Wearable Electronic Textiles for Healthcare, Wellbeing, and Protective Applications

Theo Hughes-Riley
Nottingham School of Art and Design, Nottingham Trent University, Nottingham, UK
theo.hughes-riley@ntu.ac.uk

Arash M. Shahidi
Nottingham School of Art and Design, Nottingham Trent University, Nottingham, UK
arash.shahidi@ntu.ac.uk

Kalana Marasinghe
Nottingham School of Art and Design, Nottingham Trent University, Nottingham, UK
kalana.marasinghe@ntu.ac.uk

Zahra Rahemtulla
Nottingham School of Art and Design, Nottingham Trent University, Nottingham, UK
zahra.rahemtulla@ntu.ac.uk

Malindu Ehelagasthenna
Nottingham School of Art and Design, Nottingham Trent University, Nottingham, UK
malindu.galdeniyepahalagedara2022@my.ntu.ac.uk

Parvin Ebrahimi
Nottingham School of Art and Design, Nottingham Trent University, Nottingham, UK
parvin.ebrahimi2022@my.ntu.ac.uk

Richard Arm
Nottingham School of Art and Design, Nottingham Trent University, Nottingham, UK
richard.arm@ntu.ac.uk

Carlos Oliveira
Nottingham School of Art and Design, Nottingham Trent University, Nottingham, UK
jose.oliveira@ntu.ac.uk

Lars Erik Holmquist
Nottingham School of Art and Design, Nottingham Trent University, Nottingham, UK
lars.holmquist@ntu.ac.uk

Tilak Dias
Nottingham School of Art and Design, Nottingham Trent University, Nottingham, UK
tilak.dias@ntu.ac.uk

ABSTRACT

Electronic textiles (E-textiles) can act as an exceptional substrate for incorporating sensing devices for monitoring physiological parameters, as they are comfortable to wear close to the skin. This makes them excellent for a variety of applications in the healthcare, wellbeing, and personal protection sectors. One method of creating E-textiles with good textile properties is to integrate an electronic component into a yarn to create an electronic yarn (or E-yarn), which can then be used to construct a textile. This Interactivity Lab Demonstration will present electronic textiles developed by the Advanced Textiles Research Group (ATRG) from Nottingham Trent University (UK). The group has conducted a wealth of research into the development of E-yarns and the incorporation of these into textiles and garment. At CHI, users will be able to interact with textiles capable of fall and near-fall detection, temperature sensing, acoustic sensing, giving haptic feedback, and harvesting solar energy.

CCS CONCEPTS

• **Hardware** → Emerging technologies; Analysis and design of emerging devices and systems; • **Human-centered computing** → Human computer interaction (HCI); • **Applied computing** → Life and medical sciences; Health informatics.

KEYWORDS

Electronic textiles, E-textiles, wearables, sensor systems, health, wellbeing

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1 INTRODUCTION

In the Advanced Textiles Research Group (ATRG) at Nottingham Trent University, UK, we are designing, developing, and testing novel electronic textile (E-textile) devices, with an emphasis on creating devices for the health, wellbeing, and personal-protective spaces. Textiles can offer an excellent substrate to integrate sensing capabilities for monitoring humans as textile structures are comfortable to wear, making them ideal for positioning devices next

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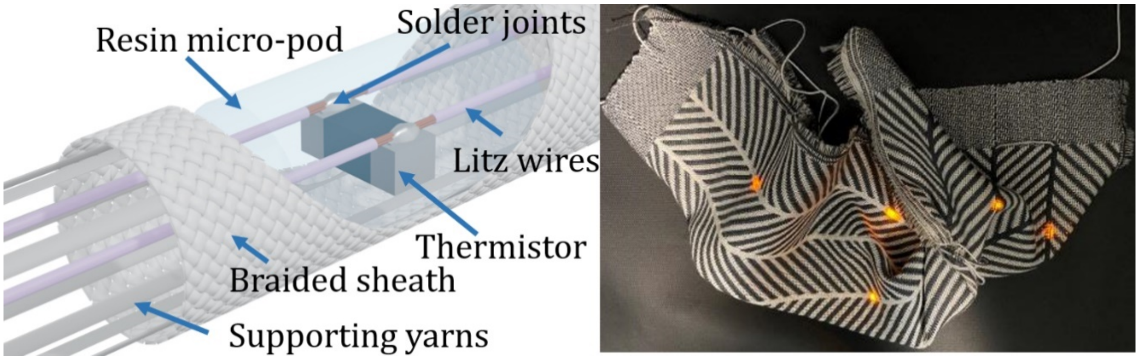

Figure 1: (Left) Schematic of the interior of a temperature sensing electronic yarn. (Right) An image of a textile woven using electronic yarns embedded with LEDs.

to or near human skin. While many methods to create E-textiles exist, many of these have disadvantages leading to poor textile properties, such as a lack of breathability or drapability, both of which are important for comfort. At the ATRG we instead focus on embedding small-scale electronic devices into the core of a yarn and then use this to create a textile. The advantage of this kind of electronics integration method is that it can result in textiles with normal properties such as drape, breathability, and flexibility.

In this Interactivity Lab Demonstration, we will demonstrate five novel electronic textiles developed by the research group: a fall and near-fall detecting sock; a temperature sensing sock; an acoustic sensing fabric; a glove capable of giving haptic feedback; and a textile solar panel. Taken together, these examples will show the potential of using E-textiles for healthcare, wellbeing, and protective applications.

2 CREATING FLEXIBLE AND COMFORTABLE E-TEXTILES

E-textiles describe a textile where electronics have been added to incorporate additional functionality. This can be achieved using a number of methods including the attachment of pre-made electronics to an already completed textile, or the knitting or weaving of conductive fibers and yarns [1]. Not all of these integration methods are ideal when considering the comfort of the end user. For example, many electronic textiles on the market will bond a flexible electronic to the surface of a pre-made textile. This removes the porosity of the textile (hindering the breathability and moisture transfer), and while the textile can still bend, it will no longer have shear characteristics and therefore will not drape. These characteristics might be appropriate for outwear or a technical textile, but would be undesirable for a textile worn close to the skin. The weaving or knitting of conductive elements normally results in textiles with relatively normal properties, but this technology is limited to creating electrode-based devices. This technology is therefore incapable of being used to create more complex devices (i.e. garments that light up). Sensors created using this type of technology are also know to suffer from hysteresis if deformed [2].

The ATRG use *electronic yarn* (or E-yarn technology) to create these textiles. First, a small-scale commercial component, normally a surface mount device or micro-electromechanical systems, is soldered onto fine, flexible, multistrand Litz wires (a multi-strand enameled copper wire, wrapped around a central fiber core, and covered in an outer fiber, o.d. $\sim 250\ \mu$m). This creates a robust electrical and mechanical connection with the device. The device, along with the solder joints, is then encapsulated within a rigid resin micro-pod that is only slightly longer than the component. Supporting yarns that run parallel to the Litz wires are also incorporated at this stage to give the final yarn a more uniform cross-section and improve the mechanical strength of the yarn. Finally, the wires and encapsulated device are consolidated within a cylindrical textile structure, normally a braid. A schematic of the interior of a conventional E-yarn with an embedded thermistor is shown in Figure 1. The final E-yarns can then be incorporated into a textile structure.

The ATRG has developed several sensing E-textiles including temperature sensing for skin temperature measurements (applicable to health, wellbeing, and personal protective clothing) [3] [4] [5] [6], acoustic sensing [7] and vibration sensing [8], gait monitoring [9], fall and near-fall detection [10], and for monitoring pulse rate [11].

A complete sensing system also requires a method of communicating data back to the user: to facilitate this, E-yarns have been developed with both embedded LEDs [12] and embedded haptic actuators [13]. Further, wearables and E-textile devices require a power supply. To reduce the reliance on large and bulky lithium polymer batteries many have explored energy harvesting to provide some, or all, of the power required by a device [14] [15]. The ATRG have focused on solar energy harvesting to provide a supplementary power supply, and has successfully engineered relatively large textile solar panels embedded with miniature solar cells [16] [17].

3 ELECTRONIC TEXTILE DEMONSTRATORS

3.1 Fall and near-fall detecting over-sock

Falling is a major risk to older adults and can significantly hinder their ability to live independently [18]. Near-falls, representing trips, slips, and stumbles can be an indication that someone is at a greater risk of falling [19]. Many devices have been engineered to detect falls, including pendants, and this feature has been included in mobile devices such as smart watches or smart phones. However, a near-fall is much more difficult to accurately detect as the changes

Figure 2: A fall and near-fall detecting over-sock.

in movement can often be quite small when compared to other everyday activities, such as walking.

The fall and near-fall detecting over-sock was created following an extensive study into where it was best to position sensors on the body to allow for falls to be detected [20] and a human centered design study with older women in order to create a garment that they would find acceptable to wear [21]: inevitably more women have non-fatal falls than men which is why this group was targeted [22].

The over-sock was created by first embedding a small inertial motion unit, which could monitor acceleration and angular velocity in three dimensions, into the core of a yarn and subsequently a textile. This was connected to a small supporting hardware module that would control the integrated chip, and the data was sent back to a computer. A study was conducted using healthy volunteers carrying out activities of daily living (ADLs), falls, and near falls, and data from this was able to train and test a bi-directional long-term short-term memory (BiLSTM) network. This was able to identify between ADLs, falls, and near-falls with an accuracy of 94.2 % [10].

The over-sock being demonstrated (Figure 2) communicates data back to a base unit via Bluetooth to visually display the over-sock's ability and sensitivity to changes in acceleration and angular velocity.

3.2 Temperature sensing sock

Skin temperature is a critical physiological parameter and can be important for understanding both pathology and thermoregulation. Temperature sensing E-yarns have therefore been created by incorporating thermistors into yarns. Various garments and textiles incorporating temperature sensing E-yarns have been created over the years including gloves and armbands [5], thermographs [4], and cycling suits [6].

One of the earliest temperature sensing garments created by the group was a temperature sensing sock [3] for the military to monitor foot temperature and prevent against non-freezing cold injury. This is the necrosis of skin and tissue when exposed to cold and damp conditions for an extended period. A similar temperature sensing sock can be seen in Figure 3. The sock includes six temperature sensors; three across the metatarsial head, one on the big toe, one on the cuboid, and one on the heel. The demonstrator transmits data via Bluetooth to a screen which will allow users to watch temperature changes in real-time by touching the sock.

Figure 3: A temperature sensing sock with six embedded temperature sensors.

3.3 Acoustic sensing textile

Over-exposure to sound can lead to injuries such as tinnitus and noise induced hearing loss [23]. As a result, workers who are in persistently loud environments, or where sudden loud noises are expected, are required to follow occupational noise exposure legislation and potentially use protective devices [24]. Despite this, new cases of NIHR and tinnitus persist. By monitoring the exact level of sound that a worker is exposed to, injury might be avoided.

An acoustic sensing E-yarn was first developed by the ATRG for the military to monitor noise exposure. The E-yarn was created by incorporating a small MEMS microphone into yarns. Due to the need for sound to reach the device the protective micro-pod differed slightly for this device, with a small cavity being left in the pod to facilitate the transit of sound. These E-yarns were then used to create an acoustic sensing helmet cover [7]. The acoustic sensing E-yarn was quite large (o.d. ∼7 mm). However, since then the availability of new commercial microphones and enhancements in the E-yarn manufacturing process have led to the creation of a smaller device (o.d. < 3 mm).

While designed to monitor against noise exposure, the acoustic sensing textile is accurate enough to record a human voice. For the demonstration, an acoustic sensing textile (Figure 4) will be connected to a screen showing the sound level. The users will be able to clap, shout, or make a noise and watch the change in the sound level on the screen.

3.4 Glove capable of giving haptic feedback

Textile sensing systems will often need a means of communicating information back to the user; one way of achieving this is through haptic feedback. Haptic E-yarns are realized by embedding small oscillatory vibration motors into yarns and these can provide an excellent way of communicating complex information to the user [13].

The glove that is capable of providing haptic feedback (Figure 5) contains four haptic E-yarns, one on each finger. This glove was developed as part of a project to provide an easy-to-use device to communicate with deafblind people who can often find communicating with the world and accessing information difficult. By stimulating different actuators within the glove, or using different vibrating patterns (amplitude, frequency, duration), the glove can be used to communicate different information.

3.5 Textile solar panel

Finally, to provide a power supply to the wearable E-textiles, we are producing textile solar panels. The panel in Figure 6 contains

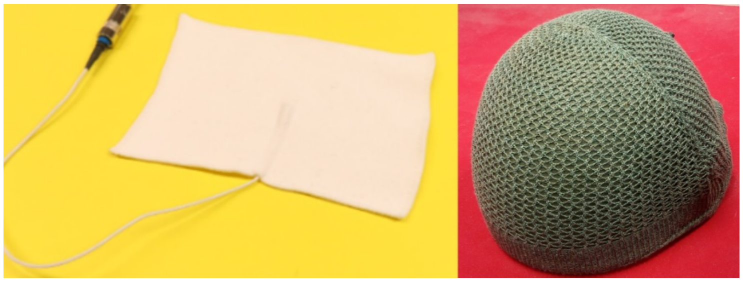

Figure 4: (Left) An acoustic sensing textile. (Right) An acoustic sensing helmet cover is an example of an innovation that could make use of this technology [7].

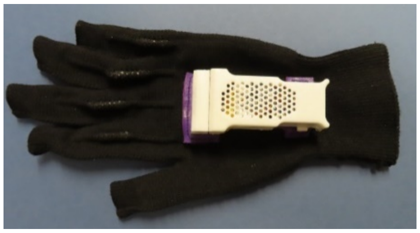

Figure 5: Photograph of the haptic feedback glove.

Figure 6: Photograph of a textile solar panel incorporating 300 miniature solar cells. This panel is of a similar design to a panel previously presented [17].

300 miniature solar cells (~4.5 mm2 active area). The panel was created using a computerized loom (Thread Controller 2, Digital Weaving Norway, Moss, Norway), highlighting the compatibility of the E-yarns with textile construction processes. Larger textile solar panels have been produced by the group, showing the scalability of this energy harvesting method, with a panel incorporating 1,200 solar cells having been created. This panel could generate 335.3 ± 22.4 mW under 99,000 Lux conditions (~0.83 Sun) [17]. At CHI, a textile solar panel will be connected to an ammeter to demonstrate its energy harvesting capability.

4 FUTURE WORK AND OPPORTUNITIES

This article has presented a handful of E-textile devices created using E-yarns covering sensing, user feedback, and power supply. This only represents a fraction of the full potential of the technology, as ultimately any small-scale device can be embedded within a yarn. This opens a clear pathway towards future research activity in this area.

While the potential of the technology is clear, a current bottleneck is the ability to scale-up production. The E-yarns used to create these prototypes were produced by hand, which is a time-consuming process requiring highly-skilled personnel. The research group have developed some automated and semi-automated manufacturing capabilities [25] [26], and the production of E-yarns made using simple two-terminal devices is possible with minimal human intervention. The creation of more complex E-yarns, such as those that incorporate IMUs, require a new production system and work on this manufacturing line is part of our on-going research activity.

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