AN ANALYSIS OF SENSOR TECHNOLOGY FOR CLOTHING

In an age of rapid technological advancements in sensors and materials, the fashion industry needs to constantly rethink ways it can exploit the potential these innovations bring and extend its appeal to a tech savvy audience. Smart clothing is a one way technology is bring cutting edge functionality to everyday garments, extending their capabilities into the realm of health and fitness tracking. Sensors such as photodiodes, electrodes and thermistors can be built into clothes and the data collected can be analysed remotely to monitor movements or detect health complications. Surprisingly, adoption of smart clothing has been slow. This is down to two factors: concerns over data privacy and the bulky, cyborg-like appearance commonly associated with wearable tech. Ultimately, smart clothing makers will only be successful if these two obstacles can be overcome. In this essay, I will examine the different approaches to sensor technology a smart clothing manufacturer might take, as well as advise safety measures to protect customers and their data.

HEART RATE SENSORS

Built-in heart rate sensors would enable an item of clothing to monitor the wearer's heart rate for medical or fitness purposes. In medical applications, it could be used to check for arrhythmias, a symptom of the heart condition atrial fibrillation[1]. The user would be alerted if arrhythmias occur, which could prevent potentially fatal heart failure or strokes without the patient ever having to see a GP for an initial diagnosis. In fitness-wear, a heart rate sensor could be used to estimate calories expended during a workout[2]. For a clothing manufacturer who wishes to incorporate a heart rate monitoring feature in their product, there are two types of sensor system to choose from: photoplethysmography (PPG) systems and electrocardiography (ECG) systems.

PPG systems use optical sensors to detect changes in the volume of blood in the capillaries[3]. They consist of a green LED and a photodiode. Blood absorbs green light, so by measuring changes in green light absorption, PPG systems determine pulse. The LED flashes light onto the skin hundreds of times per second. When the heart beats, the volume of blood in the capillaries increases and more light is absorbed. The photodiode then measures the intensity of the light reflected back from the skin and generates an analogue signal. This signal can be interpreted by a built-in microchip or the processor of the wearer's phone to measure heart rate.

[4]

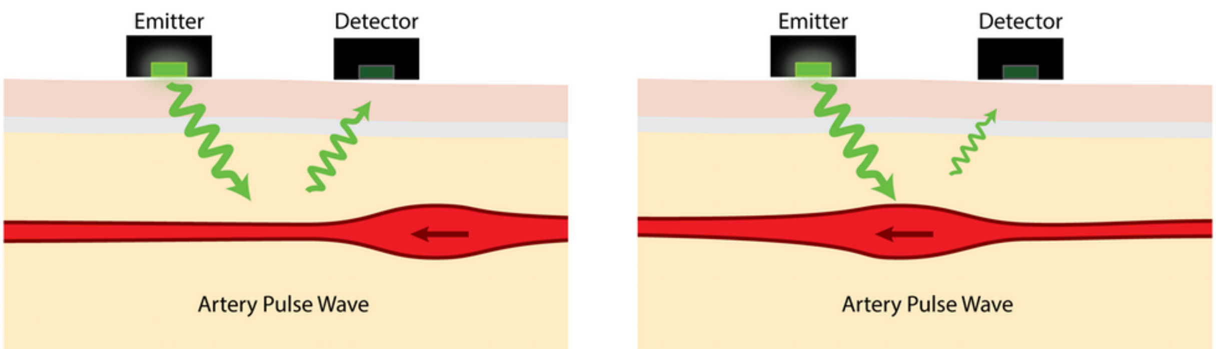
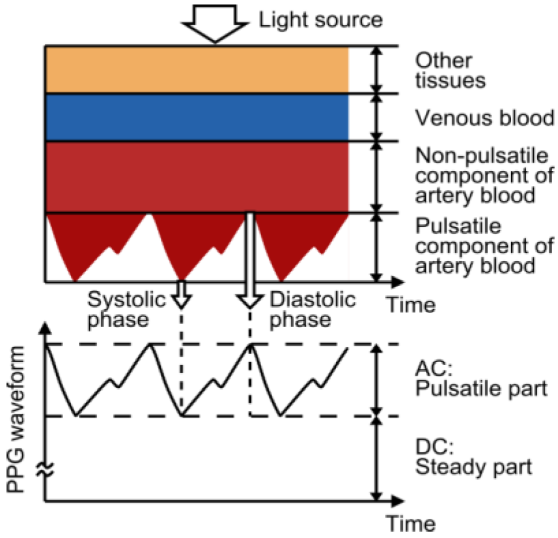


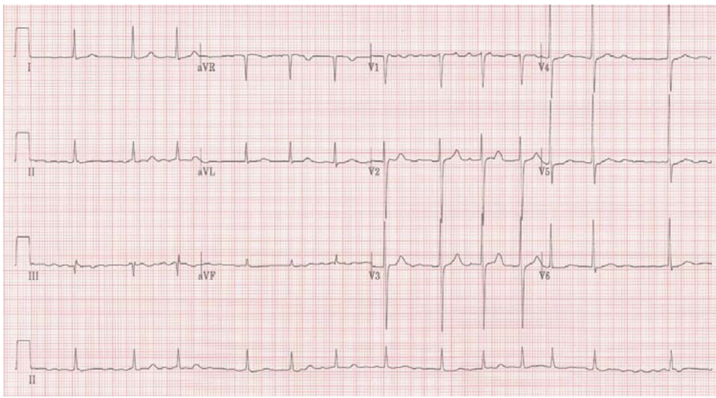
Figure 1 Optical heart rate sensing. Left: lower volume of blood preceding the pulse wave means narrower blood vessels and less absorption (higher reflectivity) of the green light source. Right: a pulse causes more light absorption (lower reflectivity). (Collins, 2018)



[5]

Figure 2 Generation of a waveform by a PPG sensor (Tamura et al., 2014)

An ECG system involves placing small electrodes on the skin that measure the electrical impulses produced by the heart as it contracts[6]. A digital signal is produced using the voltage changes recorded. This digital signal represents the heartbeat and can be analysed to detect cardiac problems.



[7]

Figure 3 An ECG graph showing an arrhythmia (DailyCare BioMedical Inc.)

Both ECG and PPG systems have benefits and drawbacks that manufacturers must weigh up when deciding which to include in their product. Both systems have the advantage of being non-invasive. They take measurements at the skin surface so could be sewn into clothing without causing the user discomfort. The drawback to PPG systems is they tend to be less accurate than ECG systems[8]. PPG systems rely on the green light emitted by the LED penetrating the skin and entering a blood vessel. The optical density of the blood due to pulses varies by no more than 2%[3], so to give a reliable estimate of heart rate, the sensors must be tightly fastened to an area with plenty of blood supply. This limitation would restrict the clothing designer's placement of PPG sensors to areas with superficial blood vessels such as the wrists. As well as being more accurate, ECG sensors have the advantage of consuming less power, so they would not have to be recharged as frequently. The biosensor manufacturing company

NeuroSky®'s BMD101 ECG sensor operates at 2.5mW, less than a tenth of the 30mW required to operate an average PPG[9]. Despite this significant advantage, PPG is an older technology than ECG and therefore, is cheaper[5]. For this reason, PPG systems dominate the heart rate monitoring wearables currently on the market, such as Fitbit® fitness trackers[10]. On balance, if the smart clothing manufacturer is looking for a cost-effective heart rate sensor they should opt for PPG. However, if their product requires greater precision and power efficiency, such as in a medical garment, ECG is more suitable.

MUSCLE SENSORS

Another sensor that a smart clothing manufacturer could include in their product is an electromyography (EMG) or 'muscle sensor'. This is particularly useful in smart athletic wear. Users could put on their smart suits before heading to the gym, then use a mobile app to track muscle activity, optimise their workout and prevent injury. EMG sensors use electrodes to measure the electrical potential of muscle tissue resulting from a nerve's stimulation of that muscle.

[11]

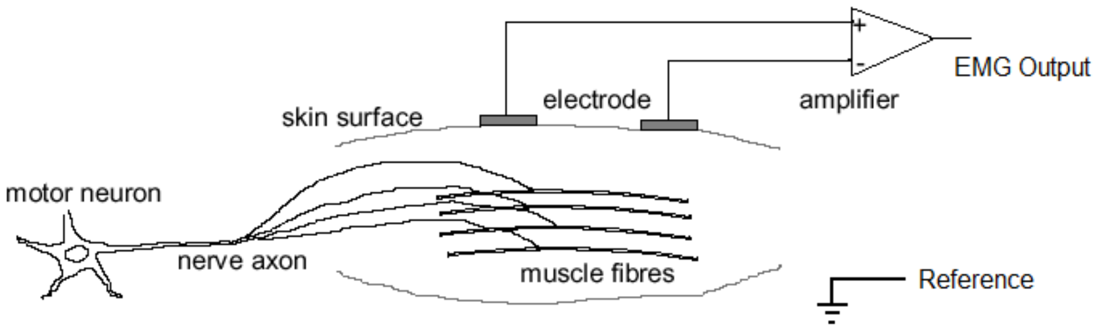


Figure 4 EMG electrode configuration (Jamal, 2012)

Athos® is a company already using EMG to move into the athletic wearables market. Athos® has produced a gym clothing line and free iOS app that together provide real-time feedback on muscle engagement[12]. Athos systems are currently being used by professional basketball team 'The Golden State Warriors'. The Golden State Warriors' coach monitors his players' workouts and uses the data to determine physical readiness for upcoming games. In the professional sports industry, the cost of preventable injuries can jeopardise a team's success. Thus, there is a market opportunity for EMG sensor-equipped smart clothing to provide injury-preventing insights.

[12]

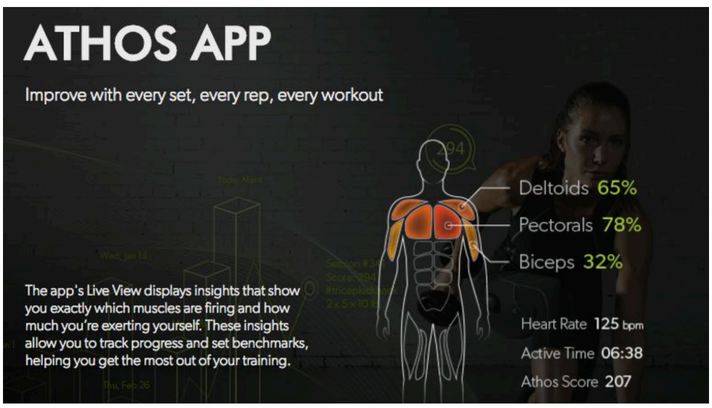


Figure 5 The Athos App (Athos, 2019)

TEMPERATURE SENSORS

Embedding thermistors within a garment is a simple way of measuring skin temperature. Temperature sensing garments have a wealth of potential health monitoring applications. For people with diabetes who are prone to foot issues, a smart sock could detect a rise in their feet temperature — a sign of inflammation — and alert the user with a smartphone notification. If left untreated, inflammation can lead to foot ulcers. With this system foot injuries could be before it is too late.

[13]

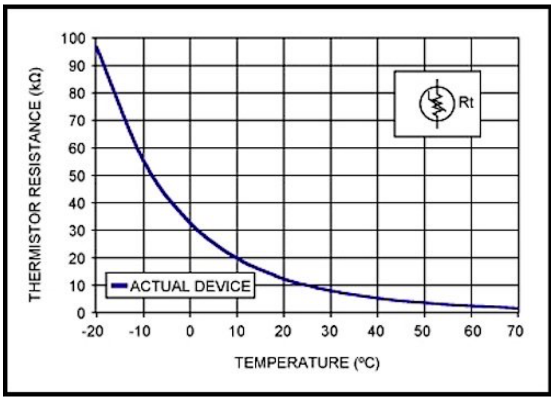


Figure 6 An NTC thermistor resistance vs. temperature (Maxim Integrated, 2001)

Thermistors are semiconductors that are used as temperature sensors as they exhibit precise changes in electrical resistance in response to varying temperature. They are ideal for smart clothing because they are durable, cheap and accurate to 1°C[14].

The use of an electronic textile integrated with thermistors would be an effective way of discretely adding temperature sensing capability to a garment. The item would appear completely normal, so would not put off the style-conscious customers. Temperature sensing yarns using Electronic Yarn (E-yarn) technology have already been created by researchers at Nottingham Trent University[15]. Their method of producing the yarn involved soldering 10 kΩ Negative Temperature Coefficient (NTC) thermistors onto fine copper wires and weaving these into a fabric. The smart textile was used to create a temperature sensing glove.

[15]

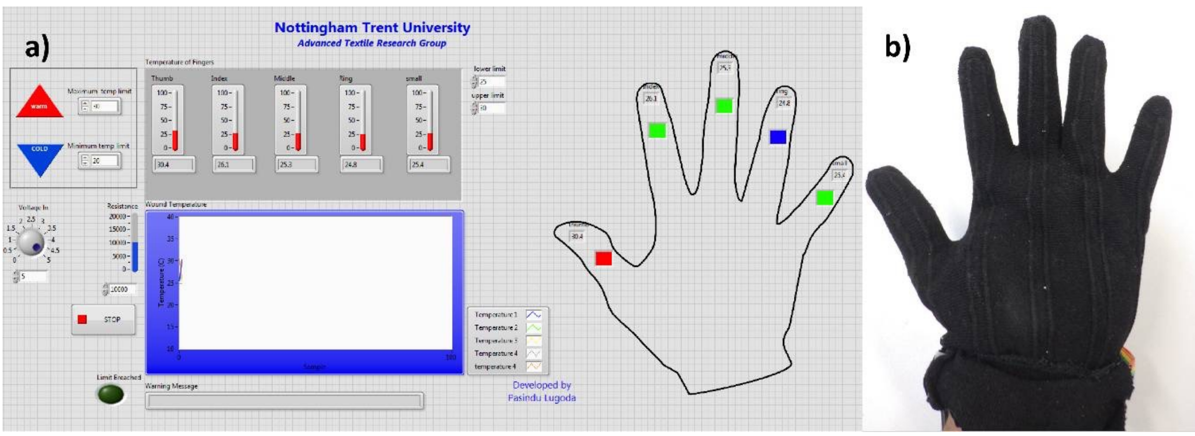


Figure 7 Nottingham Trent University Advanced Textile Research Group's Prototype temperature sensing glove (Lugoda et al., 2018)

As a safety precaution, a manufacturer wanting to use this technology in their product must ensure any circuitry is encapsulated in an electrical insulator so as to prevent electric shocks when worn. The Nottingham Trent research team chose to insulate the copper wires in their E-yarn with an ultraviolet (UV) curable polymer resin as it has a high thermal conductivity which does not obstruct the temperature sensing ability of the thermistor. Their yarn was shown to be accurate to 1°C 89% of the time[16]. Therefore, there is significant potential for the use of temperature sensing smart clothing, particularly for the early detection of foot ulcers in diabetics.

DATA PRIVACY

With so many amazing applications, it is surprising that smart clothing represents just 1% of the wearable electronics market[17]. My view is this lack of adoption is largely due to data privacy concerns. People tend to be wary of third parties when it comes to their personal data, and smart clothing companies are no exception. No one wants the stats from their daily jog leaked online or details of their health problems sold to marketers for ad-targeting. To earn consumers' trust, companies must be completely transparent about their data processing systems and protect customer data with the utmost security standards. For a clothing manufacturer looking to develop smart clothing, I would recommend they use the following two-step telemetry system to transfer wearer data as safely as possible:

1. Security Mode 3 Bluetooth to transfer sensor data to the user's smartphone where it is analysed on a purpose-built app.
2. End-to-end encryption to share data from the app to company cloud servers.

I would advise the use of the Security Mode 3 version of Bluetooth over earlier Security Modes 1 and 2 as it is significantly more secure. According to the US National Institute of Standards and Technology Security, Mode 1 Bluetooth is non-secure[18]. Mode 1 lacks both authentication and encryption features, leaving the connection susceptible to attackers. Security Mode 3 enforces authentication and encryption for all connections to and from the Bluetooth device. By using high-level Bluetooth security, the smart clothing company prevents the interception and collection of personal data sent between sensors and the user's phone.

A cloud system can perform more in-depth analysis of data. It could also be used to directly share data with health care professionals should the user wish, say, for medical purposes. Communication between phone and server must be end-to-end encrypted so that the sensitive data being sent is kept private[19]. Additionally, any data stored on company servers must comply with the 2018 GDPR[20].

For a clothing manufacturer looking to break into the smart clothing industry, possibilities range from heart rate monitoring exercise wear to temperature-sensing socks for people with diabetes. The mainstreaming of smart clothing depends on secure data processing and sensors being seamlessly integrated in a way that is functional, yet stylish. The delivery of these two services will be the catalyst for the fashion industry to embrace these phenomenal technological advances.

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