The limits of wearable powers(Bernard Murphy)

https://www.linkedin.com/pulse/20141203172252-555241-the-limits-of-wearable-power

Power isn't the sexiest topic in wearables. It's not nearly as exciting as how they will radically improve our lives, their unbounded social value or the size and stratospheric growth of the available market. But power places unique constraints on wearable solutions because the capacity of the power source must be limited if the app is to be comfortably wearable (and practical in the case of medical implants). One way to solve this problem might be to use storage methods with higher energy density than lithium-ion batteries. Unfortunately, denser energy sources tend to be explosive or radioactive, limiting their mass-market appeal. If we rule these out, the only remaining options are to reduce the power consumption of the app and to find better ways to recharge the battery.

Let's start with the battery in a smart phone as a baseline. These are big and heavy, even in the smaller format phones. So you definitely want something smaller in your wearable. A small phone battery is about 1600 mAh (milliamp hours); you might want to use a battery half that size (and weight). Assume output voltage is ~3V. That puts our reference energy capacity at 2400 mWh (milliwatt hours). A pacemaker battery delivers around 1000 mWh – I will assume the same size battery for all implants. Now consider the components that may draw on that capacity; representative examples with ***active*** power are listed in Table 1.

Feature	Active power consumption	Battery life
LTE Wireless	600-1600mW	1-4 hours
3G Wireless	400-800mW	3-6 hours
WiFi	80-125mW	20-30 hours
Bluetooth-LE	15-30mW	3-6 days
GPS	60-150mW	16-40 hours
Camera	400-600mW	4-6 hours
Display	500-1000mW	3-5 hours
Video processing	200-300mW	8-12 hours
Audio	100mW	1 day
Data processing	350mW	7 hours
Memory	30-50mW	2-3 days
Temperature sensor	10uW	27 years
Pressure sensor	10mW	10 days
Accelerometer	1mW	3 months
Gyroscope	10-20mW	5-10 days
Pacemaker	10uW	11 years
Neural stimulator	50-2000uW	1 month – 2 years

Table 1: Active power consumption of likely components in a wearable device

Battery life is the time for a ***single*** function, operating continuously, to run the battery flat from a full charge. These numbers are in fact too high since if any function is active, the CPU and memory must also be active. Battery life is extended by reducing power in components when they are not in active use. One common technique puts inactive functionality into sleep mode, reducing power consumption by 50% or more (in modern fabrication technologies). To reduce further, components can be powered down, at a cost of slower initial response-time when that functionality is called on again. And there are finer gradations of these techniques to further optimize sub-components of power. Wearables with more than a few of the features listed in Table 1 will typically operate with only a few enabled at any given time, and even those will be quickly returned to sleep or off-states whenever possible; this is exactly what your phone or tablet does to keep a charge for several days.

Communication may chew up most of your battery life. LTE is fast, high-bandwidth and long-range, but more expensive than any other feature; even idle-mode power is significant.3G is not nearly as bad, but is still no slouch when it comes to draining the battery. Recent WiFi implementations are better still, but you have to be close to a hotspot. And Bluetooth-LE is very power-efficient, but limited to an even shorter range. You have to think carefully about when your wearable has to communicate (on a hike, in your local coffee shop, or while sitting at your computer) and how much bandwidth it really needs (exchanging small packets of information or streaming large quantities of data, such as audio or video from or to the cloud). Every compromise will cost you in battery life.

Geo-location power consumption has improved significantly but is still surprisingly expensive. If required only for an occasional location check, this may not be a problem, but if you need it to stay on for any kind of mapping function, expect it to be an important contributor to power drain. Camera, display and video processing are even more expensive, especially for video or movie playback. These may not be a major factor in many wearables, but are likely to be expensive in VR apps and in optical prostheses. Audio on the other hand is less expensive, but extended audio playback will contribute significant drain.

Power burned by the CPU is highly variable, depending on what computation is required. If the CPU is running some flavor of Linux, possibly embedded in Android, and perhaps software-based encryption for security, power probably won't be too far off the estimate above. Similarly, power associated with writing to and reading from memory will vary depending on application (I used an LPDDR example in the table).

Sensors are power-sippers, but can gulp if they are also actuating or stimulating. Pacemaker power is primarily needed to stimulate heart muscle; modern designs expect batteries to last for 5-10 years or more. Power demand for neural stimulators varies widely depending on application, from very small (~50uW) for sciatic nerve stimulation up to a few mW for deep-brain or muscular stimulation.

So now you know what you must consider to stretch available battery power over several days. How are you going to recharge that battery? It would be tedious and messy (all those power cables) to have to plug in each day. Many devices now hold a charge for longer, but still on the order of days, making recharge responsibilities a burden – not what we want in an app designed to make life more convenient. Implants are a different story – we'll get to those soon. A much better approach would be to get rid of the power cables, but how do we do that? Here are some options, including direct charging for reference:

Recharge method	Power generated
Direct charging (iPhone)	1A
Inductive charging	~1-2A
Thermoelectric (heat-based)	40 uA/cm^2
Photovoltaic (light-based)	10 uA/cm^2
Piezo electric (motion-based)	0.7 mA/cm^2
Piezo electric (attached to heart)	0.2uA/cm^2
Blood sugar oxidation	1-2mA/cm^2
Ambient wireless power	Negligible unless close to antenna
Beamed wireless power	Safety limits to 1mA/cm^2

Table 2: Re-charging options

If you don't want to plug in, by far the best option for anything but implants is inductive charging. Energy harvesting, the sexy and green option generates nowhere near enough power to drive most wearables. Photovoltaics are great when arrayed in panels of many tens of square meters, but that's hardly portable. Ambient wireless is simply too weak to be useful unless you plan to stay close to the source, and directionally-beamed power has to be limited in the interest of safety – you don't want to be cooked if you accidentally walk through a beam. Adding to the challenge, most such techniques are undependable sources of power over extended periods. Piezo-electric generation based on walking motion, for example, will only generate while you are moving.

Inductive-charging has had a slow start in this domain. The first charging pads started to appear around 2009; you simply rest a device (a phone for example) on the pad to charge, as long as that device contains the appropriate induction coil and conversion/charging technology. Slowing adoption has been a need to align the charger coil with the device coil, support for only one device per pad and a lack of standards, now morphed into a standardization war between 3 primary groups: A4WP, PMA and WPC. The first two problems look like they may be fixed by magnetic resonance charging, though that technology is not yet released. Meantime Starbucks is planning to install Powermat® charging stations (PMA) embedded in tables and counters in stores across the US, and Powermat is offering free charging rings (a plug-in to a phone or tablet) to adapt your device to those stations; the hope is that these will whet our appetite for on-the-fly recharging. Widespread availability of a standard solution may be a few years away, but given the convenience of grabbing a little extra charge (called "power-snacking") wherever we stop for a while, it seems inevitable that this will become the preferred method to charge, and might in time obsolete power-cords for all electronics.

In case you're wondering why we don't immediately demand such an obviously wonderful solution, inductive charging isn't perfect. It can be 20% slower than recharging the old-fashioned way and it is quite inefficient; as much as 30-40% of charging energy is wasted as heat (compared with ~10% for traditional charging). Any app supporting this approach needs to be tolerant of that extra heat. Near-term, the FCC may limit charging power to 5 watts (per charging station, I assume), further reducing charging speed, though also mitigating heating problems somewhat. Even then there will be kinks to work out in the use model – I don't really want to take off my wearable to recharge, but I also don't want to get first-degree burns when I rest my arm on a charging table.

Energy harvesting isn't completely out in the cold for wearables. While induction-charging could also address the power needs of implants, there has been resistance to adoption for critical functions. This is driven more by risk of litigation than by technical roadblocks. At present, replacing or recharging a pacemaker requires surgery, an unavoidable event scheduled and monitored by surgeons and doctors. But if recharge becomes a personal responsibility, there is concern that a (possibly forgetful) patient may not remember to recharge and that a jury might find the manufacturer liable for not in some manner providing sufficient warning and alarms that a charge was required. However a piezo-electric generator attached to the heart can be a very capable energy source for a low power pacer, since the heart's continuous beating guarantees a steady energy source. This solves one problem though a second problem, the durability and safety of an old implant, may stymie further extensions between surgeries. Blood sugar oxidation is another approach that may be interesting for relatively low power implants where inductive charging options may be limited or unreliable, although these currently require replacement every 2 years to refresh the enzyme.

In short, design for effective power management is going to be a delicate balance for any wearable. The more capability you want, the bigger the battery you will need (making the device less "wearable") or the more frequently it will need to be recharged (also unappealing, unless you can conveniently power-snack during the day). Energy harvesting, often touted as the ultimate savior in going wireless, is a long way from being an effective solution, except in special cases. The most realistic option is some form of inductive charging, but it will take several years to converge on an agreed standard and to build up the infrastructure to support widespread charging. Got it? Now start designing your wearable app…

Sources

I wasn't able to find comprehensive summaries of power consumption and generation, so had to draw on multiple sources, mostly datasheets and technical journals. I have tried to be as current and accurate as possible, but would be unsurprised to see challenges to some of these numbers. If you have better data in any instance, backed up by one or more credible references, I would be happy to incorporate an update and recognize you as a contributor.

Battery Capacity

Modern phone batteries have higher capacity (3000-4000mAh) but are even larger and heavier. The 1600mAh battery was common in earlier generation smart phones, and seems to me at least a better reference point for wearables.

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Energy harvesting

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Induction charging

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