An Engineering Look at Medical 'Wearables'

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Many of us have seen a picture like this, or maybe something similar. We see a nice-looking gold colored wrist band, with some soft, maybe blue-ish colors around the inside diameter of the band, presumably the area that would be next to the wrist of a person when worn. Next to this 'wearable', we see some sort of Smart Phone displaying a list of medical parameters along with values, presumably from the wearer, and presumably acquired from the nice wrist band nearby.

The picture looks very nice, and maybe will help generate interest, and maybe funding. We won't say that such a device is impossible, but this is certainly well beyond the realm of even remote possibility in the next maybe 10 years, even though medical, well physiological sensing electronics have come a long way in the recent past.

It might be helpful to look at some of the physiological parameters used medically, and talk about the way these parameters are currently derived from human subjects, from an engineering perspective.

Basic Heart Rate

The functioning of the heart is probably the best starting point when seeking to assess the condition of a human subject. And the bare minimum useful information about the heart is how fast it is currently beating; this is referred to as Heart Rate. For normal adults, the heart beats somewhere between 60 and 120 beats per minute during resting and normal movement.

The simplest way to acquire Heart Rate is to place a 'Pulse Plethysmograph' (PPG) transducer up against the skin. A Pulse Plethysmograph makes use of the fact that, as the heart pumps blood through the tissue below the skin, the reflectance and conduction of light within the skin changes ever so minutely, first increasing as fresh blood is pumped into the tissue, then decreasing as blood then flows out of the tissue.

A PPG transducer uses a light source (usually an LED) and some sort of light sensor, both placed up against the skin, and fairly close to each other. The LED supplies the light to the Skin, and the sensor generates a signal based on the amount of light 'passed' through the skin from the LED. The sensor signal rises as blood is pumped into the tissue, then drops as blood flows out of the tissue. Generally the LED and sensor are matched to the same light frequency bands, and Infra-red is usually used to minimize sensitivity to changes in ambient lighting, which is predominantly in the visible spectrum.

An alternate form for a PPG transducer simply senses the physical changes in the skin that result from the beating of the heart. This type of transducer is also strapped over the area of interest. As blood enters the skin, the tissue expands slightly, then the tissue shrinks as the blood flows out. The sensing mechanism for this type of transducer is different, but the quantity measured is basically the same as the Infrared PPG described above. This second type of PPG is affected by the same limitations discussed below, except that this approch is even more susceptible to subject motion based interference.

And you can also generate the PPG signal from suitably configured Bio-impedance measurement equipment as well, but this approach is far beyond the wearables realm in size and power required.

Overall, a PPG transducer can work well to supply basic Heart Rate information. It has many limitations however. First, the LED and Sensor must be held next to the Skin. More importantly, this whole method of acquiring Heart Rate information is very prone to motion artifacts. If the sensor moves at all, this can show up in the supplied signal. And backing the sensor away from the skin will drastically reduce the sensitivity. To make matters worse, the entire body is a connected fluid system, and motion of one part of this system can easily generate signals that mimic the beating of the heart as sensed by the PPG transducer, or even causing signal excursions so great they can swamp out any amplification circuitry connected. And some locations on the body are much better than others for use of a PPG, and optimum locations don't always show up as the most fashionable or convenient locations for wearables. Finally, the magnitude of the sensed PPG signal varies widely based on both Respiration and Ambient Temperature.

From an engineering perspective, LED's are notoriously power hungry. Only turning them on for a short interval can substantially reduce power requirements. But it probably needs to be turned on at least 10 times faster than the maximum frequency you expect. For example, 240 beats per minute (bpm) is 4 Hz, so a good minimum 'sample rate' is probably 50 Hz., and 25 Hz may work too for the slow moving PPG. So you would need to turn the LED on at least this often. But it is (currently) not possible to power such a sensor chain for a month of operation on a battery small enough to fit in that wrist-band. And if you can add more gain to the sensor amplifier, you can reduce the drive current of the LED, but this process will quickly run into trade-offs between signal and noise. Increasing the efficiency of the LED will also help, but that is only happening slowly.

And we can think outside the box here a minute, too.

You can use ambient light, and the camera included in most Smart Phones to actually see this effect, the changes in light conduction based in blood flow. In a reasonably bright room, and with the camera previewing, place your finger or thumb over the camera. As the camera adjusts it's parameters, you should be able to see the slow cycling of the heart, showing up as slight changes in the brightness of the image shown. This measurement approach is currently not very effective, because the Camera electronics seem to roam to constantly adjust the parameters of the camera detector plane, and such changes can occur at periods approximating the average heart-beat. We have not found a way to completely turn off such 'wandering' of the electronics however. And placing your finger over the camera isn't exactly what people think of when you say 'wearable'.

Also, as the heart beats, the entire body ever so slightly moves. The amount of movement varies with both heart rate, overall health and tone, as well as the position of the subject (the signal will probably be too small if the subject is lying down). Still, a sensitive accelerometer can easily pick up this signal. In form, it approximates the PPG signal. But this accelerometer will pick up movement from just about anything else the subject does as well.

The bottom line is that a PPG based Heart Rate reading is only valuable as a 'ball-park' figure, especially given it's sensitivity to subject motion. More complete information about the subject's heart can only be supplied by much more 'invasive' methods (ECG plus Skin Surface electrodes), usually requiring substantially more operating power. And current PPG measurement methods require direct contact with the subject's skin.

Measures Related to PPG

Devices for measuring PO2 or Blood Oxygen content have been successfully miniaturized for over a decade. However, this technology still relies on continuous, direct contact with the subject's skin, and is usually used on a finger, which supplies a good, deep tissue field, for better signals. While the sensing path can also be affected by subject motion, the subject's PO2 value changes only slowly over time (relative to the beating of the heart), and so the effects of motion can usually be accounted for using post-proccessing of the detected signals.

This is out of our field, but we think there is research on-going to also be able to determine Blood Sugar content from some sort of LED based solution. We suspect such an approach would take a substantial amount of post-processing. It would also require continuous, direct contact between the transducer and the skin. And motion would have to be managed as well. And LED solutions still require a pretty big battery.

Respiration

Another helpful measure for humans is their breathing pattern, broadly referred to as respiration. The goal is to find out how fast or how often a person is breathing. The ball-park figure for this is usually in breaths per minute, and 6-12 is common based on activity.

Respiration transducers are generally placed around the chest, and use some means to measure the expansion and contraction of the subject's chest circumference as they breathe. The measurement means can be some sort of force or displacement transducer, or bio-impedance equipment. Even though this is the most rigorous and commonly used method, it needs to be added that substantial subject motion can easily affect the Respiration signal sensed in this manner, because other things besides inhaling and exhaling can affect the circumference of the chest.

A Thermistor can also be used to measure the respiration signal. The principal used is that, as the subject inhales and exhales, the temperature of the air flowing both into and out of the subject can be sensed, as it varies with normal breathing. The inhaled air stream is usually cooler than the exhaled air stream. This approach is less prone to subject motion, but requires that the transducer be placed such that it is exposed to the air flowing into and out of the subject's lungs, which means fairly close to the subject's mouth. This approach is mainly used for Sleep Studies, and is not a good candidate for a wearable implementation.

There is another means to sense the Respiration signal, but it requires an Electrode based connection for an ECG signal chain. The peaks of the amplified ECG signal will rise and fall in amplitude as a result of Respiration. This can supply a fairly good Respiration signal, but also requires a clearly 'intrusive' electrode connection and the ECG signal chain electronics. Using the same principal, it may be possible to derive the Respiration signal from the subject's PPG signal. It is doubtful that this approach would work very well, if at all, because of the many other factors that can also affect the amplitude of the PPG.

Temperature

Let's assume that the intent here is not to simply supply 'ambient' temperature, the temperature of the air around the subject. That might be helpful information, but this is certainly not very significant as a parameter for a wearable device.

There are non-contact methods available for measuring the temperature of a surface. They are very power-hungry. We can also place a Skin Temperature transducer directly on the subject's skin, and the electronics for this are much closer to the wearables realm. But the reading will often vary drastically, both from the adjustments the body might make in response to ambient temperature, as well as the effect that wind or other air circulation may have on the transducer.

The problem is, though, that, as a general measure, the subject's Skin Temperature is not always that critical or helpful. In cold weather, the surface of the skin cools down, as the body slows blood flow to the skin in order to minimize the loss of heat. This is especially true of extremeties (legs and arms).

The only significant temperature is really 'core temperature', and we currently have no way to measure this without actually placing some sort of temperature transducer in a location that reflects core temperature. The subject's mouth or ear canal; mounting transducers in places like that are presently the only way to access this information.

Market Observations

There is certainly a lot of interest in 'wearables', and specifically in wearable medical devices. An important distinction must quickly be made, however. There are really two separate markets currently lumped together in this field.

The casual 'lifestyle' market for wearables is certainly large. However, this market group is particularly finicky about 'what and where', and this can affect even the possibility of supplying certain measures, as we have seen above. And this market segment will not accept much more than only the slightest 'intrusiveness'; the extent to which the wearable really affects them. For example, noone wants to put stuff up against their skin unless they have to, and resistance to this obviously varies drastically depending on the actual location on the subject. This market is not real concerned about precision or accuracy, because it is just not that important. It just needs to work fairly well. And it can be noted that 'disposable income' is what fuels this market.

The medical care and research fields demand a much higher level of accuracy for the measured parameters, and some minimal intrusiveness is tolerated as a result. Information about the heart is generally supplied from a high resolution ECG signal, taken from three or more skin surface electrodes. The shape of the waveform and/or the actual millisecond Interbeat Interval (IBI) are the usual target of such measurements. Surface muscle activity (EMG) is also generally measured with skin surface electrodes and substantial amplification, as is Eye Movement and Position (EOG). Brain-wave activity (EEG) is measured with skin surface electrodes as well, but is often accompanied by dedicated, multi-channel recording and computationally intensive display / visualization equipment. And electrodes on the skin can also be used to measure the conductance of the skin, which can vary substantially due to psychological factors. Skin conductance measurement is used to track Hot Flashes as well. Overall, this demand for quality data severely limits the applicability of wearable technology for the reasons discussed above. Also, we can note that the economics of health care are constantly fueling the pursuit of simpler, less expensive and more accurate measurement methods for these parameters.

Conclusion

We recently saw a write-up on a very rugged microphone, and somewhere in the discussion they mentioned the use in wearable medical devices. Well, we need to stop and think a minute here. There is a measure that uses an acoustic signal to assess the heart. The measure is called Heart Sounds. A doctor using a stethescope is actually listening for this exact sound. The use of a rugged microphone might work well for this, but it would probably need to be surgically embedded in the chest to be effective. On the surface of the skin, it would generate noise from ambient acoustic signals, and even subject movement. And even there, we would question how popular of a wearable solution this might be.

It is important to think through assertions about wearables, stated or implied, in order to be able to evaluate what is really going on. Medical instrumentation is not a new science, but this background can help understand what currently can and cannot be done. UFI has been supplying electronic instruments for research and teaching in the Life Sciences for decades. Electronics has come a long way, but in our opinion, that wrist band is still just a nice idea.