Body Covers as Digital Display: A New Material for Expressions of Body & Self

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Abstract
Within the domain of wearables, our paper explores opportunities for self-expression, learning about the body, and interactions with others that are enabled through the physical and interactive properties of a new kind of digital display. Recent advances in the manufacturing of thin, bendable electronics and a novel architecture for arranging pixels permit the fabrication of a 'display material' that challenges conventional perceptions of this medium. Envisioning digital displays as a material means that their design is no longer limited to rectangular screens, but can be scaled in size; cut, folded or molded; or combined with other materials and devices to create compelling interactions. In this paper, we explore some of this potential in the context of configuring body-worn items such as clothing. As a more concrete use example, we further present and discuss some initial ideas for aesthetic, expressive and functional configurations of body casts as a specific kind of body cover.

Author Keywords
Display material; flexible display; smart material; wearables; body interface; autonomous pixel.

Introduction
In the era of pervasive and ubiquitous computing, as technology gets embedded into existing objects and our

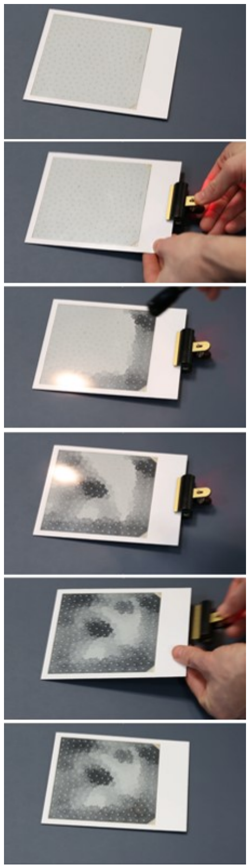

Figure 1. A thin, e-ink display prototype that, when activated with a battery-clip, responds to light (here: applied with a torch). Once the battery is removed, the painted on image remains visible until reconfigured.

environment, the boundaries between our physical and digital worlds become increasingly blurred [4, 11]. Decreases in size and weight of new sensors; the manufacturing of thinner, more flexible materials for electronics [8, 16]; and alternative methods for increasing the longevity of batteries or harvesting energy [3, 14] expand the design space for wearables.

Recently, this started to include the human body, or parts thereof, as an interface. Early designs propose the addition of often bulky hardware components to allow for projections to the skin for input [5], or assessing changes in the position of a device on the body [2]. Other emerging designs explore the incorporation of technology as decorations that are added to the skin; and intended to blend with the body. Often inspired by beauty products [19], these aim to achieve fashionable and socially acceptable forms of wearable computing. Examples include false nails with embedded tags or electrodes [11, 19]; conductive eye-lashes and make-up [13, 19]; temporary skin tattoos with functional components [12, 22]; and hair extensions [20] or wigs [18] as input devices. In moving closer to the body and utilizing the *"skin as a canvas for applying sensors and attaching other computing devices in ways that enhance the human experience"* [19, p.71], the body can be transformed into an expressive user interface [15], whilst also offering scope for more discrete technology interactions by disguising them for instance as cosmetics.

Within the domain of wearables also are prosthetics, which have the added advantage of easily hiding computational elements. Electronics can be more easily embedded within them, and in less invasive ways than chip implants into the body [9], or other insertables placed under the skin [6, 7]; allowing for semi-permanent augmentations to the body for affording truly ubiquitous interactions.

Our research explores the design space for novel digital displays and to this end, we next introduce a new form of interactive display material, called Autonomous Pixel. The lightweight, dynamic nature of this material makes it a natural fit within the context of technology worn on the body. Here, we illustrate its potential for clothing, and for enhancing orthopedic casts more specifically. The applications proposed emphasize challenges in the design of a display surface for it to be aesthetic and ergonomic; usefully integrated with other materials or devices; and to offer compelling interactions. We seek to explore these challenges in more depth through discussions and prototyping activities with other attendees at the workshop.

Autonmous Pixels: A Display as Material

Contrary to conventional displays, the Autonomous Pixel technology [17] breaks out of a row/column grid for distributing pixels. Instead, each pixel has its own embedded electronic components for input and output, making it independent from other pixels. Each pixel accesses power through a thin layer of substrate that it sits on. This eliminates the need for any wiring for each element, and gives the display large flexibility of use. Furthermore, the shape and resolution of each pixel can be defined, as can their input (i.e. light, touch, heat, pressure) or output modalities (i.e. e-ink, OLED, LCD).

The new architecture further allows for the manufacturing of pixels on substrates such as thin, bendable plastic that can be fabricated as roll-to-roll sheet material, potentially at very low cost. As such,

Figure 2. Adaptability of the display material to the individual style of the person.

the display material can be more easily produced at scale, applied to complex surfaces, and deformed across multiple aces. In addition, since the pixels are self-contained, the material can also be cut and folded into freeform shapes. As a *transmaterial* [4], whose physical properties such as light transmission, flexibility or color could be configured in novel and exiting ways, it provides a new class of responsive surfaces.

Our research investigates the kinds of configurations and new interaction opportunities that could be enabled through a material such as this. Figure 1 shows an initial display prototype that exploits e-ink technology as the output element. When powered via a battery, the pixels become responsive to light and turn darker with exposure. In our example, light is drawn onto the material with a torch. Once the battery-clip is removed, the image remains until it is reconfigured. Using a removable battery and configuring the material through light – rather than digital data transfer – has the added advantage that, once configured, the design does not require any additional hardware or power-supply. This makes it particularly suitable for wearable applications. We further explore other physical properties such as transformability, texture, unique pixel shapes, and multi-sensory/ data input and output modalities to identify more and diverse ways to interact. For more technical details on how the display operates, see [17].

Configurable Body Covers

As a flexible material that can be cut and folded as well as combined with other materials such as textiles, it lends itself to the creation of configurable clothing – the body 'skins' that we wear every day. With its potential to transform items of clothing, the material may offer rich opportunities for creativity, expression and performativity, especially for industries such as fashion. For example, Verhoeven [21] designed a beautiful collection of gloves that translated the anatomy of the hand into material; experimenting with the relationship between function and materialization in the design of these wearable skins. Such like examples invite curiosity as to how designers of clothing and fashion may adopt a configurable 'display material' as described in our paper, in their future work.

However, there might also be many interesting applications outside of fashion. In the following, we describe body casts or medical bandages as one very concrete example of a configurable body cover within healthcare. The applications proposed are intended to achieve a personalized design that allows for self-expression, communication and learning. As such, the focus is less on data capture or real-time measures and monitoring of physical properties of the body for delivering effective health interventions. Our ideas are intended to stimulate debate on what constitute socially acceptable, aesthetic, expressive and functional interactions with this configurable material on body covers such as body cast; and how to address common design challenges such as issues of user control, or the visibility of displayed contents in different use contexts.

Cast Expressions: Aesthetic, Communication & Learning
As a bendable material that can be molded around any three-dimensional shape, displays could be applied to, or worn over, wearable medical aids such as body casts and bandages. Exploring this scenario in more depth, we envision for the material to work in conjunction with a mobile app that allows the user to switch between different display modes and functionalities, to stay in control of the content shared.

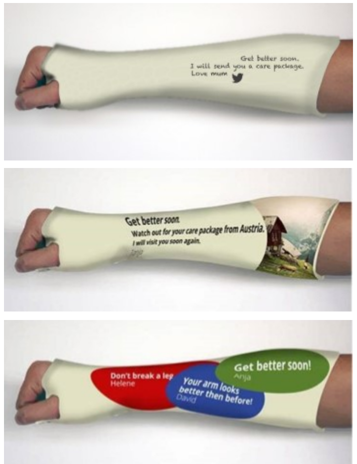

Figure 3. Social messages (i.e. personalized tweets) visualized on the cast.

Figure 4. Interactions with the cast to visualize inner parts and the workings of the body to aid understanding.

As a display for any kind of content, opportunities for visual customization are endless, offering rich scope for *self-expression*. This may involve the selection of specific imagery that the person likes, or specific patterns to express a certain style or adapt the cast to the person's clothing (Figure 2); facilitating its blending with, or becoming of a decoration of, the body. As a configurable material, the person may choose to display a certain self-image, or support of a political movement, charity or country. These currently take many shapes such as fan clothing, the British poppy pin, or image overlays in support of a particular ideology on Facebook profile pictures. As described with our prototype, the cast may also be configured to allow the person, or others, to draw on it through a (digital) device. Other playful configurations could entail feature visualizations such as a cyborg arm, or a countdown showing the time left unit the cast is getting removed.

We can further imagine uses whereby a remote relative or friend may send get-well messages that the cast wearer can choose to display, privately or publicly. It could be configured to retrieve and show the latest news-feed of a person's social networks (Figure 3) to see what their friends are up to, whilst one might be home or hospital bound. Other *social uses*, may involve the sharing of certain visual features, patterns or functionalities when getting into the proximity of certain others; and configurations of social games or affordances that invite icebreaker activities, as is inspired by Kan et al.'s [10] Social Textiles project.

We can further envision potentially uses for *learning* or *communicating* about injuries underneath the cast. For example, in visualizing the insides of the body, the cast could facilitate explanations of medical procedures and the healing process by a clinician (Figure 4). This resonates with a design by Almeida et al. [1], who invited self-examinations by augmenting the body with visual markers that linked to displays of pelvic muscle structures on a mobile phone. This was sought to aid understanding of the basic anatomy and hidden body parts. Another compelling example is Young's [23] design Bruise. Young used a textile with a pressure-sensitive film in sports clothing that changes its color (via a chemical reaction) at the location where an impact occurred. Our body cast could i.e. visualize the intensity of scratching to communicate discomfort.

Conclusion

We have introduced the design potential offered through a thin, bendable display material that is easily customizable in form and shape; thereby offering a new surface material in the wearable technology space. Exploring initial ideas as to how configurations of this material could come to matter in the design of clothing generally, and orthopedic casts more specifically, we described a range of applications to invite discussions at the workshop. While digital configurability may enable a multitude of uses, there are many open design challenges, such as: how to best incorporate the display element with other materials; how to identify trade-offs between computational power and associated battery requirements for the wearable; how to potentially attach external power supplies either temporarily or permanently to configurable body covers (i.e. a decorative brooch, or something that is hidden or integrated within the cover)? What display properties, contents and interactions may be more or less appropriate for different kinds of body covers and body parts? In the context of wearables, it will further be worth exploring lower-tech instantiations of this material that exploit benefits of not requiring battery power unless (re)configured; or offering new forms of interactions through the way in which the material gets transformed (cf. example of 'painting with light').

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