Second-Skin Sensing: A Wearability Challenge

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Abstract

The gold-standard sensors in many sensing areas have been primarily developed for use in a highly controlled medical or clinical setting, with the chief goal of optimizing their accuracy. Unfortunately for wearable technology, this often means that short- or long-term wearability has been significantly compromised. This paper discusses two case studies where sensing difficulty was experienced due to the necessity of maintaining sensors very close to or in contact with the skin: electro-dermal sensing and bend sensing. Problems for mainstream wearable technology are discussed.

1. Introduction

Sensing many aspects of the body's physical and physiological functions is often performed through the skin. Electro-dermal sensors, temperature sensors, bend or elongation sensors, fluid sensors, and many other sensors rely on monitoring or mimicking the skin's activity for optimal accuracy. Conflicting with this goal, many aspects of wearability in body-mounted technology require some degree of airspace between the body and the technology [1] to preserve user comfort. In the case of sensors requiring actual skin contact, the means by which sensors are affixed can easily cause further discomfort.

The effect of user discomfort or difficulty of use in a wearable device is often non-use of the device by the user. This is especially true in devices with non-crucial functionality: devices that provide a relatively marginal degree of quality-of-life improvement (such as context awareness), rather than a life-saving medical function.

This paper will outline 2 case studies—electro-dermal and bend sensing—in which the requirements for wearability and sensor accuracy were in opposition, and discuss efforts towards solving these problems.

2. Electro-Dermal Sensing

Electro-dermal sensing is used to monitor heart activity, muscle activity, and galvanic skin response, among other things. These signals are obtained by measuring the electrical potentials between pairs of electrodes, generally sitting on the skin's surface. In a medical setting, the skin is first prepared, by removing the layer of dead cells and any body hair. Conductive gel is applied to create a better electrical connection, and the electrode is affixed to the skin using an adhesive, to prevent electrode slippage or movement [2]. While all of these preparations help to provide a clear and accurate signal, they are potentially too extreme to be performed over a long period of time, or even on a short-term basis for a marginal benefit.

In the wearables community, several projects have addressed the need for wearable electro-dermal sensing [3,4,5]. To improve wearability, these projects have generally used contact (not adhesive) electrodes, made of either metal plates or conductive textiles. While such prototypes have yielded useable signals, they have almost exclusively been evaluated in stationary, controlled environments, sometimes with the advantage of conductive gel.

While slightly noisier, contact electrode signals can be nearly as accurate as those recorded by their adhesive counterparts when the subject is stationary. However, when movement is introduced (sometimes as little as a deep breath), the signal rapidly deteriorates. More extreme movement, such as that created by jogging, results in a signal that is entirely obliterated by noise [6]. EMG and ECG signals prove differently problematic: the EMG response is recorded as an increase in sinusoidal wave amplitude, while the ECG signal is a consistent, cyclical waveform of a much lower frequency. The ECG waveform is a distinct pattern, while the EMG response looks more like noise.

Using garment-integrated contact electrodes to measure EMG is a difficult proposition, because muscle contractions often result in a change in body contour. This changes the force present between the garment (including electrode) and the body, which can create a new or improved connection. This can make detecting the "rest" levels difficult or impossible, and otherwise obscure the actual muscle response. A more consistent electrical connection can be established to record ECG data, since the contractions of the heart do not result in significant changes to the body contour. However, the signal is similarly affected by movement. Noise is introduced by the movement of the dermis over the musculature, and by the contractions of trunk muscles that cover the heart.

The addition of conducting gel improves the quality of the electrical connection between the skin and the electrode. Similarly, as moisture builds up between an impermeable electrode and the skin, the connection also improves. Gel is conceptually not that different than moisturizer, and it is not inconceivable that users could be willing to apply a conductive layer each morning, as long as there were no adverse health reactions. However the movement effects are still present, and still prevent the acquisition of a reliable signal. Advanced analysis could permit the detection or removal of "noise" areas, but the distinction between, for instance, a noisy signal and a heart problem, can at times be difficult.

The newer hydrogel electrodes provide a more comfortable substitute for traditional adhesive electrodes, and are moderately re-usable, but they are not washable and thus can not be incorporated into standard undergarments. An improved solution would incorporate the attractive physical properties of both a hydrogel ("tacky" surface, solid skin connection), and a metal or conductive fiber electrode (washability, durability). Alternatively, an array of redundant electrodes could provide a better chance at a good connection, although simultaneously presenting a vast increase in processing requirements.

3. Bend Sensors

Bend sensing is often used in wearable sensing to detect body movement or joint position. It is generally accomplished in one of two ways: by a segmented resistor whose components move farther apart (thus becoming more resistive) when bent, or by a measure of the amount of light lost by a bent fiber optic filament (more bend=more loss). Both of these techniques require the sensor to be secured firmly to the body—either adhered to the skin or encased in a skin-tight garment.

For bend-sensing on the body, a slightly more wearable solution is the use of textile-based sensors, generally extensible textiles coated with a conducting polymer [3,7,8,9]. The polymer becomes more conductive as the textile is stretched or compressed. This solution also requires skin-tight garments, in order for the textile to stretch perceptibly as the body moves.

An alternative, which reduces the need for skin-tight garments, is to use the polymer to coat a 3-dimensional structure, such as open-cell foam [10]. Such a structure preserves the favorable qualities such as softness and flexibility, but allows for a sensor that responds to deformations of the textile surface (i.e.: folds, bends, flexion) rather than extension of the textile. Thus, a looser garment can be used to detect movements [11].

Unfortunately, the aforementioned conductive polymer solutions trade a degree of accuracy for their obvious wearability advantages. The polymer itself is noisy and inconsistent, preventing absolute sensing of bend angle, for instance [12]. Clever integration of such sensors, however, can produce useful results. For instance, foam sensors have been shown to work well for event-detection applications, where the magnitude or quality of the event is not as important as the occurrence or frequency. Such applications include the use of the sensor to monitor repetitive stimuli such as breathing, or in a switch-like application to detect the movement of a designated body part [13].

Similarly, combinations of these event-detection sensors could yield a more context-aware output. Combinations of various foam substrates could also yield more sensitivity, where differently compressible foams are layered, and the deformation of each layer is detected (compression of stronger layers indicating a larger force).

Another solution, the integration of piezoelectric materials into textiles, is also promising [14]. However, the full range of accuracy of these materials in a garment-integrated application is yet unknown.

The ideal solution combines the accuracy of a fiber optic or segmented resistor sensor with the flexibility, washability, and softness of a foam or textile sensor. Detection of garment movement is a more wearable means of deducing body movement than requiring the sensor to mimic exactly the movement of the skin itself.

4. Conclusion

The need for truly *wearable* body sensors is clear: while invasive, restrictive, uncomfortable sensors are the only choice, viable applications will remain restricted to those arenas (medical, military) where the body sensing function is crucial to the subject's health or well-being. But the trade-offs for sensing accuracy must also be overcome to preserve the full range of possible applications. An understanding of the requirements for mainstream wearability is necessary to further wearable body-sensing research in this direction.

6. References

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