Group B16

September 22, 2022

Senior Design 7

Professor Shi

Phase 1 Progress Report

Meetings

The group has met a total of four times. Being that our group is very large, it is difficult to get everyone together at the same time. That being said, our meeting attendance went as follows:

1. Leah Serena Jack Tim and separate meeting of Jean Nick Jake and Brendan
2. Leah Serena Jack Tim Jean Nick Jake and Brendan
3. Jean, Jake, Leah, Alex
4. Jean, Leah, Alex, Tim, Serena

Each meeting had a different goal in mind. Our first meeting was divided, but the goal was to meet the rest of the team. Once we heard back from professor Shi and found out that all of us would be working towards a larger goal, we decided all of us had to sit down and meet. Alex wasn't yet on the team, but everyone else was there. At this meeting, we talked about preliminary ideas—possible consumers, ways that we could harvest energy, what would be efficient or feasible, etc. We talked about different forms of energy harvesting and decided on four types to split up and research independently. Our third meeting had less people in it, but we were comparing research and findings. During this meeting, we also caught Alex up to speed, as he came into the group a little late. Finally, at our most recent meeting, we caught each other up on individual findings again. We also divided up responsibilities for phase 1. We also discussed a game plan for the remainder of Phase 1.

Meeting Minutes

As stated above, our group's first two meetings were done in an informal manner with the first being split between the two sections of our group before we were combined as one larger section. The meeting that Jean, Nick, Jake, and Brendan had was with our advisor, professor Yong Shi. In this meeting, the baseline goals such as creating a fully functioning device capable of phone charging was set out for us and they were tasked with communicating these specific goals to Leah, Serenca, Jack, and Tim upon the third meeting which was the first time the bulk of the group was able to meet together. Professor Shi also provided the whole group with two journal articles to review that gave a wide scope view on biomechanical energy harvesting devices. By the third and fourth meetings, we were able to begin recording the details of our discussions in meeting minutes. Some of the key points are listed below.

Meeting 3

- Triboelectric energy research progress was presented with promising results
- Triboelectricity efficiency issues related to high frequency agitation requirements were deemed less severe than first expected
- 4 layer structure to triboelectric generators was discussed
- Heel strike mechanism options for increasing energy output were discussed including crank slider mechanisms and gear trains meant to fit inside the sole of a shoe or boot
- Nano scale energy generation and collection was considered
- Alex was brought up to speed on the groups progress and research into AC-DC conversion was established as a future goal

Meeting 4

- The layout for the progress report and phase one report was established
- Piezoelectric efficiency when integrated into heel strike mechanisms was discussed
- Means to enhance efficiency of heel strike were considered

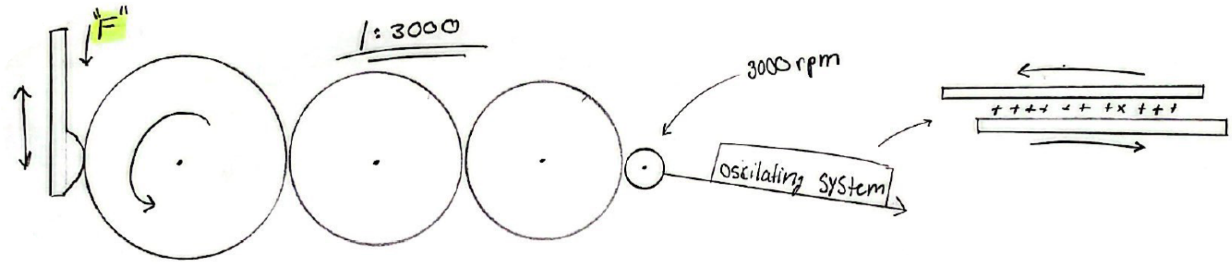
Senior Design Project Description and Goals

People give off large amounts of energy when they're moving around. Some examples of this include walking, running, absorbing electric current from our surroundings, or even just the heat energy we give off during the day. In addition to this, most people also use a cell phone in their day to day lives. Our project aims to harvest this passive energy and convert it in order to charge a cell phone. The need for electronic devices, such as our cell phones, is always increasing, all while their components continue to become more advanced and powerful. However, this power comes at the cost of requiring more energy to fuel its functionality. While phone batteries have improved in both capacity and efficiency, there is only so much that can be done before design issues concerning space and heat exhaustion become problematic. With phones becoming more tied into activity and fitness analysis, they have also become more of an essential component to keeping up with fitness, among other activities, in our modern age. Unfortunately, the rapid improvements in both the software and hardware of these components have only added to the issue of balancing device lifetime with performance. Thus, our motive is to provide a method for the many individuals who depend on their phones to keep up with their active lifestyles. Carrying around a portable charging device can be quite tedious, especially for a runner, as they are typically heavy and take up a fair amount of space. For people who love to travel, the burden of having to consistently devote time to searching for an outlet instead of spending more time enjoying the journey is all too common. In general, constantly worrying about whether or not your phone is running low on battery power is an inconvenience that most of us are familiar with at this point, and our mission is to use the energy we generate from our busy lives to ease the restrictive burden that our phone batteries plague us with.

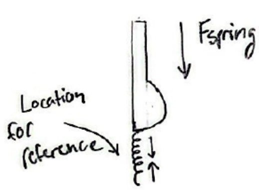
Tasks Completed

- **Heel strike** (Leah and Brendan) - In order to walk, at some point the heel must strike the ground. The force with which the heel strikes the ground in theory can be used to generate electricity. First and foremost, on average the amount of force generated would be equivalent to a person's weight. If they are moving faster, the force generated would be larger. This can be an issue for smaller people like children, but there is potential to adjust for mass variations. To best harvest the energy for a heel strike, a crank slider mechanism can be used. The heel would push down on a lever, and this lever would in turn move the other components of a 4 bar linkage. This linkage would then spin a gear as part of a gear train. Used in conjunction with a generator, the spinning of the gears caused by the force of the heel strike can provide AC current. In order to charge a phone, we would need to convert this AC current to DC current using rectifiers. Nano rectifiers exist, and may be useful to us in this project, but more research needs to be done to understand if this system can be replicated on a small enough scale to use as part of a shoe insole.
- **Triboelectric** (Jean and Jake) - Triboelectric energy production is centered around the creation of electricity through frictional forces between two different materials. These particular materials often come from synthetic polymers, but recent research has shown certain organic materials such as dried leaf powders can interact with the same synthetics and generate electricity. There are several orientations that the materials can take to function efficiently including contact separate, freestanding, and contact sliding. The most useful of these orientations for our bio mechanical energy production needs would be the contact sliding variant wherein the two triboelectric materials slide over each other horizontally at very high frequencies. Different modifications to the materials were also researched to determine if and how the amount of electricity generated could be increased. These included adding additional roughness to the contact materials which would increase the coefficient of friction between the states enhancing the energy potential. Beyond this, specific material modifications such as adding a film of polyvinylidene fluoride (PDMS) have been found to alter the material properties of the "charge trapping" layer in triboelectric energy generation devices increasing them over 178 times the standard level. Taking all of these elements into account, triboelectric materials are a viable option for our project although the frequency at which we can induce the necessary frictional forces has to be contended with. By increasing the frequency, we can likely produce adequate amounts of energy to charge a portable battery, but this frequency requirement will have to be defined before we can delve into full scale design.

However, we are confident that the necessary frequency, regardless of what it is, can be achieved with the use of a gear train. In order to achieve enough power to generate the amperage to charge a battery in sufficient time, we know the frequency of the oscillating parts is going to need to be very high. The below image shows an example:



For the sake of simplicity, let's assume we have determined a material X needs to oscillate against another piece of itself at 3000 rpm to hit our power requirement. That means we would have to have a ridiculous gear train ratio of 1:3000. This is quite alarming, but not as alarming as the input force "F" required to produce enough torque to turn this system(F_{human} would be the force generated from a human walking, likely using the heel strike method, and would likely be applied to a plunger of sorts which turns the system, as depicted). Luckily, there is a solution: finding a way to keep the gear train in constant equilibrium when it is not turning(right on the verge of turning) with the use of some sort of added input force that we will call F_{spring}.



F_{spring} could be exactly that, a spring/contracting element located in some area of the mechanism and aids in providing the necessary force on the plunger that will turn our system.

If F_{spring} = "F", the gear train would be on the verge of rotating, with no added F_{human}. However, when a person starts walking, $F_{human} + F_{spring} >$ "F" and the gear system would turn, generating the necessary power. By using this method, a gear system could be used that would be unfathomable if we were only using the F_{human} input and it could allow us to achieve the frequencies we need. This would also allow us to tune the system to each user. Since F_{human} will not be the same for every person, the system could have an adjustment to increase F_{spring} for lower F_{human} scenarios.

- **Piezoelectric** (Nick and Serena) - Piezoelectric energy converts mechanical strain into electrical voltage and one source of that strain can be human motion. Piezoelectric energy can be harvested to convert walking into electrical power, a very important concept if this energy source is used in order to charge an IPhone. Piezoelectric energy sources use crystals and when mechanical vibrations are applied, an electrical oscillation output results which can act as a source of power. In order for the power to be useful an electronic circuit is required to regulate the power output. From one study a Heel Strike Generator was developed in which four piezoelectric elements were used in the heel of a boot so that as the user walks, electrical power is generated. In order to use the Heel Strike Generator, the user steps down and compresses it, as a result the lead screw and gear train convert the linear motion into cam rotation. The rotating cam causes the crystal stacks to produce a voltage that is regulated by a circuit made to take in the AC voltage signals and produce DC pulses that charge a storage capacitor. The stored charge is discharged through a DC-DC converter to create a 12 VDC output pulse. Piezoelectric energy harvesting from motion of the body is a large possibility as this avenue is already being explored for similar applications.
- **Thermoelectric** (Jack and Tim) Creating an article of clothing that can harness electrictricity from one's body heat is slowly becoming a reality. Technology utilizing the Seebeck Effect to retrieve power from multiple layers of different materials. These materials using the difference in temperature from the body and the air can produce power that can power devices. Studies have proven you can power not small devices such as a flashlight only using your hand's heat. With this, there may be the ability to develop a large enough piece of material covering entire legs that can gather more than enough heat to charge a phone. In another project, TEG or Thermo Electric Generators were used to provide constant power to a watch using only the heat of a person's wrist on the wristband. Another example of how such small amounts of power can be generated reliably even on small areas of skin contact.

  A lot of quantifiable research has been done in the study of thermal biomechanical energy. The efficiency of this type of energy is dependant largely on (a) the difference between body and ambient temperature and (b) the thermal conductivity of the device's material. Thermal body energy is released via 2 heats: sensible heat and latent heat, with sensible heat being the free temperature gradient energy and latent heat being the evaporation of sweat by the body. At base activities these values are similar, however at high activities latent heat is as high as 70% of the total heat, resulting in large energy loss. The total sensible heat of a walk person is 100W, with the range of energy efficiency being 2.5% - 6%, leaving 2.5-6 W gained (this would require the whole body). For perspective, an iPhone charges at an average rate of 20W. Smaller scale products have been developed such as the Seiko Thermal Watch that operates on only 0.000001 Watts to operate. Options such as a low scale backup battery product, like a watch that doubles as a portable battery could be feasible. Thermal energy has to do with the body's mechanical energy as well. In general, muscles boast a 25% energy efficiency, with 75% being lost as heat. This highlights the large potential for thermal bioenergy as a source of energy, with the issue being collecting and the efficiency ratios. TEGs do have the potential for higher voltage by compiling thermocouples in series, however the issue of low energy efficiencies are a concern. The outstanding pros are that TEGs can operate silently without mechanical structures, can be added to various structures and materials, and have a long operating lifetime without any maintenance, making it an ideal addition to an average consumer without much impact in day-to-day life.

Tasks In Progress

Our current tasks in progress revolve around the various energy paths options we have identified for the development of our project. Taking advantage of the size of our group, we were able to do extensive research on virtually all of the main promising forms of biomechanical energy. Currently we are assessing the pros and cons of each energy source to make an education decision as a whole which we will move forward with. Finalizing this energy source will be done alongside the confirmation of our professor, who will be able to add insight to our current findings. A number of body parts have been already identified as potential focuses for harnessing biomechanical energy, including the knee, feet, heel, and wrists. There is also the current decision being made to either develop a constant charge device or a battery oriented one.

Remaining Phase 1 Tasks

As for the Phase 1 as a whole, the remaining tasks follow our decision of the energy source and storage method for the device. Our group will conduct research for the AC-DC conversion methods and designs, highlighting the advantages of each and deciding on a position. We will also investigate different energy storage components in terms of size, weight, and efficiency, highlighting the comfort of the user. There is also the necessary research into the intended power output for the device, comparing it to devices we expect to charge it with. Other tasks on the agenda include confirming our target customer, form of delivery in terms of apparel, and identifying the needs of said customer and in turn the product. The remainder of our resources will be spent finalizing the power generation and physical constraints of the device, conducting a preliminary technical analysis, and creating a Gantt chart for the project's lifespan.