

Failure Modes of Wearable Computers

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Background

Society has been enamored with wearable electronics for many years. From the futuristic suits in Tron to the recent use of Google Glass, taking electronic technology to this next level has fascinated us. Wiki defines wearable computers, also known as body-borne computers or wearables, as miniature electronic devices that are worn by the bearer under, with or on top of clothing. This class of wearable technology has been developed for general or special purpose information technologies and media development.

The wearables market is perhaps \$3 billion to \$5 billion today, rising to potentially \$30 billion to \$50 billion over the next three to five years as forecast by the analysts who add that there may be upward of 15% of smartphone owners who end up buying a wearable.

The breadth of applications is staggering as shown in Figure 1 from Beecham Research.

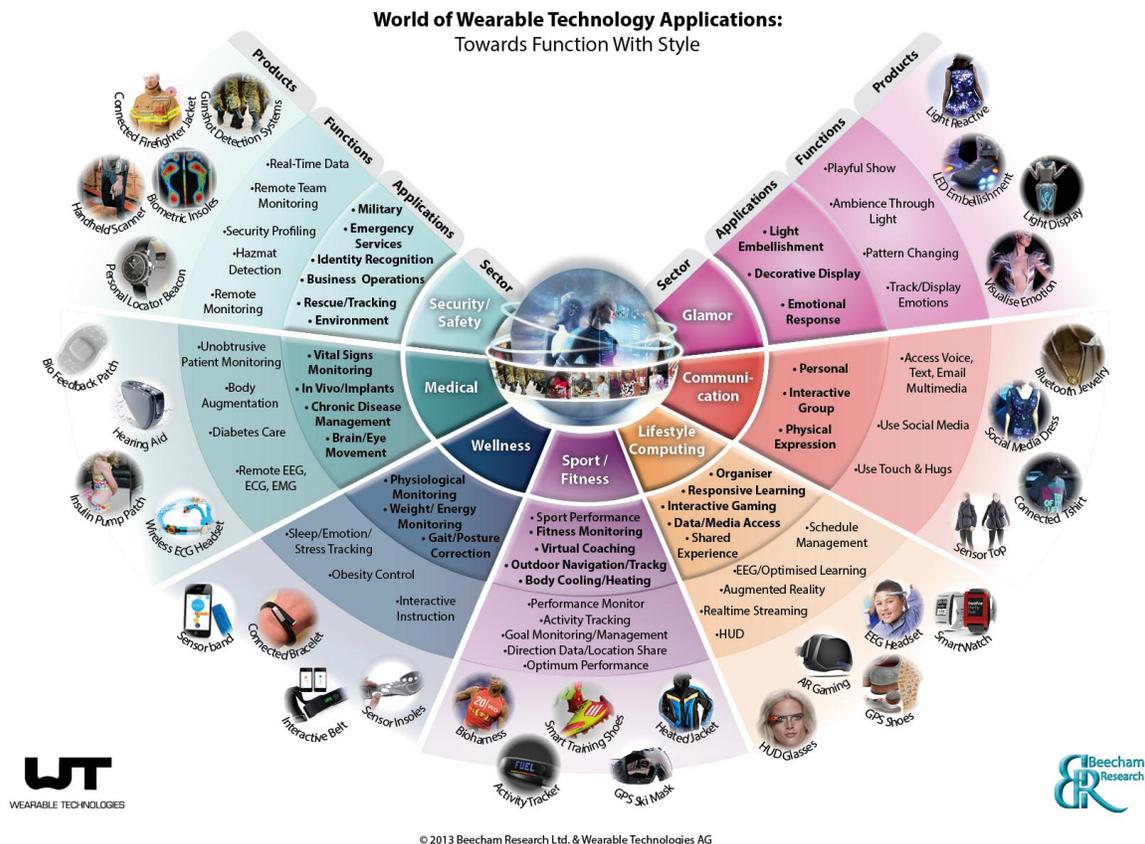


Figure 1

Figure 2 provides some interesting examples of wearable electronics/computing, ranging from Google Glass to prosthetic arms and woven electronics on cloth.

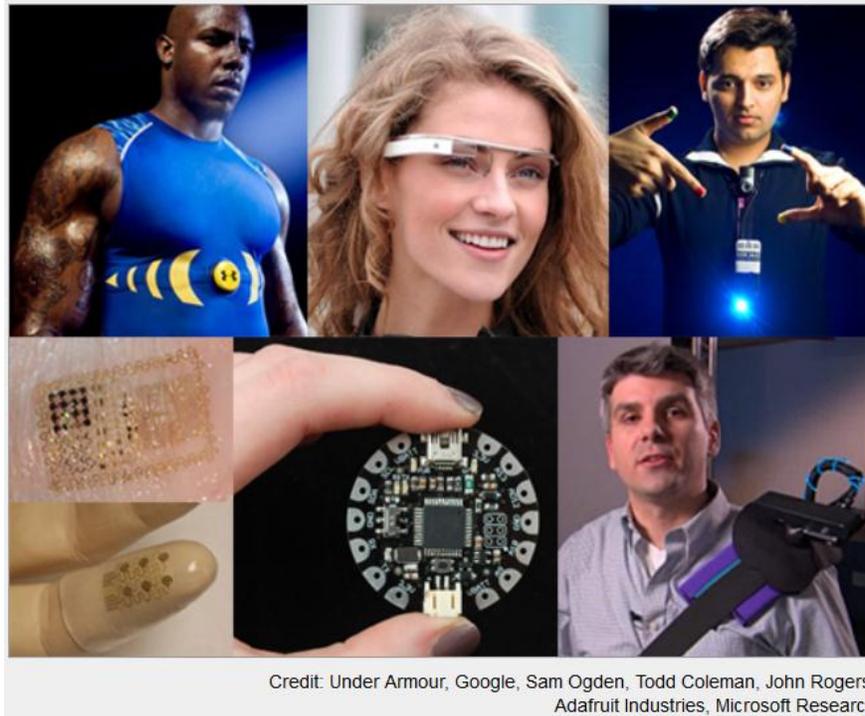


Figure 2 – Examples of Wearable Electronics

Figure 3 is an image of digitally aware footwear which houses a GPS chip, a pair of microcontrollers and an antenna. The left shoe points you in the right direction with a compass-like circle of LEDs on its toe, while the right shoe's row of LEDs indicates progress to your destination.



Figure 3 – GPS Shoes

Figure 4 is an example of epidermal electronics. These ultra-thin electronic patches bend and stretch with the skin while sensing a patient's skin temperature, brain waves or heartbeat patterns and transmitting the data wirelessly to a hospital computer.

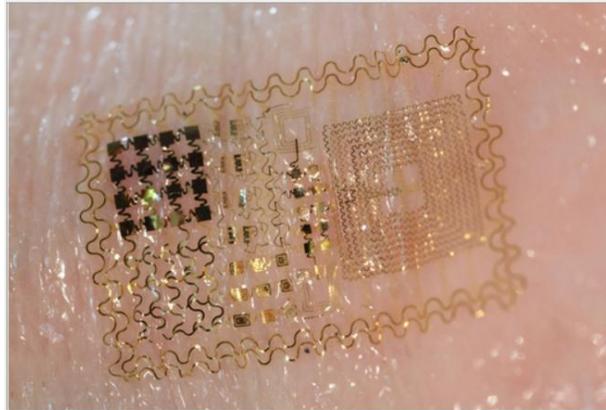


Figure 4 – Epidermal Electronics - Credit: Todd Coleman

And finally, Figure 5 shows the next generation warrior who will carry multiple wearable computers/electronics to be more effective on the battlefield.



Figure 5 – Wearable Electronics on Soldier of Tomorrow

What are the requirements of a typical wearable electronics device? They must be non-restrictive, portable, always accessible, easily controllable, and have both localized communication and possibly wireless communications capabilities. The soldier systems must be much more robust and be able to withstand rain, sand and dust, thermal shock, solar radiation

(UV exposure), icing, high and low temperatures, fungus growth, water immersion, mechanical shock and electromagnetic (EMC) compatibility. As such, these systems are costly and have long development cycles.

Similarly, Victorinox has developed a watch that can survive a 10 meter drop, hours in a washing machine, and even 2 passes of being run over by a tank. It can stay watertight up to a depth of 200 meters and can operate from -51C to +71C in addition to handling 12g of acceleration. The problem; the average consumer cannot afford the watch.

The commercial industry for wearables does not design for these environments due to cost constraints and life expectancies of the products. But, does that meet the consumer's expectations? Doubtful.

Understanding the various issues that could impact wearable electronics from a reliability perspective is necessary for the consumer and the manufacturer to achieve a common set of objectives.

Issues

Wearable electronics falls into the categorization of "Next Generation Technologies." DfR Solutions defines these technologies as those the supply chain or the user will implement because they are cheaper, faster, stronger, etc. One of the most common drivers for failure is inappropriate adoption of these new technologies. As most of us have little or no influence over the packaging technologies chosen for implementation, we need to be aware of the pitfalls and what actions need to be taken to assure that the new technologies are reliable. With new markets of electronics, there are typically several issues that need to be addressed from a reliability perspective to assure these new applications are both safe and reliable.

Packaging Approach

Due to the small form factor requirements of wearable electronics, packaging approaches like QFNs, uCSP and CSP and MEMs sensors are popular solutions for these products. DfR Solutions has published numerous papers and articles on the issues associated with these packaging technologies and the methodologies that must be implemented by the OEM to assure long term reliability. Similarly, System in a Package (SiP) will see wider usage as the functions of power management, microcontrollers, and the various sensors will be comingled into a single package. Smaller passives will also typically be utilized. Again, there are several known failure modes associated with both these packaging and passive configurations. However, with the advent of wearable electronics, there are more issues to consider.

Sweat

It has been documented in blogs that many Apple iPod Nano's have shorted out due to sweat. Users resort to placing their units in baggies to protect them while in use. Similar issues have

been encountered with cell phones coming in contact with sweat. Openings in the products enclosures let this moisture penetrate to the electronics; and sweat, since it is also salty, is the worst combination possible for causing shorting or dendritic growth.

It's necessary for designers/manufacturers of wearable electronics to address this issue; otherwise, product life expectancies will not be achieved and warranty issues will abound.

UV Exposure

The sun is important for our health; but, overexposure can result in significant health issues ranging from sunburn to skin cancer. The wearables industry has created sensors that can measure the UV and provide protection to your body by wirelessly transmitting data to your cell phone. But, what provides protection for the wearable sensor itself from exposure to UV?

Temperature Exposure

Electronics that can come in contact with the skin must maintain an operating temperature that will be at or below the core body temperature of 98.6F. Temperatures above that result in the wearer being uncomfortable and if the temperature goes higher may cause pain and a high level of discomfort. (1) Figure 6 illustrates this issue. As such, wearable electronics, in some cases, must be manufactured to medical electronics standards including Pb-free requirements and also the ability to minimize tin whiskers.

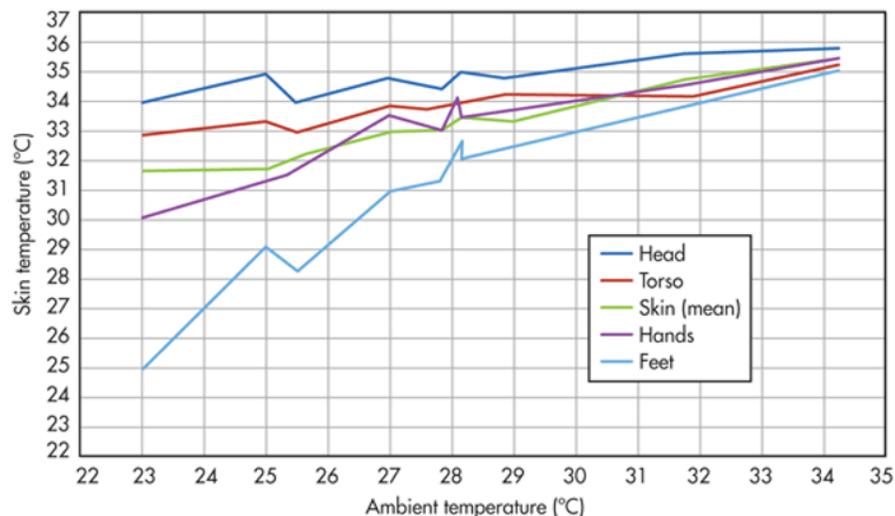


Figure 6 – Core Body Temperature Variations

Tumble/Drop Test

Wearable electronics are much more susceptible to being either dropped or tumbled onto a surface. It has been documented that multiple drops are much more damaging to the electronics

than a single drop. The issue with wearables is that the product moves with the user and can encounter multiple types of drops that are unconstrained in nature. How do the products survive?

Tumbling, or as some call it, clattering, is a result of an object being dropped on one corner, rotating, striking another corner, and so on (2). These multiple shocks to a wearable system can be devastating.

Clearly, an understanding of the methodologies for providing support for the electronics as well as understanding the failure modes that may be encountered is vital. This is where DfR Solutions can provide you, the OEM, with the insights necessary to design and configure a viable wearable product.

Drop in Water/Toilet

How many times have we heard of someone leaning over their toilet and their cell phone falling out of their pocket into the water? We then hear of them putting the phone and battery into rice to remove as much moisture as possible. Some cell phone manufacturers have addressed this issue by coating the circuit board with either a conformal coating or a superhydrophobic coating to protect the electronics. Doing so allows an assembly to be submerged as shown in Figure 7 for prolonged periods of time without failure.

This issue of exposure to water and rain must be addressed for wearable electronics to survive.



Figure 7 – Cell Phone Being Dropped in Water.

Repeatable Bending

Cyclic bending has been used as a technique for assessing the mechanical durability of the solder joints of parts mounted on circuit boards, or even the strength of the PCB itself. Typical testing causes the PCB to deflect either 1 or 2 millimeters and the cycle count can be in the hundreds of thousands. Today, with wearable electronics, this issue is even more prevalent because the

application must “feel” like a textile rather than like the normal rigid or flexible circuit board. Some OEMs are creating products where the electronic circuit is placed on a stretchable material. The issue involves the long term performance of the stretchability and connectivity. Wearable electronics will involve large numbers of stretching cycles. Will degradation or aging occur? What is the impact on the conductors and the connectivity of the device? These questions must be answered prior to a product being released to assure customer satisfaction.

Copper Bend and Torque

To offset the cyclic bending issue, some systems are implementing a Silicon Nanowire structure so that the interconnect can be stretched rather than be part of a rigid circuit board construction. Again, what is the durability of this new technology? Can the nanowires handle multiple bend and torque operations? DfR Solutions concern is that in most cases the application is fielded before these questions are answered to assure market penetration. The problem is that the customer expects reliability of these new products.

RFIDs on Humans

Another technological area for the use of wearable electronics is that of RFIDs integrated into clothing that enable monitoring of people without their conscious involvement. The healthcare industry is using these types of RFIDs to monitor heart rates and other body functions and to send the data to a localized reader for analysis. Lack of sufficient manpower in a nursing home, for example, would benefit from the RFIDs in patient wristbands to monitor patients and make the staff more efficient. The antennas would be printed on the band to enhance communication. Going back to previous sections of this white paper, the RFID must not be affected by sweat, moisture, and humidity or bending by the patient. The issue is whether the RFID tag has been adequately analyzed to determine its reliability and ability to function without failure in a medical application scenario.

Batteries

Another important issue is low power design due to the limited power available in the wearable system. Although the capacity of batteries has increased, it has not been able to handle the ever increasing power demands of wearable systems. Does the application use disposable batteries with short lifespans, or are rechargeable batteries used? It is well documented that problems can occur with thermal runaway of lithium-ion rechargeable batteries. Having a runaway situation on a wearable piece of electronics could be harmful and potentially dangerous. Some designs are looking at ways to enhance power management to prolong battery life. Others are looking at conductive textiles as a means of power management. This creates a situation where the robustness of the design and its ability to manage power may be crosswise with each other.

Others are using forms of energy harvesting to power their wearable electronics. These approaches are derived from the mechanical energy of people’s own moving or accelerations on

transport, an electromagnetic energy that is derived from light, and the heat transfer caused by the difference in temperature between the human body and the ambient.

The Army Program for the Electronic Soldier.

The army is looking into wearable solar panels for soldiers to facilitate delivering power to the other electronics carried. Soldiers carry about 12 pounds of batteries currently and getting new batteries to the soldiers is a dangerous assignment. Some companies are looking into kinetic power through a wearable knee brace that provides energy to the electronics. Interestingly, the fashion industry is also producing dresses for women that incorporate solar cells. The army will definitely perform rigorous reliability assessments of these systems, but will the commercial fashion industry? (3)

Summary

The wearable electronics industry is still in the development mode as prototype and experimental products lead the way to more robust consumer offerings. From products with high expectations on lifetime to low-cost disposable devices, there is a wide expectation of how this industry will develop. Clearly, more applications will find ways for us to use and process data from our everyday lives, assuring that wearables will continue to rely on innovations in packaging. These innovations must be examined with respect to reliability if they are to find acceptance in the marketplace and meet customer expectations with regard to reliability. Let DfR Solutions, with its extensive background in reliability, understanding of the failure modes and mechanisms that can be encountered, and our breadth of technological capabilities work with you to assure your product's viability in the marketplace.

References

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