Energy harvesting

Challenges, solutions and use cases

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Introduction

This document contains my thoughts on energy harvesting as a field. Specifically it attempts to reason about how we should act on RISE Sensor systems in order to develop energy harvesting solutions.

- What are the problems?
- How do we adapt to them?
- Can we adapt?

After attempts to answer these questions follows some recommendations on related technologies which could be of use in the case of constructing a fully featured autonomous sensor system.

Challenges in the near future

The most concrete issue is of course finding projects now. There are some challenges discussed below with the technology itself which are external to economic forces that contribute to the struggle of attracting companies.

Custom fitting

When considering the selling of energy harvesting solutions we always run in to the problem of custom fitting. Every customer has their own bespoke setup. Our solutions need to be adapted for every single one. Usually there's no *one size fits all* solution which can be easily applied.

For research, this isn't a problem as we're happy to build something for the specific subject. As far as I can tell it just isn't feasable if the goal is to sell a product.

The closests we could get to a profitable model would be to target giant, enterprise customers who themselves have extremely consistent setups. Transfer rates of solutions to other customers would be low, but with a client at sufficient scale it would be possible.

Niche mechanical needs

Both piezoelectric and triboelectric harvesting can require uncommon mechanical situations in order to produce notable amounts of energy.

Piezo needs stretching in excess of aucoustic vibrations in a material. Not only that, the stretching needs to occur at $> 5\,\mathrm{Hz}$ or in massive amplitudes strain-wise.

Tribo on the other hand needs two surface repeatedly sliding over each other or periodically making and breaking contact. I would wager that this is even more uncommon.

Sensor and communication effiency

The better we make our communication and sensor electronics, the less attractive energy harvesting becomes for anything that isn't a permanent fixture on another product.

In temporary setups we can already achieve over a month of uptime on a 130 mAh battery. And when the solution is temporary, batteries aren't a problem for the end user, not even environmentally since they are rechargeable.

Challenges in the far future

In addition to the short-term technical challenges, there are long-term problems for energy harvesting which might prove even more impactful for the field.

Electrification

Although it might seem counterintuitive, digitalisation or electrification is a goal that opposes energy harvesting in many ways. IOT-devices and other common sensors require electrical power but live in an entirely different bracket of power consumption, often in the 10s or even 100s of mW. We can get by on a single mW as the worst case scenario.

The process of digitalisation results in a vanishingly small number of places whithout electricity where energy harvesting could make a difference.

All of this without even mentioning larger scale electrification such as electric vehicles or other high powered environments where energy harvesting is entirely useless.

In any place where you might ask: *Why don't we just plug in a cable?*, like at Ahlstom, we shouldn't even be trying to apply energy harvesting. The scientific merits are of dubious qualuti and as we have noticed, it's a hard sell.

Diametrically opposed goals to a good product

When companies are designing a powered product, regardless of the energy source the goal is always to minimize the wasted energy. We on the other hand need waste energy to feed our devices.

As the powered product is optimized, our solution performs worse. This creates a toxic incentive structure which the manufacturer generally wont accept. No matter the degree to which our solution can satisfy a customer in the present I still think it is difficult to convince them to make use of (or buy) a device with an incentive structure opposite of their own.

Strategies to combat challenges in the near future

Below follows potential strategies that could be employed or researched in projects to solve or work around the discuseed challenges.

Custom fitting

One mitigating strategy is to invest in the few solutions which are less sensitive to local variations at each site of implementation. In my estimation they are thermal and photovoltaic harvesting. Both of these can work as self-contained boxes, with the slight caveat that a thermal block needs somewhere hot to sit which might require accomodating changes to the environment or the box.

It might also be possible to go for the complete opposite approach: **Custom-fit everything**. By 3D-printing it seems possible to design general, parametrised mounting design which could be quickly adapted to fit any location.

The most concrete example I can think of is a cantilever for vibration harvesting where we plug in a desired resonant frequency and the design warps to produce this desired frequency response.

If we want to get really experimental we could leverage generative design through Autodesk products, COMSOL, or building something of our own.

Niche mechanical needs

With clever geometrical designs we could expand the possible locations for a piezo/tribo harvester, although one should be careful with vibrating solutions. Vibration as a means of generating energy will always have some resonant frequency around which it'll perform the best. If we're not careful this'll just contribute to the *Custom fitting* problem even if it solves this one.

Sensor and communication effiency

Improving the efficiency of our electronics is still interesting because it lowers the energy floor onto which energy harvesting can be used. I think that for this to actually become relevant we'd need to lower the floor by a factor of 10, which might be possible almost entirely through software.

Strategies to combat challenges in the far future

Below follows potential strategies that could help in aligning our own goals with the industry's outlook on energy harvesting as a whole.

Electrification

Look for situations that can't be electrified. This would have to be sites totally devoid of power for them to be "immune" to electrification.

There can also be conflicts of ownership like for Nokia. In their case the car is electrified but they don't own the car and thus can't assume anything about it's internals.

We already are considering local non-electrified parts of systems considered to be electrical as a whole like in the HHK-cluster. This is still a worthwhile goal and is most likely to occur in physically larger systems.

Diametrically opposed goals to a good product

I don't know what to do here. If I was a company I'd never want to adopt a solution which opposed my own goals.

If I'm a small company, I'm looking to grow, partially by improving my own product to surpass the market. When looking for growth I'd want a technology that synergizes with my own and strengthens it, not the other way around.

If I'm a big company with an established solution I might be more lenient since the product moves slower. But on the other hand the plans I make are across longer time scales. Both aspects sort of cancel out to still put energy harvesting solutions in a bad light.

The only solution I can think of is to harvest energy from the environment rather than the product itself. This would in principle only leave us with photovoltaic harvesting which we haven't done much of.

Use cases

Usually you'd use energy harvesting to power a sensor in an area which can't be provided power by regular means such as a cable. This could be because the area is hard to reach or entirely dislocated from where any reliable power source is situated.

Factory

It seems difficult to motivate the use of energy harvesting for any use case in a factory. Extension cords are easy to access and basically all parts of a production line are already being powered by electricity.

If you'd want to mount a sensor temporarily to investigate root causes of issues, it is much easier to just use a large battery.

Handheld devices

On a handheld, eletric device such as a power tool there isn't much point to energy harvesting either. The draw of a sensor compared to the tool itself is completely negligeble.

However, I can see a use case for non-electric tools such as chainsaws, clearing saws, lawn mowers or air-powered device (nail guns) which are entirely mechanical in their functioning. One problem here is the fact that a sensor unit would be far away from any potential receivers of data, meaning that BLE, the most energy effecient wireless communication proves useless for real time data.

It would be possible to create a self powered diagnostics display which doesn't send the data anywhere, but does show a user some data in real time. This could be implemented using an e-ink display which can draw as little as 16 μW.

It is of course also possible to log data which can be stored in Non Volatile Data Storage (NVDS) to be downloaded later by a technician. This could be used for warranty purposes like how the warranty is voided on more expensive cars if you rev the engine too high.

A potentially interesting data to log would be detection of being dropped from high places. Even non-electric devices like a chainsaw would be expected to break if dropped from a large height. The amount and severity of drops could be recorded for service or warranty recommedations.

Larger machines (excavators, cranes, etc.)

The use cases here are pretty much the same as for handheld devices since there can be large, far away parts that are not electrified.

There's an additional use case of wirelessly transmitting data to the dashboard via BLE and possibly through BLE relays if needed.

Electronic gates in remote/unestablished locations

There might be an opportunity to construct a gate with an electronic lock which doesn't need any consistent power source. It could feature an RFID reader or something similar which could be powered by the door handle.

On a construction site there are revolving doors which are used to guard certain areas from workers without the proper training. These already require quite a bit of torque to rotate, this could be used for harvesting purposes.

This could replace the cumbersome process of many physical keys for areas like public workers in the municipality.

Keys could be cryptographically signed with blockchain technology or other means to provide access to some gates but not others, without needing data in advance.

Health monitoring for groups of animals

Some simple health symptoms like high temperature could be measured on packs on animals with energy harvested from their movement or heat. This would allow a farmer to quickly scan a herd for signs of any disease.

Synergetic technologies

Energy harvesting works better with some technologies than others due to the small amounts of energy it can generate.

Bluetooth Low Energy (BLE)

Ultra low power BLE modules such as the *ERF1002* can transmit real time data with a power draw of 0.9 - 2.8 mW. This is around the upper limit of *one-size-fits-all* energy harvesting solutions, but is way below the limit of bespoke, custom fitted systems.

E-Ink displays

I think this is an unexplored area of user interaction. E-Ink displays require basically no power to show a static image. Energy can be saved up for a long while before updating a small part of the screen to save on energy.

Flash memory

Saving data to a NVDS such as a flash memory costs relatively small amounts of energy and doesn't use any energy at all to hold on to already saved data. This can be used to implement logging systems for long running tasks but is insufficient to store real time data for longer periods of time.

Comparisons to research

The amount of published works on energy harvesting has been increasing per year over the last 2 decades. I do not know if this is to be taken as an indication of interest from industry, but it at least runs contrary to my pessimistic views.

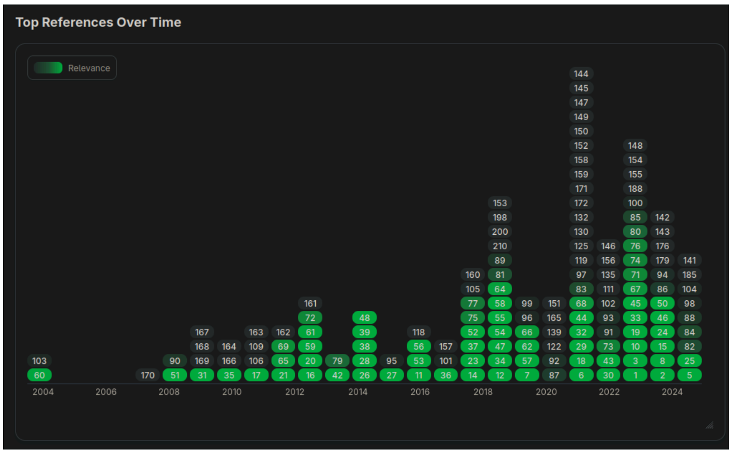

Figure 1: The amount of relevant references pertaining to energy harvesting over time during a research run on Undermind. Articles colored in green are the most relevant to the subject.

As can be seen in figure Figure 1, there was a peak around 2021 but this is more likely due to economic factors than the actual merits of the research.

Many of these references boast about harvesting in the μW range which is entirely too little for us at the moment, or possibly ever if we're looking to communicate wirelessly. When the research seems content with entirely unpractical amounts of energy it leads me to believe that they can't reach much higher. Even with advanced techniques we can't access they still don't reach orders of magnitude above our results.

What should we actually do?

We should generally lean into the sensor and systems design part of our work more than the energy harvesting. There is still lots of work to be done in developing sensors with extremely low power consumption.

Ultra-low power systems

Much of our work should be transferrable if we shift the focus from autonomous to ultra-low power systems. In fact that is basically the entire source of my progress since I started working at RISE. The development of an ultra-low power BLE module has enabled the energy harvesting to work, not the other way around. Our energy harvesting hasn't improved significantly.

We do thermal harvesting using the exact same parts and electronics as we did when I arrived (LTC3019 and TEG). We do magnetic harvesting in the same way as when I arrived (simple coil + rectifier). And to be honest, we don't have a good grip on those techonologies at all. We've just built first drafts and haven't gotten the chance to evolve them beyond that stage.

As for the power draw of sensors we can in principle only perform temperature measurements at the current stage of our research. We are missing any kind of force measurement at the μW which would unlock strain, pressure and acceleration readings in addition to force.

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