## Energy harvesting

A potential solution to power a device such as is being created in this project would be energy harvesting. This is the process of using some of the energy the human body naturally expends during its normal function and converting/storing this for use by a device, this is often transparent to the end user.

Methods for doing this have existing in many forms for hundreds of years but have only recently become viable to power wearable electronics. This is due to efficiency improvements in both the harvesting methods and in the devices they are intended to power. Below I will outline the details of several of these methods and their suitability for our purposes.

### Mechanical harvesting and automatic watches

This is likely the oldest form of energy harvesting done by humanity with origins known to be dating back at least as far as Daniel Schwenter (1585-1636) and his idea to use respiration to wind a mechanical watch (Richard Watkins, 2016) however this approach is not known to have been used practically.

Commonly this method involves a weight connected to a shaft in such a manner that when attached to the human body this weight will cause the shaft to partially rotate due to the common movement of the person. This shaft would then be used with a ratcheting mechanism to wind a spiral torsion spring storing the collected energy for slow and constant release via a lever escapement (WF&CO, 2019).

The amount of energy stored by mechanisms as described above can power a mechanical watch for upwards of 50 days from a full charge (Hublot, 2019) however at a cost of £262,000 a mechanical device like this is far beyond the funding and scope of this project. Research has been completed into the efficiency of these mechanisms and this is thought to be approximately 45%.(Longhan Xie, Carmen G. Menet, Ho Ching, Ruxu Du, 2009) This however does not give us power in a form that can be used to drive electronics.

This problem has to a certain extent been solved by companies starting with Seiko with their ‘Kinetic’ range beginning in 1988 (Seiko, 2018) followed by various other companies including Citizen and Swatch. These watches contain a mechanical harvesting system as described earlier but instead of transferring energy to the escapement of a watch, they power small generators and in turn a battery or capacitor used to run a quartz clock movement. As these technologies are proprietary the actual power values are not disclosed to the public however upon research some have theorized the production to be within an order of magnitude of 1 joule every 2 days or 0.000277778 Watt hours (Wardell, 2016). At the 1.8v minimum we are likely to need for our microcontrollers this can be converted to 0.15432 mAh using the formulae

Or in our case

Or 154.32 Microamps. This is likely enough for our electronics but is unlikely to be enough to drive a haptic feedback device like a vibration motor.

### Piezoelectric

This method works on the concept that many materials (often crystalline) generate small quantities of electricity when put under mechanical stress, this may be from compression or deformation (flexing) this is often used in industry to detect vibration or sound. In order to use this energy circuitry is required to normalize the energy produced.

When put under stress the piezo element will output a voltage in a range based on the amount of mechanical stress inputted. This can typically range from 20/30 V + down to zero hence the requirement of a buck regulator or similar to keep the output voltage at a level that is safe to use without burning out energy storage components or the microcontroller itself.

Piezoelectric energy is a reversable process so care must be taken that the energy harvested cannot be conducted back into the piezo element as this would result in deformation of the element and in turn loss of the potential energy.

The amount of energy created with this method is quite low with high voltage outputs and low current (ampere) output. It is not uncommon for elements to put out voltages in a range up to 100 volts or more if under extreme load (such as being hit by a hammer) but the ampere output is usually less than 100 microamps (Elhalwagy. et al, 2017; Hickman, 2017). With outputs like this, losses involved in rectifying and converting the energy output may result in very low efficiency.

### Seebeck/Peltier

The Seebeck/Peltier effect is the effect that when a temperature gradient is applied to a conductor the energy will excite negatively charged particles (electrons) at the hot end of the conductor and cause them to move towards the cold side producing a tiny voltage. Due to the tiny amount of energy produced connecting these in series as would be done with a battery results in the series connections losing the energy generated via resistance and the effects of the temperature gradient. To counter this a second material is used to provide the reverse connection, they are doped in such a way that positively charged particles move from the hot side to the cold thus continuing the flow, these are the same concepts as in semiconductors and are called p-type and n-type conductors.

The output of a thermoelectric generator (TEG) such as this is affected by several factors. Starting with materials used, we are looking for materials with a high electrical conductivity and a low thermal conductivity and at room temperature, in our case the likely choice would be bismuth telluride (Bi2Te3) as it provides these properties at room temperature. Note other materials exist but either exhibit these properties in the wrong temperature ranges or require use of complex and expensive nanotechnologies bringing costs above the already expensive bismuth telluride.

Research has already been conducted into the viability of this form of energy production (Melissa Hyland, Haywood Hunter, Jie Liu, Elena Veety, Daryoosh Vashaee, 2016) . They conclude that in a best-case scenario we can expect production of around 20 μW/cm2 with a more realistic output of 2-8 μW/cm2. Given that our device electronics will likely only have a footprint of a few cm2 additional TEG’s would need to be located in the wristband giving additional cost and complexity to the design.

### Solar

Solar cells have been relatively common in portable electronics since pocket calculators popularized them in the late 1970s (Tout, 2019) and with recent pressure for renewable energy sources have become popular to power everything from cars to homes. These cells, also known as photovoltaic cells receive energy in the form of light and use this to excite electrons in a layer of a semiconducting material to produce an electrical output. Being a relatively mature technology, these devices can be found in many form factors, the main one I will look at here is the BPW34 silicone pin photodiode (Vishay.com, 2008). This device measures 5.4 x 4.3 x 3.2 mm and has a surface area of 0.23 cm2. It can produce around 50 µA under good conditions. For our purposes this means several of them may be required to meet our power needs even under good near ideal conditions. Given that our device is going to be wrist mounted it is unlikely that these conditions will be met due to clothing covering cells, shallow light angles from the user having mobility of their hands as well as factors like being indoors. This means in order to meet our power requirements multiple cells would be required as well as a method to store the energy for continued usage, this would add complexity and cost to the project.

### Conclusion

Below is a table summarizing the above methods –

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Technology | Cost | Complexity | Size/Practicality | Power potential |
| Mechanical | High (Commonly <£100) | High as no pre made units are available | Acceptable as often already installed in wearables | Viable as already used to power similar wearables |
| Piezoelectric | Low (£1-5 for device and associated electronics) | Minimal as units already exist | Large to produce required power output | Low power density |
| Seebeck | Low(£1-5 for device and associated storage) | Minimal as units already exist | Large to produce required power output | Low power density |
| Solar | Low (£1.50 per cell as of 15/03/2019) | Minimal | Many cells required to negate physical limitations | Viable as multiple cells can be used |

Given that a wearable device will often have a lifespan of less than 5 years, the complexity and cost of the above methods and the low cost and ubiquity of high capacity low volume batteries such as the CR-2477 by Panasonic (Mouser, 2019). The work involved in producing a product with a harvesting method like this is likely not worthwhile.

The aforementioned battery has an output of 3v meaning it can power the device directly, a capacity of 1000mAh meaning it can potentially power a low power device for several years. As well as having a large operating range in heat, solid state that is unlikely to be effected by movement and no reliance on light meaning it will likely provide a more reliable power source for the lifetime of the device.

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