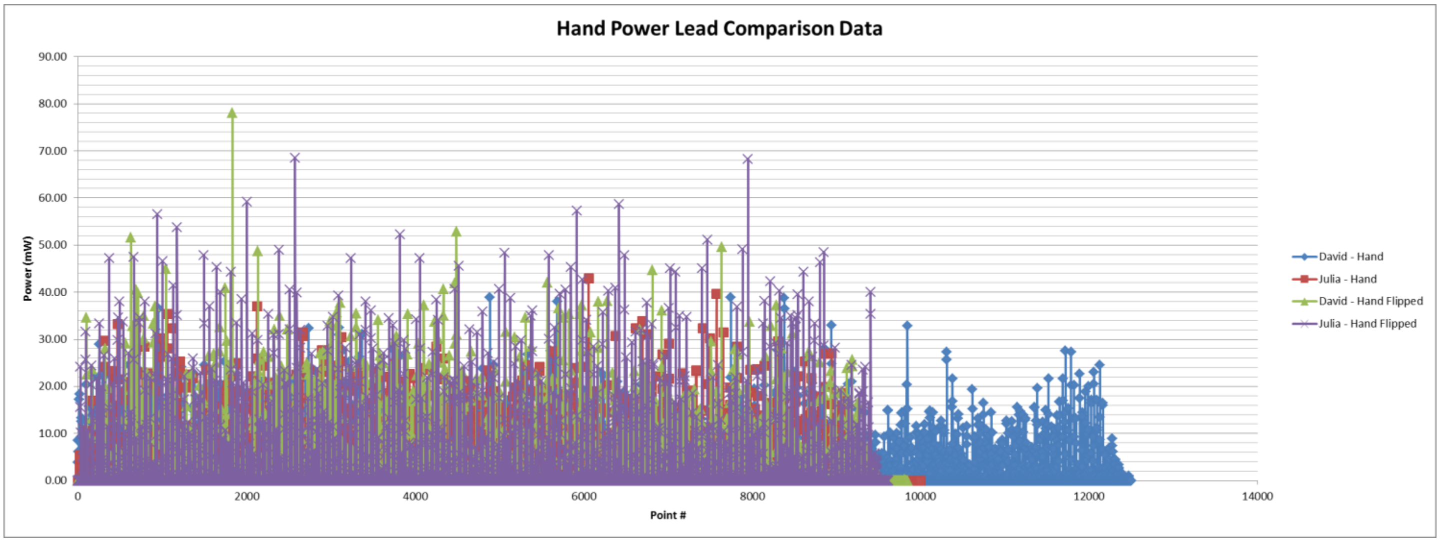

Figure 5: Power data comparison with device in hand – normal lead position and flipped

Power Comparison

- Normal Lead Orientation
  - Male: 3.94mW
  - Female: 3.92mW
- Reversed Lead Orientation
  - Male: 5.50mW
  - Female: 5.76mW

- Scaling Factor

$$\textit{Scaling Factor Male} = \frac{\textit{Reverse Lead}}{\textit{Normal Lead}} = \frac{5.50mW}{3.94mW} = 1.3959$$

$$\textit{Scaling Factor Female} = \frac{\textit{Reverse Lead}}{\textit{Normal Lead}} = \frac{5.76mW}{3.92mW} = 1.4694$$

  - The scaling factor creates a range for each of the other limb positions. With both signals combined, the nominal generated power is the average of the high and low points of the range. Those two numbers (from the male and female ranges) average to find a single nominal value for power generated from that limb and position.
  - All positive power values that read at least a 5 on the 1024 range (~5.9µW) are averaged to create the lower bounds of each range.

Power Data for the Energy Scavenged

- **Hand Data**

For the data runs with the device in hand, the runner grasps the Arduino with the power connection on top and the coil on the opposite side towards the body. *Figure 6* shows this technique and all hand data runs are ran in this position.

Figure 6: Device held in hand with vertical orientation

Figure 7 shows the graph produced from the normal lead orientations for the hand data for both male and female.

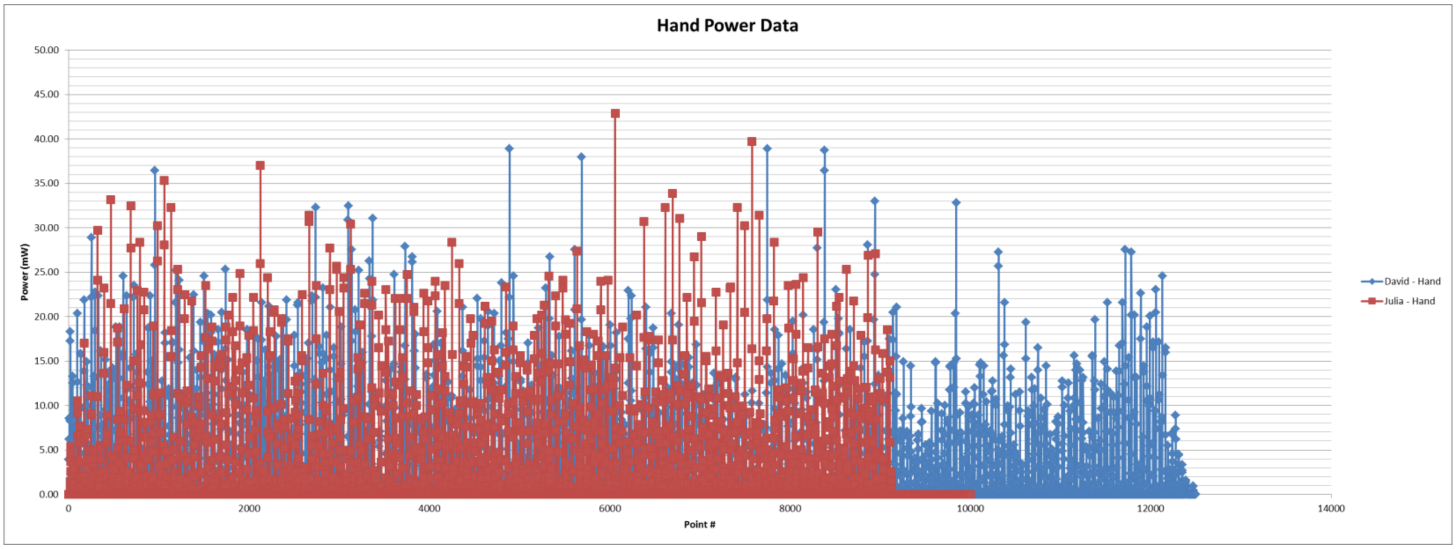

Figure 7: Power data scavenged from male/female runs with device held in hand

Run Times:

Male: 1:54.5 or 114.5s

Female: 1:47.7 or 107.7s

Nominal Power Generated:

Male: 3.94mW – 5.50mW

Female: 3.92mW – 5.76mW

Combined Average: **4.78mW**

Additional Data Analysis:

The hand has a large range of motion while running and as a result has some of the highest numbers for scavenged power data. Numbers often reach over 20mA at any given time. The average power for both reaches over 3.9mW with all positive power values averaged. The high end of the range comes directly from the flipped lead test to create a total combined average of 4.78mW. This proves to be the best position for scavenging with the device as the hand has an efficient, large, and quick range of motion to keep the magnet moving at high speed.

- **Calf Data**

For the calf data runs, the runner wraps the device on the upper part of the calf for device stability. Note that as with the hand runs, the power connection is on the top side of the device during the run with the coil oriented vertically as well. *Figure 8* shows this orientation and depicts the device position for the following data runs.

Figure 8: Device wrapped on the upper part of the calf with vertical orientation

Figure 9 shows both male and female runs with the device wrapped on the calf with normal lead orientation. The calf data proves to provide much less power than the hand as the main force driving the magnet movement comes as the foot contacts the ground with each stride.

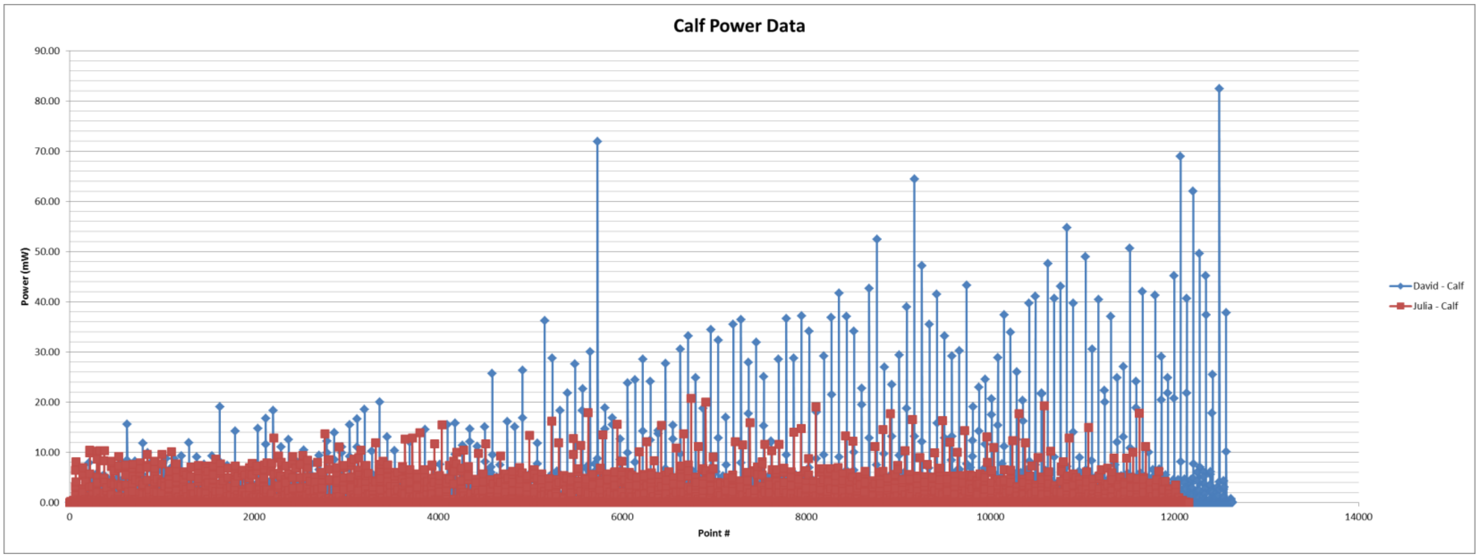

Figure 9: Power data scavenged from male/female runs with device wrapped on calf

Run Times:

Male: 2:01.0 or 121s

Female: 1:55.4 or 115.4s

Nominal Power Generated:

Male: 2.31mW – 3.22mW

Female: 1.71mW – 2.51mW

Combined Average: **2.44mW**

Additional Data Analysis:

Vertical orientation of the calf data yielded smaller numbers that some of the other limb positions but stays reasonably constant throughout the run and comfortably within the power range throughout most of the dataset.

One anomaly is the nominal increase of spikes over the course of the run on the male data set. The bulk of the data remains in the comfortable data range but the very high spikes skew the average a marginal amount higher than it would be otherwise. One explanation could be the wrapping loosening as the run went on but the core of the data would also increase in that case but it does not. Notably, the spikes are also reasonably “rare” given how quick the Arduino logs the data.

➢ Hip Data

For the hip runs, the runner wraps the device around a belt that is fastened around the waist. The device is placed on the right side of the hip for these runs but either side is fine as long as the power connection is on the top side and the coil oriented vertically. *Figure 10* shows the hip data runs. The hip data set proves to be the closest the hand in terms of power generated. The hip has nice power spikes when each stride contacts the ground.

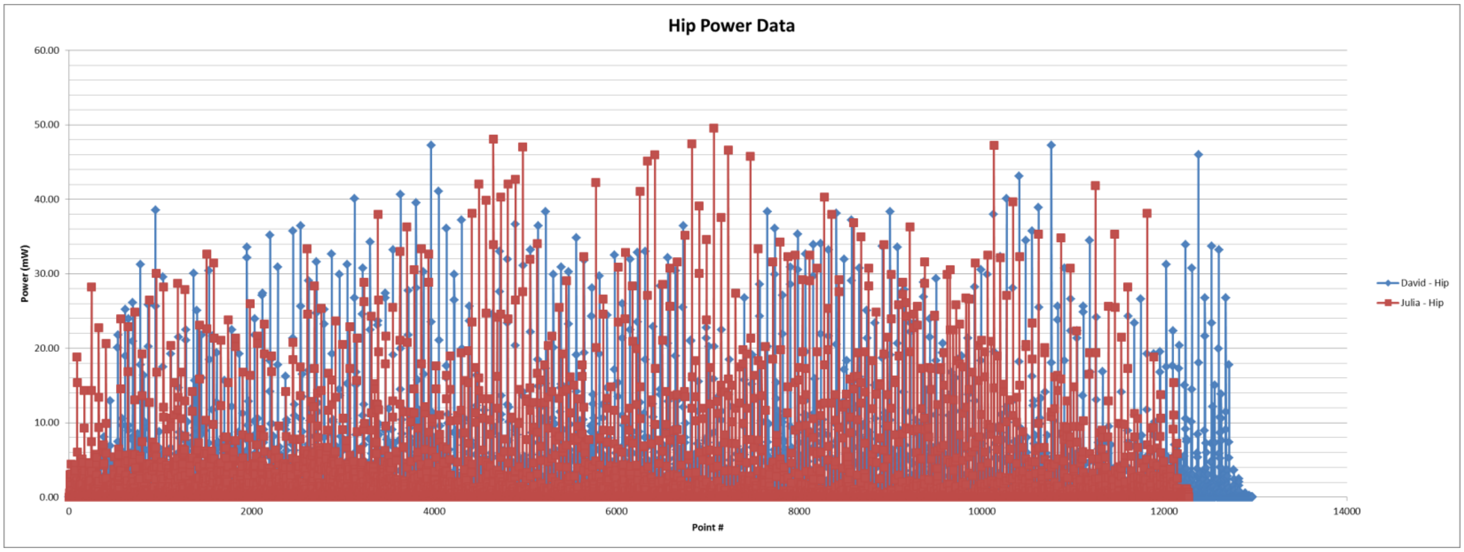

Figure 10: Power data scavenged from male/female runs with device on hip – vertical orientation

Run Times:

Male: 2:01.6 or 121.6s

Female: 1:57.7 or 117.7s

Nominal Power Generated:

Male: 2.85mW – 3.98mW

Female: 2.90mW – 4.26mW

Combined Average: **3.50mW**

Additional Data Analysis:

Hip data provided some good number spikes but belt used to fasten the device to the body would occasionally loosen and require retightening so there are occasional spikes that go marginally higher than they would otherwise. The spikes are infrequent enough given how fast the data is logged to not throw of the average in a dramatic way.

- **Upper Arm Vertical Orientation Data**

For the upper arm data runs for vertical orientation of the device, the runner wraps the device around the upper part of the bicep with the power connection on the top side as with the other limb positions. *Figure 11* shows the device in this orientation and depicts the technique used for the vertical orientation male and female runs.

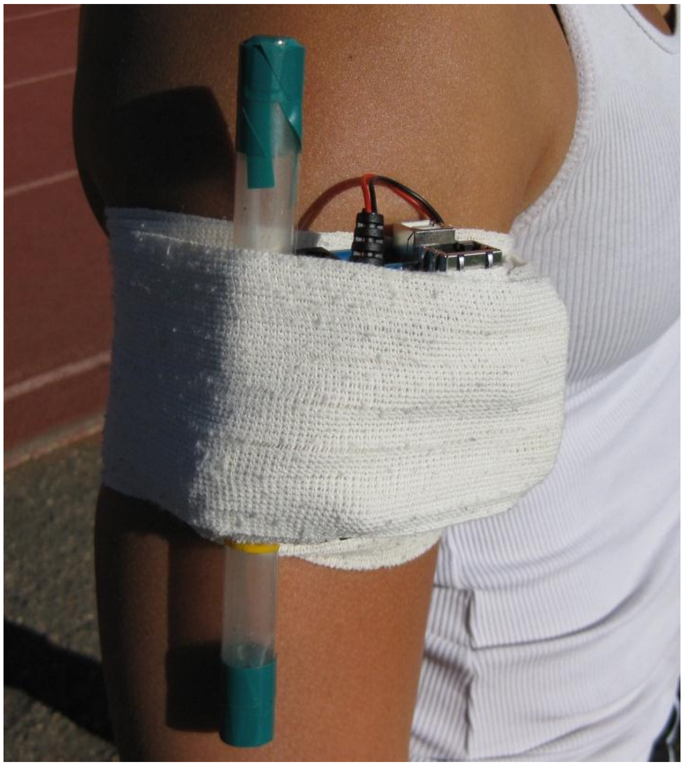

Figure 11: Device wrapped on upper arm with vertical orientation

The upper arm motion is almost entirely level on a horizontal plane and as a result, the vertical orientation for the upper arm yielded the smallest power numbers for any of the data runs. *Figure 12* shows the almost negligible energy generated. The male data run did not move the magnet enough to produce any numbers over a couple µW. The female dataset provides noticeable power but still not on a useful level compared to the other limb positions.

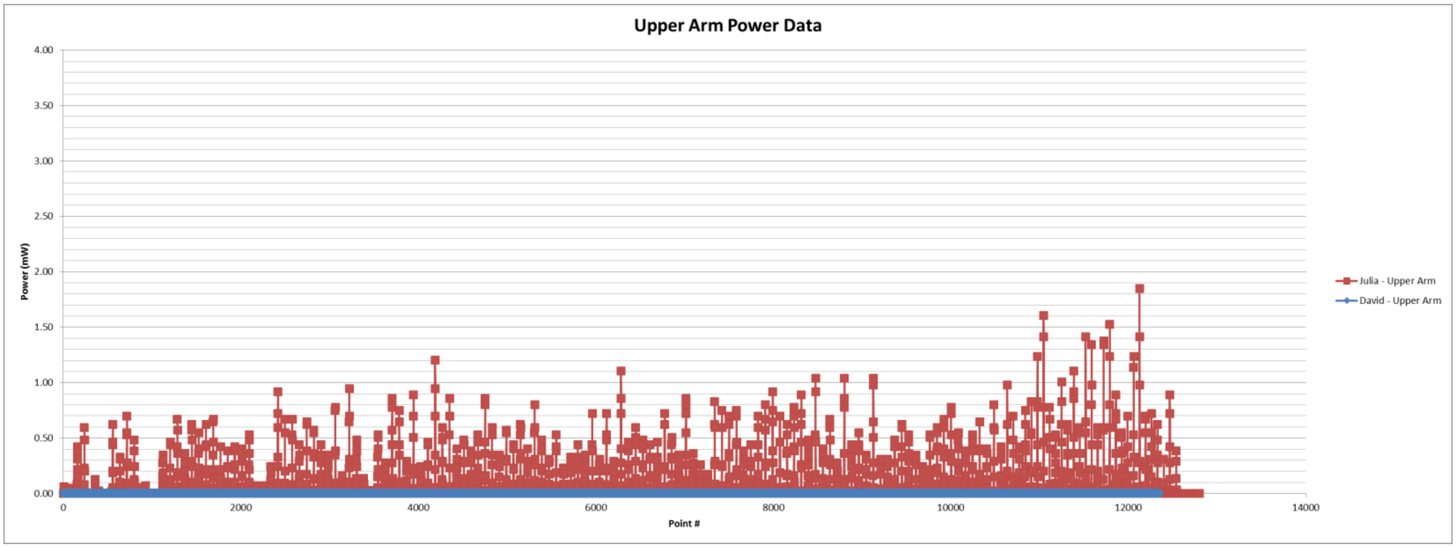

Figure 12: Power data from male/female runs with device on upper arm -vertical orientation

Run Times:

Male: 1:56.4 or 116.4s

Female: 2:00.1 or 120.1s

Nominal Power Generated:

Male: 0.00mW – 0.00mW

Female: 0.20mW – 0.49mW

Combined Average: **0.24mW**

Additional Data Analysis:

The power scavenged from the upper arm with the device parallel to the limb (vertical orientation) proved to provide little to no energy at all. On spikes the power peaks at around 2mW which is much lower than any of the total averages on other tested body locations.

For the upper arm, vertical orientation does not prove feasible for device applications but is the most natural way and space effective way to orient the device. The horizontal orientation runs show a better example of potential energy from the upper arm.

- **Upper Arm Horizontal Orientation Data**

For the horizontal upper arm data runs, the runner wraps the device on the upper bicep similar to the vertical orientation upper arm runs. Here though, the coil is oriented perpendicularly to the arm and the power connection is on the forward side of the body for access. *Figure 13* shows this orientation and depicts the wrapping method used for these data runs.

Figure 13: Device wrapped on upper arm with horizontal orientation

Compared to the vertical orientation, the horizontal positioning for the device manages to scavenge much more energy. However, even with this orientation, the upper arm proves to generate the lowest power numbers over the tested limb positions. The small range of motion the upper arm has during a run attributes for these lower data numbers. *Figure 14* shows the male and female data runs for the horizontal orientation of the device. Note that even with some reasonable power spikes, the nominal power range for the upper arm remains very low.

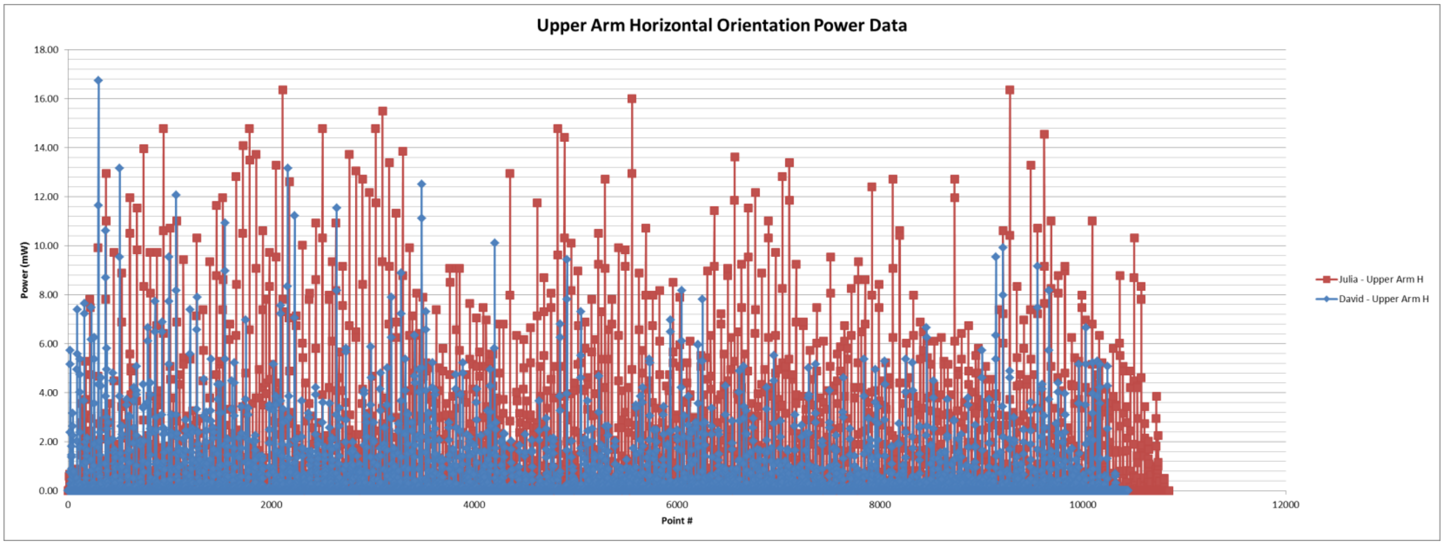

Figure 14: Power data from male/female runs with device on upper arm - horizontal orientation

Run Times:

Male: 1:54.4 or 114.4s

Female: 1:57.2 or 117.2s

Nominal Power Generated:

Male: 0.99mW – 1.38mW

Female: 1.57mW – 2.31mW

Combined Average: **1.56mW**

Additional Data Analysis: The horizontal orientation of the device on the upper arm utilizes the larger range of motion the arm can provide and much more energy can be scavenged this way. The upper arm still does not compete with the other limb positions but yields an average high enough to prove feasibility if one needs to place a device there. However only very low power applications would make sense as both orientations of the upper arm provide the lowest power numbers scavengeable from the body.

➢ **Treadmill Data**

Male Treadmill Runs

The treadmill data runs use the same hand device orientation depicted in *Figure 15* and *Figure 16*. The male treadmill runs show that as anticipated, the power scavenged increases with the speed of the runner. Note that the running motion on a treadmill is different from that of the track as the body is not moving forward. This produces noticeably less power than on the track but the purpose of this data is for the trends in power that come with the runner's speed.

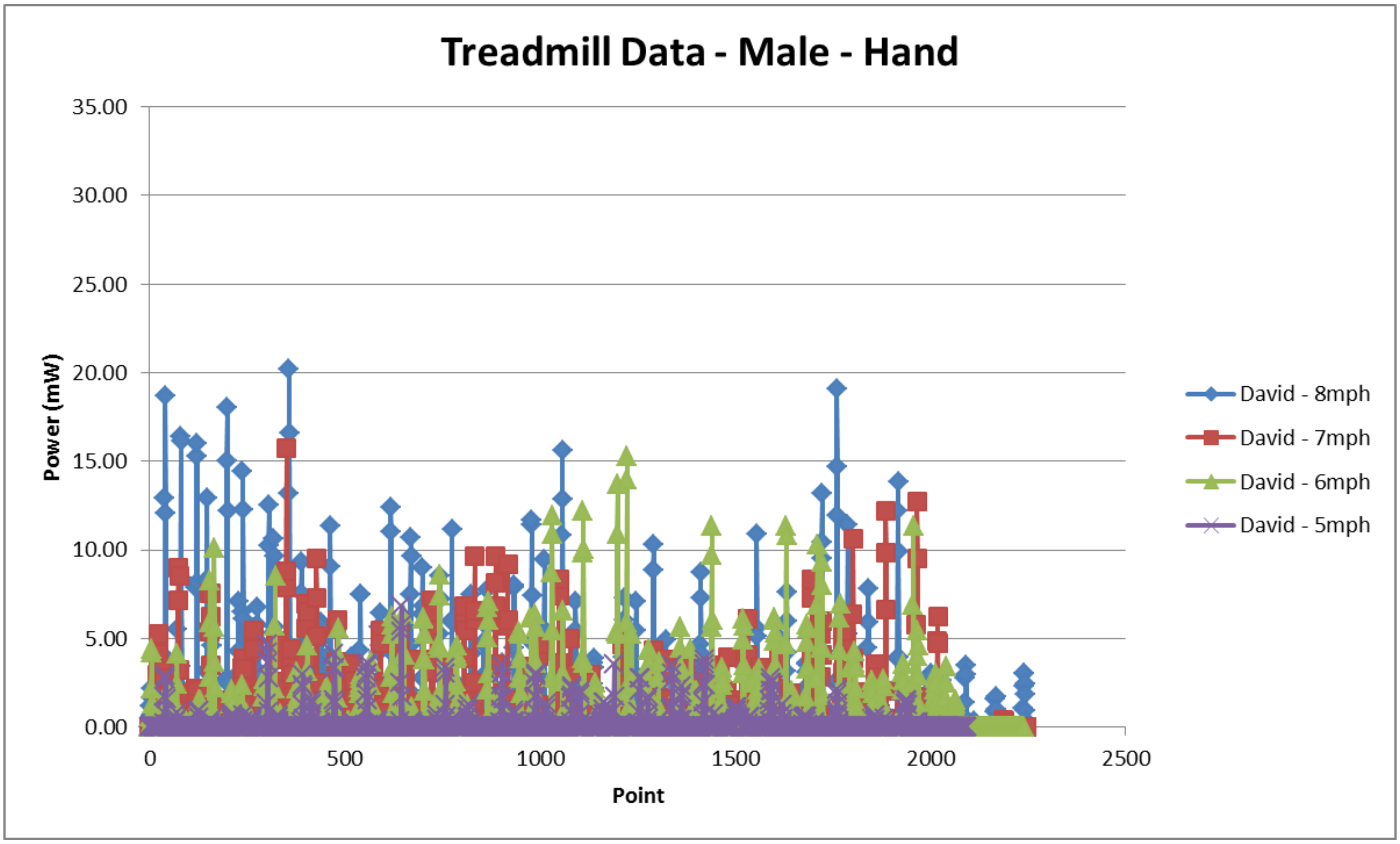

Figure 15: Male treadmill data at 8mph, 7mph, 6mph, & 5mph to show how speed affects power

Male Power Data:

Average Power Data:

8mph: 2.28mW

7mph: 1.51mW

6mph: 1.59mW

5mph: 0.65mW

Female Treadmill Runs

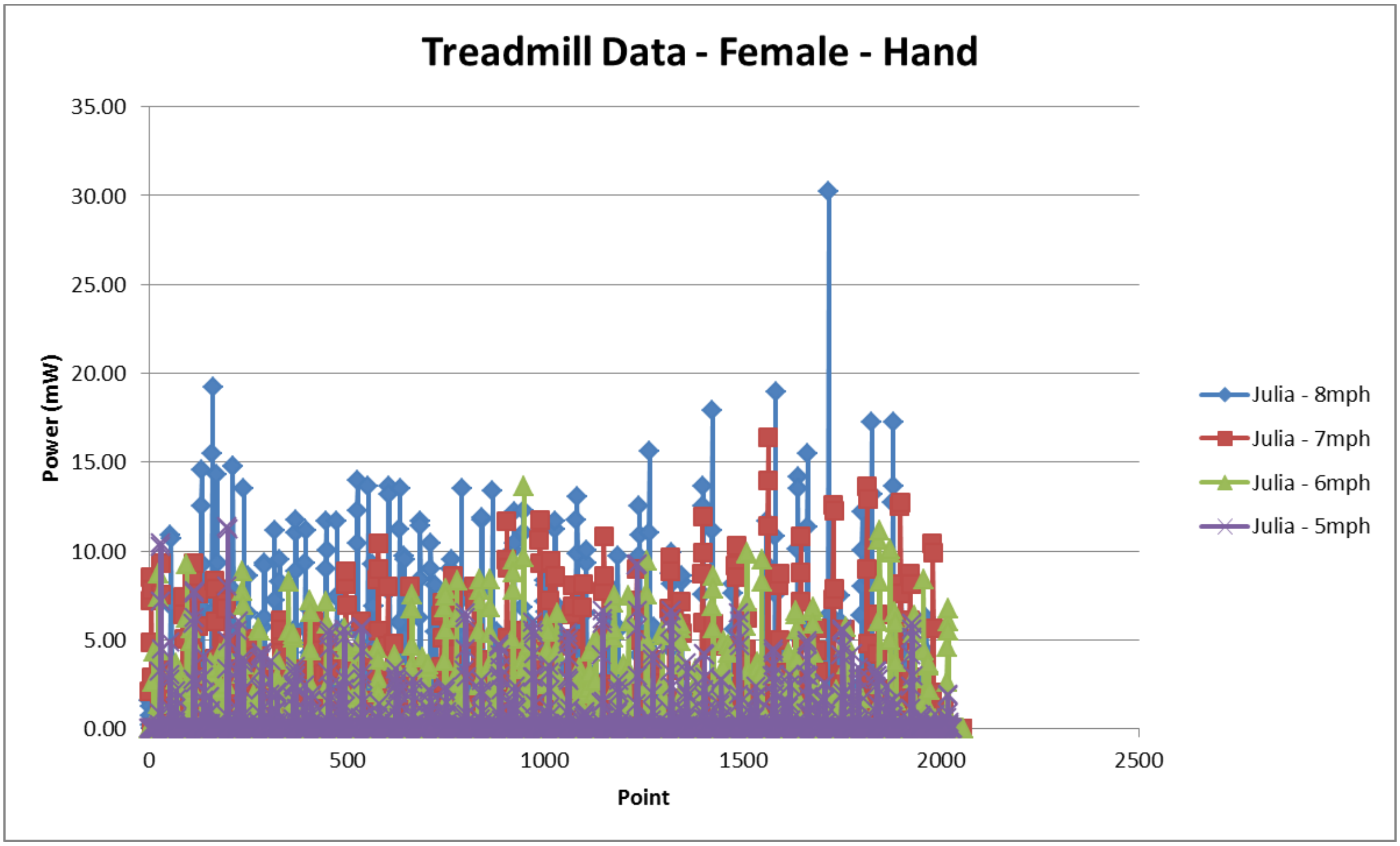

Figure 16: Feale treadmill data at 8mph, 7mph, 6mph, & 5mph to show how speed affects power

Female Power Data:

Average Power Data:

8mph: 3.36mW

7mph: 2.47mW

6mph: 2.04mW

5mph: 1.49mW

Data Analysis:

Nominally the power generated increases with speed as the speed of the magnet increases as it moves through the coil. The male data follows the trend but remains constant at 6mph and 7mph. A possible reason for this is consistent strides or arm/hand movement during those speeds. The 8mph and 5mph values still hold the trend. The female data holds a linear power sweep from 5mph to 7mph but seems to begin an exponential increase when the speed jumps to 8mph. The speed ranges cover a light jog to a quick run and both cases show an over 2x increase in scavenged power with the run.

VIII. Practical Applications

The data confirms the feasibility of the original concept that inspired the research in this study. The "Smart Defender Running Buddy" addresses the basic health and safety needs of its user. Devised specifically for nighttime runners, the device powers LEDs to illuminate the running path while opposing LED cautionary lights increase visibility in the midst of passing vehicles. In addition, the mechanical shape of the device functions as a defensive weapon, while an audible alarm may be triggered to attract attention. The physical shape and interface utilizes ergonomic engineering for comfort and utility, adjustable for various users, while its energy efficient design allows for versatility in any environment.

The Smart Defender Running Buddy functional design drew inspiration from the presently unmet safety needs of joggers and runners. Analyzing the dangers encountered during outdoor exercise, the product functionality combines existing technology into a single handheld device to address potential environmental hazards, facilitate crime and accident prevention, and provide feedback for the personal health of the user. These major risks include poor environmental lighting, low visibility for drivers in passing vehicles, and assault and abduction. Power sourcing potential features—an LED flashlight, GPS, alarm system, and heart rate monitor encased in a portable tactical shape useful for fending off predators in hand-to-hand combat—requires further parameter adjustment and idealization.

The interfacing should include easily learnable pushbutton and switch user controls for quick and intuitive access in critical situations. Also appealing to the ease of use, the device is completely self-powered, optimized for ideal loading conditions, and mechanically engineered for efficiency for the kinetic hand movement specific to running [2]. This allows for a reliable power source versus that of batteries or alternate sources [6]. Based on functionality, implementation, and interface, the Smart Defender serves as the ultimate complementary accessory for runners of all levels.

Additional information regarding project analysis or project plan can be found in Appendix A.

The original prototype: "The Smart Defender Running Buddy," contains various useable accessories given the power recorded. *Figure* 17 depicts a concept sketch for this device. Potential requirements and specifications for this prototype are outlined in *Table 2*.

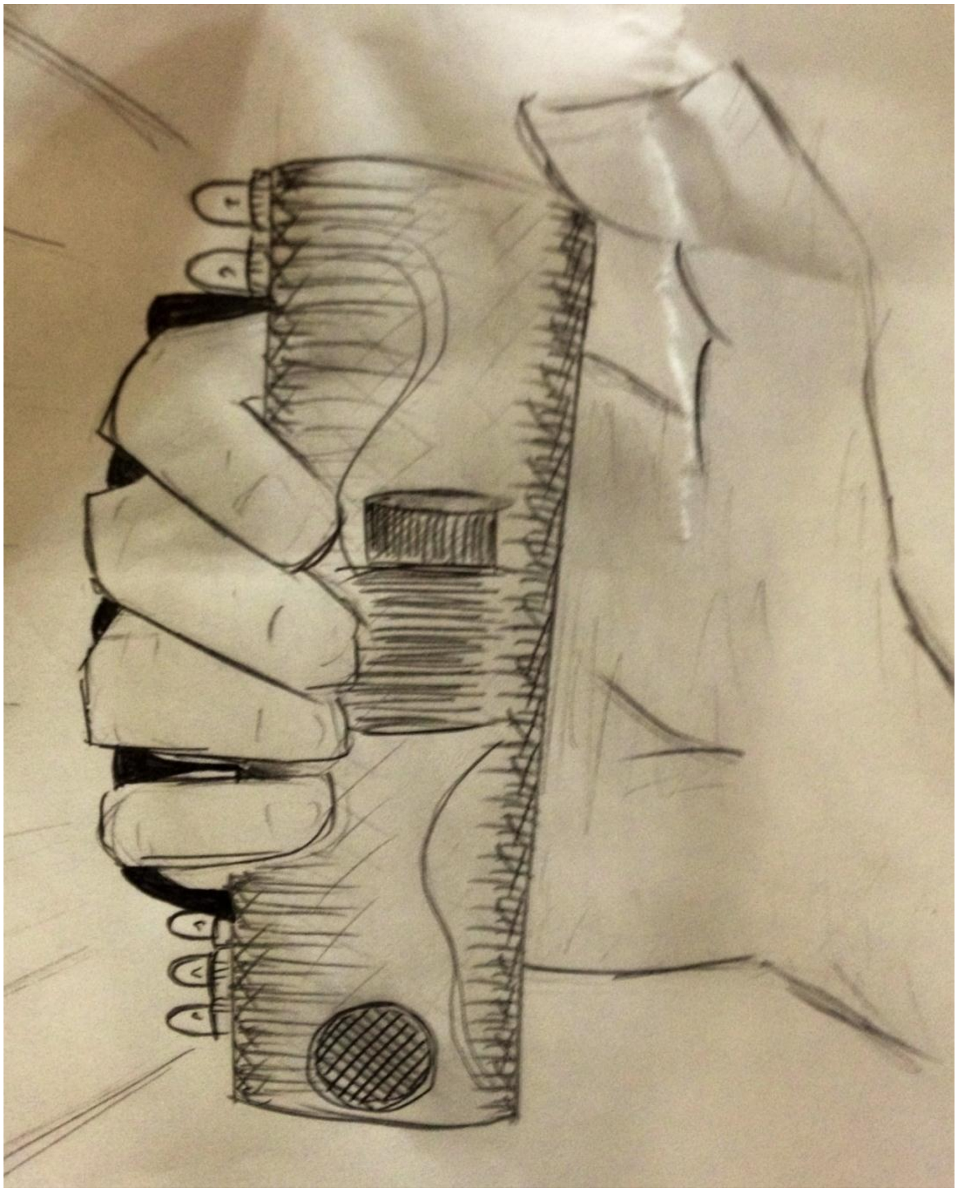

Figure 17: Concept Sketch of "Smart Defender Running Buddy" Prototype

Marketing Requirements	**Engineering Specifications**	**Justification**
1, 2	*Weighs* no more than 5oz	Easy to carry by hand and maximizes portability. Light enough to not be uncomfortable when running long distances.
1, 2	Between 4 and 5" in *length* and 1.25 - 2" in *diameter*.	This is an ideal length for power tools for even pressure distribution.
3, 6	Provides power to enable function for at least 30 s *without recharge*	System should hold charge for short time to allow for small rests during use without functional losses.
5, 7	Provides enough power to power *LEDs* that emit at least 25 lumens	This is the measure of typical handheld flashlights presently on the market. This provides adequate visibility if running at night.
2, 6, 8	*Scavenges energy* 100% from environment, no batteries or external power sources	Device uses recycled energy and with no dependence on batteries, it is functional in any environment user can run in. This makes the device as environmentally friendly as possible.
1, 4, 5	Ability to use pushbutton and switch *user controls*	Intuitive controls for ease of use and learning for the user.
4, 5, 8	Can power an LCD that displays *Heart Rate*	Cardio exercise is typically done based on heart rate, and being able to easily access this data limits other devices a runner would need to have on his/her person to work out.
3, 4, 5, 8	Can power an *alarm system* emitting at least 130 dB	If runner is attacked or gets injured, they can activate an alarm to scare away a threat and/or aid in them being found.
3, 4, 5, 8	Able to power a *GPS Tracker* in case of emergencies	If runner is lost or stranded, GPS tracker allows for location to be pinged so the runner can be easily found.
Marketing Requirements 1. Ease in handling or carrying 2. Portable 3. Reliable in various environments 4. Intuitive interface with recognizable controls 5. Controls appropriately placed for easy access while multitasking 6. Environmentally friendly 7. Visible lights to caution vehicles and pedestrians 8. Economical for user		

Table 2: Summary of Marketing Requirements and Engineering Specifications

The marketing requirements outline the necessary characteristics for ease in overall usability necessitated by the target customer, as outlined in *Table 2*. The product should function with ease in all practical environments in portability and handling. In use, controls should be easily accessible and appropriately placed, while each function performs effectively. Overall, the product should require low cost maintenance and be environmentally friendly. The resultant features as described above derive from user anthropometrics, activity multitasking and usability, and typical task environment, and should perform to the minimum engineering specification.

Device weight and dimensions come from ergonomic analysis of power tools for even pressure distribution appropriate for user anthropometrics within two standard deviations of average population measurements [12]. For tasking, the device should hold charge for a minimum of 30 seconds to account for rests between exercise and source power completely from the environment during exercise so as to maximize environmental friendliness and reliability. LEDs and alarm ratings come from existing technologies currently on the market. Each feature may be tested to meet the corresponding engineering specification.

IX. CONCLUSION

The parametric study over the various body parts yields conclusive results. The hand proves itself as the best body part for scavenging energy with this technique. The data then shows the hip as second best followed by the calf then upper arm. The hand provides the most reliable way to power the various handheld accessories detailed in Section VIII.

If the device is taken further, than steps in optimization can be implemented. For instance, the coil length, number of turns, and overall tube length can be altered to affect the power output given a specific application or power benchmarking. The load resistance can also alter to tune the device closer to max power transfer. The resistance used for testing was chosen purely for its ability to keep data reliable and comfortably within the range that the Arduino could read.

Signal rectification acts as a major hurdle for taking the device into an accessorized/productized state. To power most of the devices and reliably charge a battery, the incoming power must be rectified. However, the most conventional forms of full wave rectification introduce ~1.4V drop which for the current levels, would significantly reduce the output power. Certain workarounds for this can be a set of smart components with sensors that open/close with voltage values but these sensors would require power of their own which makes them not worth pursuing.

This project demonstrates the feasibility of scavenging power from the human kinetic movements and examines some of the accessories a human energy scavenging system can power. The data presented can be optimized and used as a baseline for further study and future applications as this information is not presented anywhere with this type of parametric study where different body locations are compared for their energy scavenging potentials.

X. References

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Appendix A

ABET Senior Project Analysis

1. Summary of Functional Requirements

The device physical design specification requires that the device is easy to carry and handle and is surface mountable. Commercially available materials assemble the device for sturdiness and full enclosure to undergo repetitive forceful motion. Meanwhile, the device must not contain any customized parts so that it may be reproducible for outside party testing and implementation. For testing purposes, the switches should be intuitive and easy to activate so that it does interfere greatly with running and testing.

To achieve these, the final product should not be more than 8 ounces and 4.5 inches in width so as not to change the running stride and to allow for easy handling for even small-handed test subjects. Next, an SD memory card provides non-volatile storage so that the data may be extracted and analyzed with commonly used hardware. A physical plug which is easy to activate and deactivate triggers automatic data acquisition with the Arduino board. Finally, materials available from public retailers make up the construction of the device, while the complete enclosure allows for better handling so as not to displace any parts while testing.

Specifically in an application, the circuitry defines an energy harvester that translates the kinetic energy from the running motion into linear motion. The power processing interface transforms this into electric energy and outputs power through to an energy storage device. The voltage regulator sources the appropriate power output to each function block, where the outputs are controlled by the user.

2. Primary Constraints

Outside of the root function of the device (scavenging energy) lays the challenges of the project. Many tradeoffs such as material quality versus price resulted in a less efficient device. Furthermore, the limited time of the project span allowed for a limited number of test subjects. Many other factors in one's running stride contribute to the amount of power output. For the scope of the project, we limited these parameters to position on the body and running speed. In implementing the device into an application, further challenges include obtaining enough power to demonstrate the feasibility of implementing a heart rate sensor/LCD, GPS Beacon, Alarm, and any other extra safety features. These features prove difficult to implement on a size and power scale. The goal is to run completely on scavenged energy but the power requirements for certain features will require us to be creative and potentially force us into using a small power source (watch battery) if the assorted features were added. The biggest constraint of the project lies in the amount of power we can generate from the running motion and how efficiently we convert it into useable energy.

3. Economic

Providing this data to applications and design engineers allows a comparative measure and suggests an ideal mounting point and angle for device implementation. This reduces the need for further investigative research for prospective self-powered energy harvesting electronics design.

For the suggested practical application, average consumers that run during either early morning or at night will find the product useful and will invest in owning one. The device assists in preserving the Earth's resources as it is nearly completely powered with scavenged energy, replacing batteries normally used for current lighting devices. The development phase of the project is the main cost of the project. Labor and resources needed to complete the design all contribute to these costs. If the product is commercialized and features added, manufacturing and labor expenditure add to the actual costs associated with the product. Benefits come into play with the presentation of this data and if the device is productized with various safety features. If manufactured on a commercial basis, David & Julia will be the primary benefactors of the project if it is entered into the market. Very little maintenance is required for the device, since only the emergency battery may need replacing during the product's lifecycle. Complete design and prototyping requires development time of 9 months, including the summer quarter. Specific tasks and details are outlined on the Gantt Chart attached in Appendix B for further information. Once the project concludes, the device will either be tested and productized and/or the project report will be documented as a valuable reference for handheld energy scavenging devices.

The overall cost of production estimates to $4225.00 (see *table 3*) for the first prototype though cost per unit will decrease as production rises.

				The Smart Defender Running Buddy							
Optimistic Cost Estimates				*Middle Cost Estimates*				*Pessimistic Cost Estimates*			
Parts	Money ($)	Iterations (#)		**Parts**	Money ($)	Iterations (#)		**Parts**	Money ($)	Iterations (#)	
Circuitry	40	3		Circuitry	40	4		Circuitry	40	5	
Packaging	25	1		Packaging	25	1		Packaging	25	2	
Tools	40	1		Tools	40	1		Tools	40	1	
Labor	Hours (Hr)	(Cost/Hr)		**Labor**	Hours (Hr)	(Cost/Hr)		**Labor**	Hours (Hr)	(Cost/Hr)	
Time	180	20		Time	200	20		Time	250	20	
	Total Cost	**3785**			**Total Cost**	**4225**			**Total Cost**	**5290**	
			Cost = (Optimistic + 4*Middle + Pessimistic) / 6								
				Total Cost Estimate		**4329.17**					

Table 3: Initial Cost Estimates Table for senior project design of first prototype

4. If manufactured on a commercial basis

For the practical application, "The Smart Defender Runing Buddy", an estimated 2000 units will be sold between the Los Angeles and San Luis Obispo counties during the first year of production. At a manufacturing cost of $36 per unit, $72,000 covers the cost of this estimated number. Selling for $72 per unit through local fitness retailers yields a profit of $36.00 each, totaling $72,000 profit for the first year. Since the device requires no extra parts and operation cost of the device is negligible, there are no additional maintenance costs for the lifetime of the device for either the producer or consumer.

5. Environmental

The device proves incredibly environmentally friendly as it scavenges energy from running and has no emissions or outputs that could harm the environment. As a result, the product does not directly use any natural resources from the environment and this indirectly preserves the natural resources available on the planet. The commercialized version of the product may impact other species where if attacked by a predatory animal, the alarm, lights, or device itself may be used as a weapon to scare them off. During normal use the device poses no impact to other species other than the potential sensitivity to light some animals may have.

6. Manufacturability

The main manufacturing issues come from the ability to acquire high quantities of needed circuitry and packaging, to cheaply and assemble the device with very little labor expenditure (mass production). Potentially outsourcing labor and importing parts can help in lowering the manufacturing costs in the long run if the product is taken to market. Since the actual energy harvesting mechanism is composed of only commercially available parts rather than customized pieces, the implementation of the device is relatively inexpensive and reproducible in a low-technical facility. However, an actual application may require additional customized parts designed around the encased tube.

7. Sustainability

Upon implementation, the scavenging system makes steps towards sustainability in that the device aims to show that energy independence is possible for certain product features. The final product is very sustainable and the only potential maintenance that may need to continue proper operation is replacement of a small battery that to powers the emergency functions if no other power is present for emergency features. As a result the project supports and aids in the sustainable use of the resources we do have. The most effective upgrade would be as technology advances, the energy scavenging system could be replaced with a more efficient system that generates more power. Challenges of this improvement would be cost of new materials and parts or the size of the parts can impact how heavily the device needs to be re-designed to make the upgrade.

8. Ethical

The design process is done ethically and responsibly given funding and resources. Throughout development, we perform our own work and cite anything that we did not develop throughout the course of the project. Holding with the IEEE code of ethics, we accept full responsibility of decisions and actions performed during development and will not make any decisions that could harm the public or endanger the environment. If the product is commercialized, manufactured must be kept ethical and if labor is outsourced, it must be done legally and following regulations necessary with doing so. As the future product may be packaged such that it serves as a defensive weapon, ethical use of the product constitutes potentially violent use *only* in situations where defense in that form is necessary. Along the same lines, it is possible that misuse of the device can occur if one decides to without reason use the product as an offensive weapon. This is a risk present with any defensive device.

9. Health & Safety

The only health or safety concerns associated with the design phase of the project include potential injury that can come from misuse of tools or parts during construction and testing. Manufacturing safety issues come from similar tool use or if machines mass produce the device, those machines can act as potential safety hazards. The device is designed with safety in mind. During normal product use with added features, the indicator lights and physical design of the device are meant to keep the runner safe from passing traffic or aiding in recovery or searching in the event of an emergency. Similar to ethical points, the misuse of the device could prove to be a safety hazard for others.

10. Social & Political

The project has no political issues during the design phase except the potential need for a patent if we decide to commercialize the device. Direct stakeholders include consumers who use the device and the creators and overseers of the device or anyone who uses the collected data for their own project applications. Indirect stakeholders include passing traffic or pedestrians that see the lights on the device while a runner is using it and any individuals that may come into contact with a device designed with our collected data as a premise or base point. Direct stakeholders are benefitted from the added safety features and the profit that the system earns its developers. Indirect stakeholders are given more visibility of runners and can better react to their presence should they have to. There is no real "harm" to either party during device use. The only inequities caused by the project include the added safety that those who use the device now experience.

11. Development

Techniques in energy generation are used in creating power using a moving magnet. We optimized the design to be as power efficient as possible as the energy available during use is limited and provide accurate data of the power generated from various parts of the body. Organizing the large amount of data and presenting it in a useful fashion proved to be one of the largest challenges throughout the course of the project.

APPENDIX B

Parts Lists and Costs

Part	Number	Cost each ($)
Arduino Uno R3	1	$20.00
Ethernet Shield R3	1	$29.00
40 Gauge Wire	1	$10.00
9V Battery	1	$2.50
3/8" x 1" Neodymium Magnet	2	$3.39
1/2" x 1" Neodymium Magnet	1	$5.54
Assorted Tape	1	$3.00
	Total Cost	$76.82

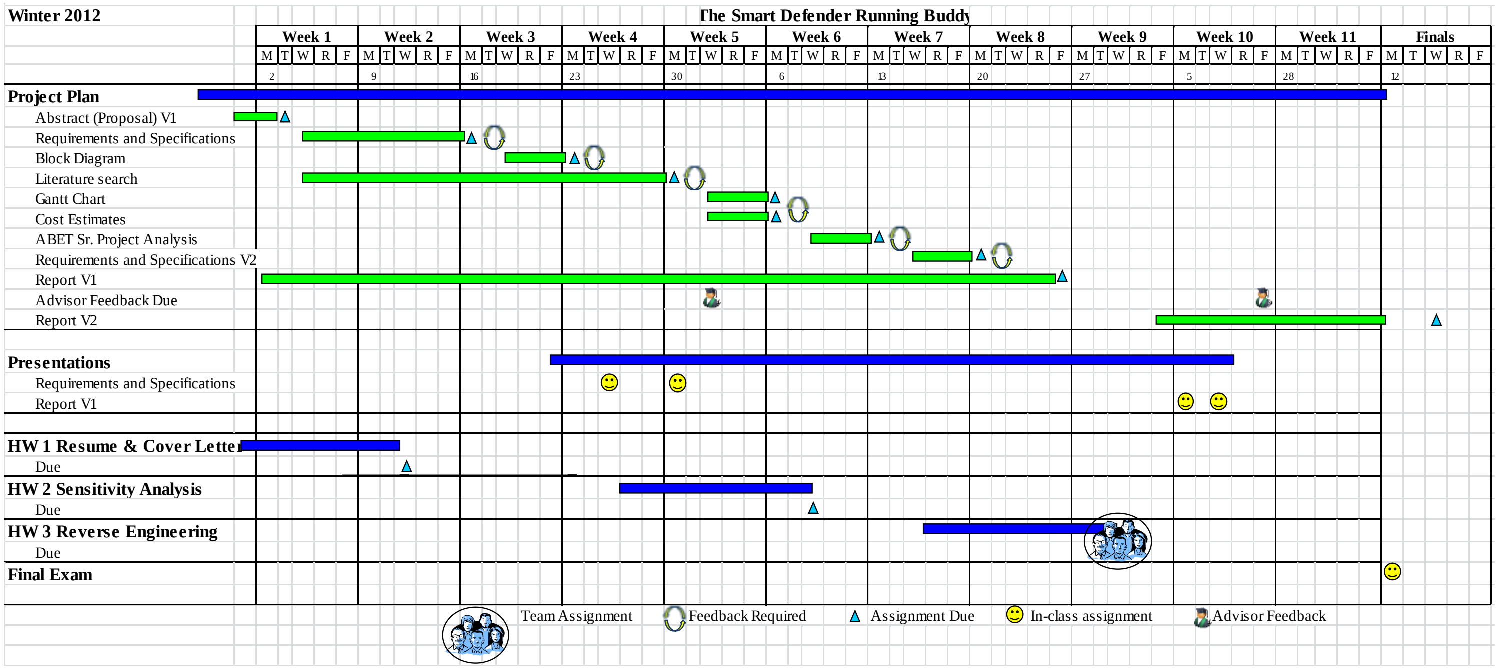
Table 4: Parts list & parts cost for the scavenging system

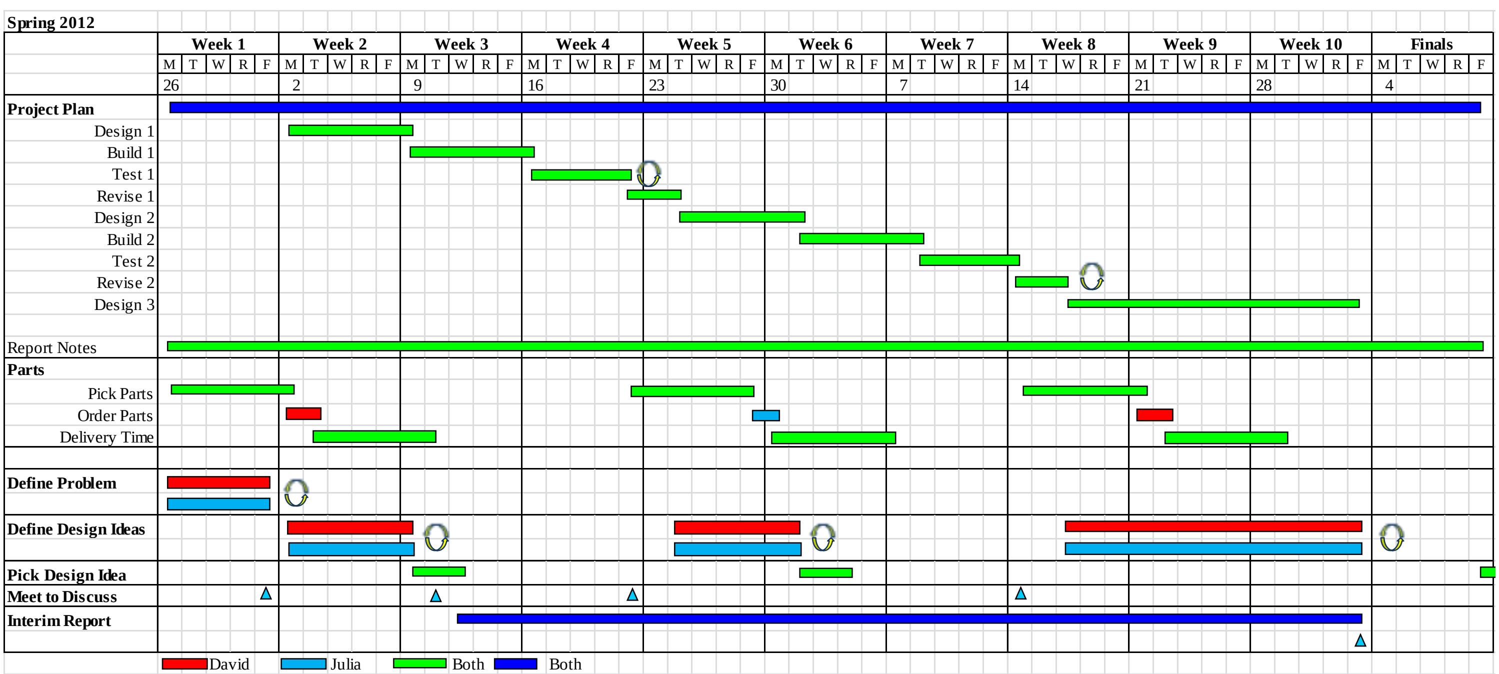
- *Arduino Uno*: Microcontroller for the project data logging.
- *Arduino Ethernet Shield*: Contains the SD card functionality for project data logging.
- *40 Gauge Wire*: Allows for a space efficient high turn (1000) coil.
- *9V Battery*: Provides Arduino power on the go for running with the device.
- *3/8" x 1" Magnet*: Repelling magnets on the ends of the device.
- *1/2" x 1" Magnet*: Sliding magnet through the coil for device power generation.
- *Tape*: Used to fasten pieces of the device together for one data logging package.

APPENDIX C

Schedule & Time Estimates

Schedule – Original Project Time Estimates





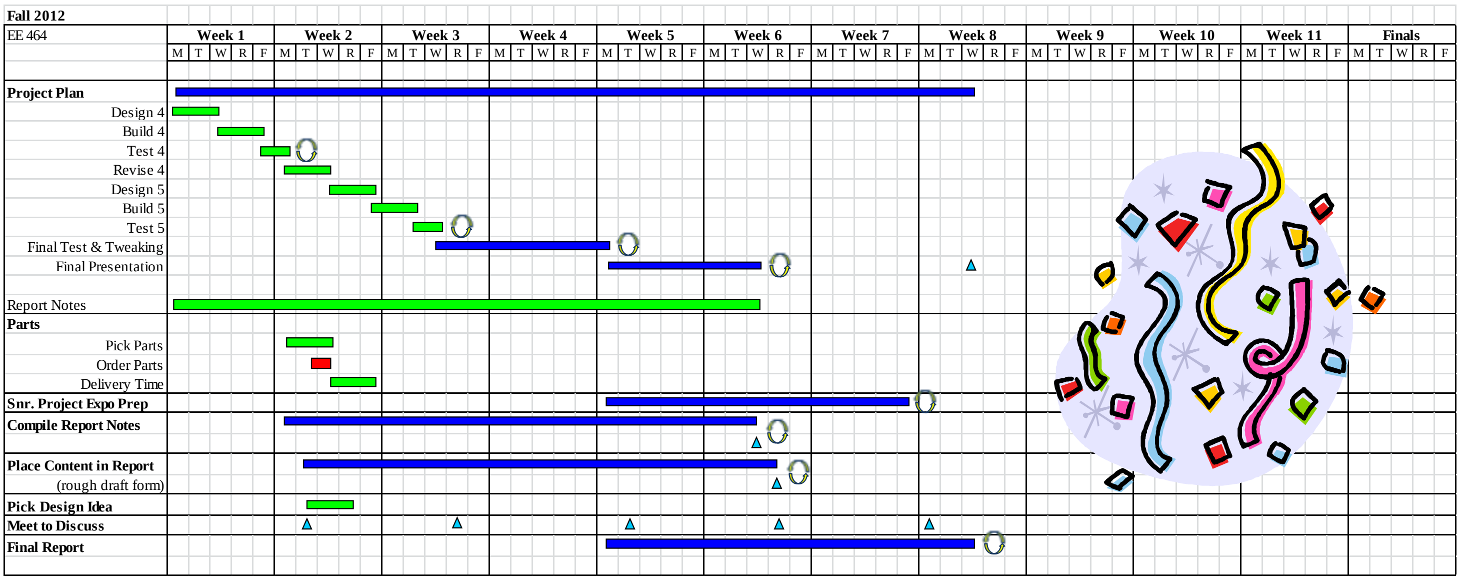
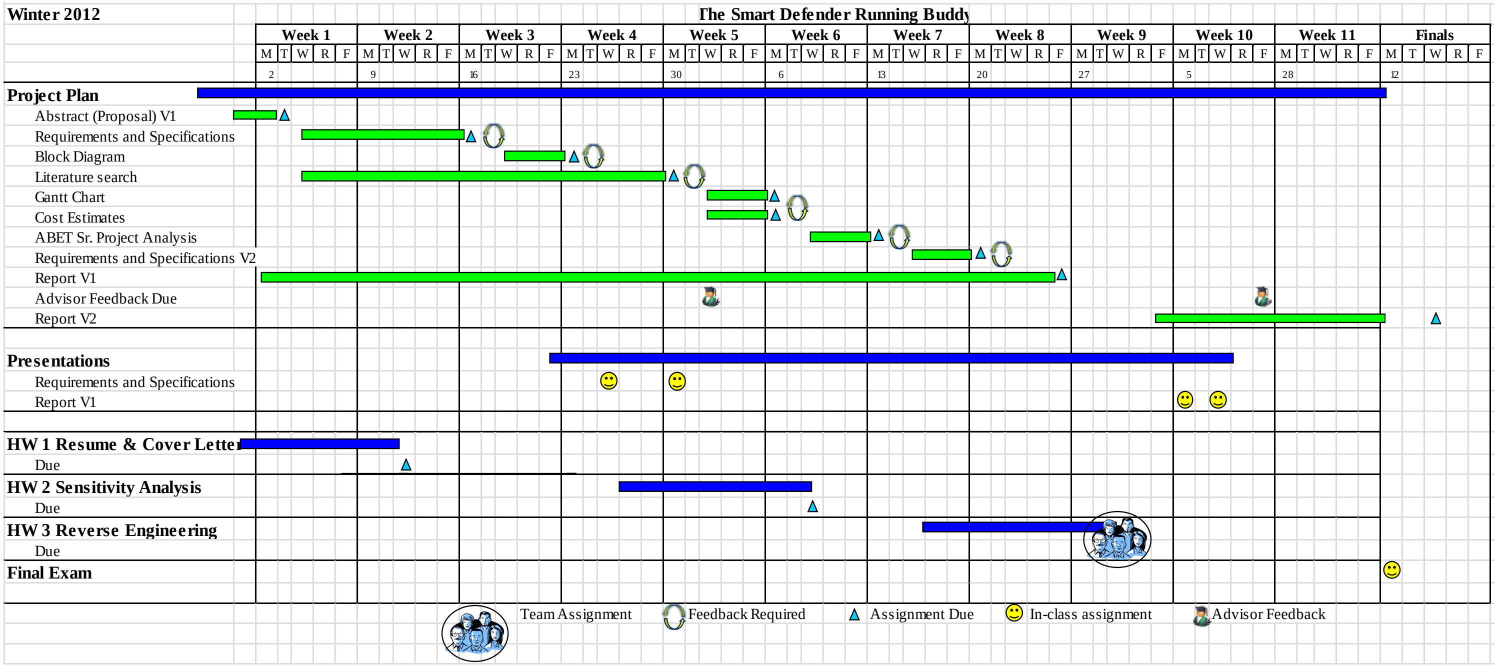
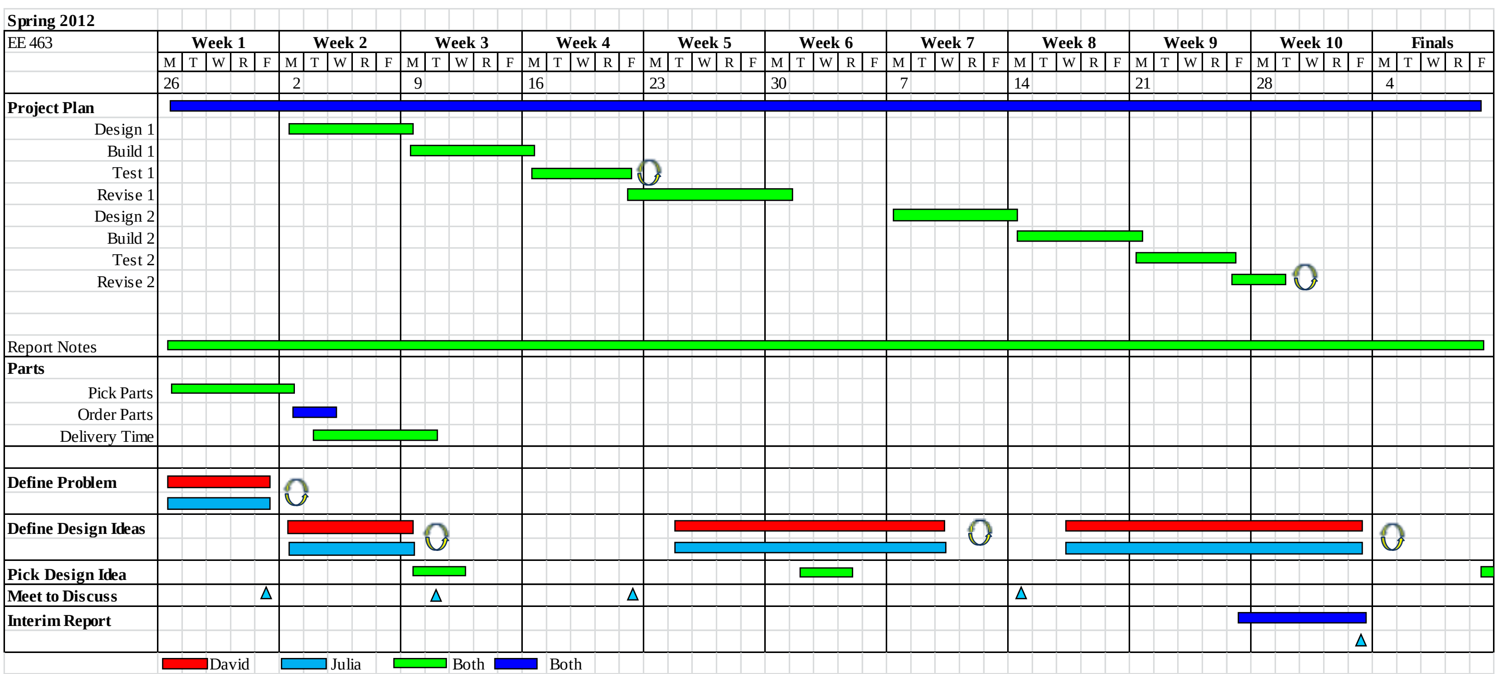


Figure 18: Gantt Chart of initial project plan

Schedule – Actual Project Time





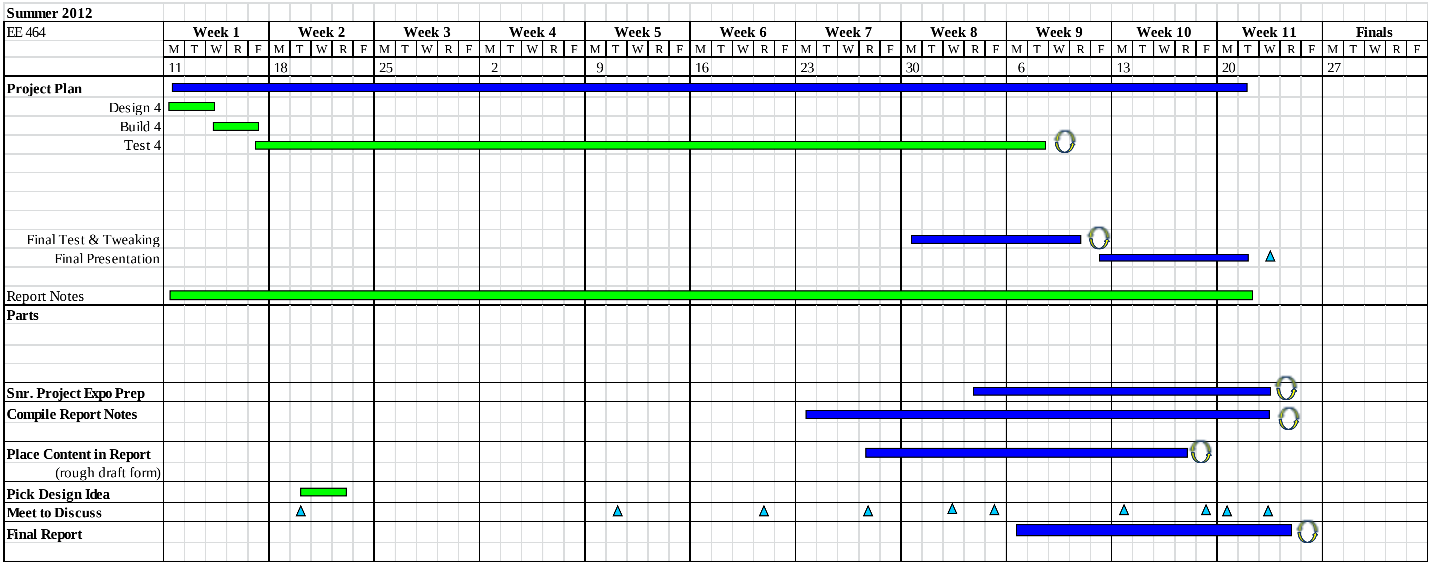


Figure 19: Gantt chart of actual project cycle

APPENDIX D

Program Listing

- **SP_DataLog_v2**

```
/* David Marusiak & Julia Carrillo
 * Senior Project Data Logger
 *
 * Begins logging right on power up. Power on and begin running!
 */

/* Version History
 *
 * v2 - Took out delay between loop runs and the serial lines.
 * v1 - Initial Data Log program.
 */
#include <SD.h>

// Set by default for the SD Card Library
// MOSI = Pin 11
// MISO = Pin 12
// SCLK = PIN 13

int ChipSelect_pin = 4; // Default = 10 but shield uses 4
int power_pin = 8; // Power Pin

void setup()
{
  // CS Pin is an output (Writes to SD Card)
  pinMode(ChipSelect_pin, OUTPUT);

  // Card draws Power from Pin 8, so set it high
  pinMode(power_pin, OUTPUT);
  digitalWrite(power_pin, HIGH);

  if (!SD.begin(ChipSelect_pin))
  {
      // Card Failure
      return;
  }
  // Write High Value to File to Indicate Start
  File dataLog = SD.open("dataLog.txt", FILE_WRITE);
  if (dataLog)
  {
    dataLog.println(1024);
    dataLog.close();
  }
}

void loop()
{
  int energyValue = analogRead(A0); // Read Pin A0 for scavenged value
                                    // Ranges from 0 - 1024
```

```
  // Open a file to write to (Only one file can be open at a time)
  File dataLog = SD.open("dataLog.txt", FILE_WRITE);

  if (dataLog)
  {
    dataLog.println(energyValue);
    dataLog.close();
  }
}
```

APPENDIX E

Hardware Configuration/Layout

The final hardware configuration of the device includes the Arduino, the coil & magnets, and load resistance for power conversion. *Figure 19* shows the final layout of the device used for all the energy scavenging runs with important features labeled. The A0 pin on the Arduino reads the voltage value across the resistor that the coil generates.

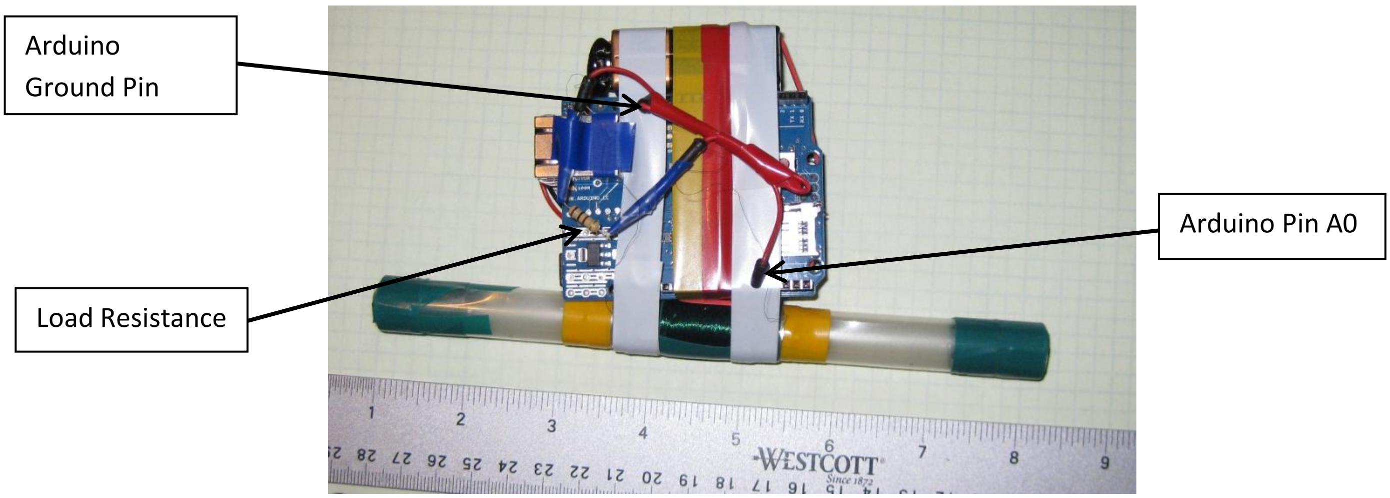


Figure 20: Final hardware layout of the energy scavenger with Arduino Pins identified

The device logs data to an SD card during operation. The Arduino Ethernet shield proved the simplest venue for allowing SD card data logging. *Figure 20* shows the slot on the shield where the SD card is inserted. Note that this side of the device is directly opposite the power connection.

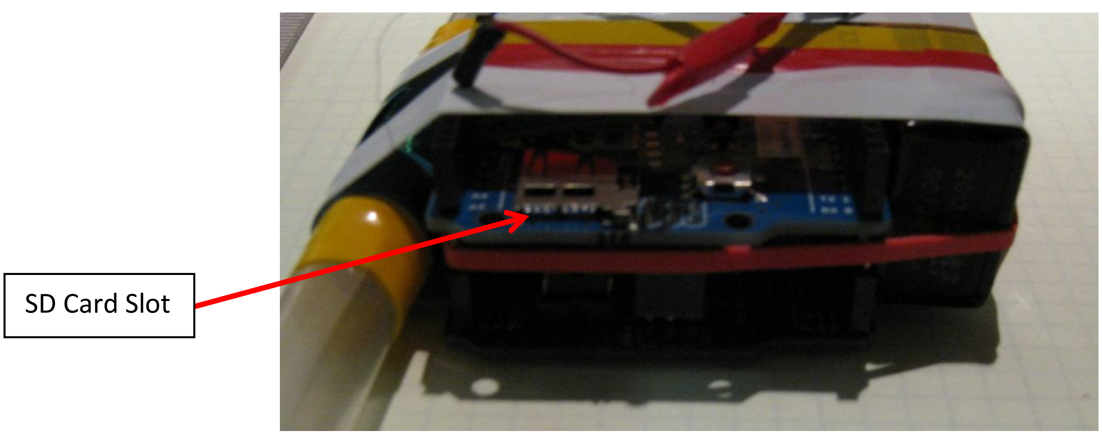


Figure 21: Final device layout with SD card slot labeled for reference