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Reactive-Wear: Incorporating Autonomous Sensing and Display into Wearables

Abstract

"Reactive-wear" is a term I use to describe clothing and accessories that autonomously respond to stimuli and information. Such garments and devices exist in a realm where the fields of wearable technology, ubiquitous computing, and human-computer interaction overlap. By processing input from body-based or environmental sensors, or aggregate information from networked devices, these wearable systems can drive diverse types of output -- light, sound, tactile, kinetic -- translating data into evocative and/or functional displays, and thus make manifest a user's emotions, physiology, ambient conditions, or any information that the wearer or their environment might express. These functional fashions might amplify body and mind, provide the user with augmented senses, simplify the relationship between data and bodies, and affect interpersonal interactions. Reactive-wear could engender profound re-negotiations of the human-technology interface, enabling novel connections between people, information, awareness and expression.

1. Introduction

The field of ubiquitous computing imagines a future of transparent, always-on technologies that are seamlessly integrated into our lives. Sometimes called pervasive or calm computing, this paradigm mates sensors, displays, networked capabilities and microprocessors to provide automatic and invisible computing, triggered without direct user engagement [1]. While much of the research in this specialized field focuses on the user's environment, it is also possible to embed ubiquitous computing in wearables.

Incorporating electronics into clothing, accessories and adornments opens a hybrid field where body meets technology, form meets function, and fashion meets engineering. Such activated bodywear could enable new modes of communication and expression. Research in this discipline has potential to impact everyday lives. The degree to which such devices might enhance our live remains in the hands of the creators: poorly designed devices have the potential to hinder as well as to augment. As Chris Hables Grey notes in *The Cyborg Handbook*, "the technologies themselves are ambivalent and capable of many contradictory uses." [2]. Yet there are a number of projects in this growing field, discussed in this paper, that suggest that technology, thoughtfully applied to fashion, might actually allow us to deepen our understanding of what it means to be human and to enrich our relationships with one another.

The field of inconspicuous computing embedded into garments and body-worn devices is part of the broader field known as HCI or human-computer interaction. Wearable-computing pioneer Steve Mann has suggested an alternate term -- humanistic intelligence, or HI -- in order to de-emphasize the separation between ourselves and our apparatus, envisioning instead these devices as natural extensions of our minds [3]. The conscious mind is often oblivious to environmental fluctuations and even to the physiological processes governed by the synaptic circuitry of our own brains. Automatically amplifying these otherwise invisible signals via incorporating technology into things we wear may expand the potential of our minds or even increase our human connection.

Bodywear that integrates technology has been variously labeled as “smart clothing”, “smart wear”, “e-textiles”, or “fashion-tech”, with “wearable technology” or "wearables" being currently the most popular terms. The focus of this paper will be the intersection of this nascent field of innovation with ubiquitous computing and HCI/HI, that is to say: wearables with a level of awareness that automatically responds to stimuli and information without manual user input. Captured data and/or passive sensing can actuate custom body-worn displays and other devices. To use a succinct and memorable designation, distinct from the larger fields of smart clothing and wearable computing, I will refer to projects in this emerging field as “reactive fashion” [4][5] or simply “reactive-wear”.

2. Hardware Components

Two key elements required for reactive-wear are input and output, or I/O. With input from body-based or environmental sensors, or aggregate information from networked databases or local devices, one can drive diverse types of output: light, sound or tactile displays; remote actuation of simple devices (motors, pumps); or remote control of more complex devices (cameras, mobile phones). With the appropriate linking and programming of these interfaces, data can be translated into evocative and/or functional displays that manifest emotions, physiology, affiliations, ambient conditions, or any other information that the wearer or their environment might express.

The majority of this section covers means of acquiring data (input) and means of expressing data (output), the fundamental relationship that allows for the processing of automatic responsive behavior. Other necessary components for fully functional reactive-wear are also summarized, including data processing, connectivity and power source. Current research regarding interface and computing elements applied to textiles and wearables demonstrates many innovative and robust components. I will provide an overview of individual modules and integrated combinations available for the production of reactive-wear, referencing both off-the-shelf products and original research. Convergent reactive-wear projects will be covered in Section 3.

A number of reviews exist as excellent primers for artists, designers or engineers embarking on explorations in wearable technology: from Cho, Lee and Cho of Yonsei University's Smart Wear Research Lab [6]; Lam Po Tang and Stylios of Heriot-Watt University [7]; Berzowska of XS Labs and Concordia University [4]; and Van Langenhove and Hertleer of Ghent University[8]. Further examples and technical details of many components discussed in this section can be found within these works.

2.1. Input Options

Keyboards, buttons and similar manually activated switches are common methods of data input. While there have been many recent advances in textile-based switches [6][8], their direct user engagement places them outside the scope of this paper.

Sensing physiological processes. Heart-rate monitors are available at any sporting goods retailer. Other easy-to-acquire devices detect multiple health-related metrics, such as Body Media's "Sensewear" and "FIT" armbands [9] and various systems from FitLinxx [10]. Such commercial products for health monitoring generally include built-in numeric displays or the ability to download collected data to an off-board computer.

Most standard body-sensing systems are rigid and thus uncomfortable for extended use. One alternative is "textrodes": fabric-based ECG (electrocardiograph) electrodes like those developed by Van Langenhove and Hertleer [8]. Two different types of flexible textile-based electrodes have been developed and extensively tested at Yonsei's Smart Wear Research Lab [6]. At MIT Media Laboratory's Affective Computing (MIT-AC), Rosalind Picard leads a team of researchers developing cutting-edge smart-wear components. Their "Passive Wireless Heart-Rate Sensor" detects a beating heart from up to 1 meter, obviating skin-worn sensors entirely [11].

Motion and movement sensing. Body position can be sensed by measuring varying amounts of light transmitted by plastic optical fiber (POF) as it flexes. Dunne, Walsh, Smyth and Caulfield of University College Dublin tested POF to monitor seated posture [12]. Conductive polymers and knits also produce electrical signals from changes in stretch or flexion [6]: Dunne, Brady, Smyth and Diamond, working with the Adaptive Information Cluster, a joint university centre in Dublin, developed comfortable foam pressure sensors coated in piezo-resistive polymer to measure respiration rate or sense gestures [13].

Retail options for body-worn movement sensing are generally related to the animation and film industry, where various types of motion capture systems translate human actions to digital characters. Most of these systems are cumbersome, although some have potential wearable applications: the 5DT Data Glove is fairly comfortable, and their newest model has an optional wireless package that mounts to a belt allowing for more mobility and less on-body wiring [14].

"Smart Shirts" and harnesses. Several companies have incorporated a range of physiological and body-movement sensors directly into garments and fabric-based harnesses. These systems are designed to reduce discomfort; often include multiple sensors as well as other components; and generally collect and/or transmit data for off-body display only. Though they may not be intended for on-board processing or direct display, such systems could certainly be adapted for reactive-wear. The extensive research and development required to manufacture these robust products is viable due to relevant applications in personal health care, athletics, and remote monitoring of emergency personnel, soldiers or hazardous waste workers.

The Georgia Tech "Wearable Motherboard" was originally funded by the US military for monitoring combat soldiers and is now available as the Sensatex SmartShirt. Using textile sensors and connectors to pass signals through a knitted conductive grid to a pocket controller, the shirt transmits heart rate, respiration and body temperature to a nearby PDA or computer [15].

Other commercially available options include solutions from two small start-ups: Zephyr and Textronics. The Zephyr BioHarness measures heart rate, respiration rate, temperature, activity and posture. The Zephyr HXM measures heart rate, speed and distance for athletic training [16]. Textro-Sensors® and the Textro-monitoring™ system from Textronics are fabric-based systems for monitoring heart rate and respiration that do not require electrodes on the skin [17].

Ambient Sensing. Microsensors that translate external environmental signals-- temperature, solar radiation, air quality, sound, movement or proximity-- into digital data are widely available on the commercial market. Small rigid sensors specifically designed for inclusion in fashion projects, for measuring light, temperature, etc., are available from a small company called Aniomagic [18].

Network Data. Utilizing appropriate connectivity, on-board processing and software development, it is possible to incorporate data from local servers or the internet as system input. Political, cultural, personal or social events aggregated from servers or mobile devices can be downloaded into embedded wearable systems. See section 2.5 for wearable networking systems and components, and section 3.5 for projects which incorporate network data to drive reactive output.

2.2. Output: Visual Display

Data gathered via input may be expressed as functional and/or aesthetic visual displays. Changes in illumination or color can be accomplished with several technologies and various methods of application.

Illuminating Acronyms: EL, LED and POF. Electroluminescence (EL) produces a neon-like glow. Light emitting diodes (LED) create points of light. The same POF used to sense motion can also transmits light from an external source, usually LED, to illuminate either just the tips of the fiber or along its length anywhere the sheath has been abraded [6]. EL modules are made from phosphorescent powders or thin film (TFEL) and can be purchased as wire or panel. LEDs are becoming ever smaller and brighter. EL is manufactured in more individual colors, while LEDs are available in color changing modules that shift from one to another via electrical actuation as power is varied to red, green and blue elements. Both technologies are readily available for incorporating into products or prototypes. Both have low energy consumption compared to other light sources [19][20]. Unfortunately, EL is not ideal for wearable applications: fragile connectivity and high voltage can make it problematic, especially in moisture-rich environments. POF-based fabric, which distributes light from LEDs into hundreds of glittering points, is manufactured by Luminex [21].

Illuminated garments. Janet Hansen of Enlighted Designs was the first to bring LEDs and EL to a retail line of elegant garments, using custom programmed controllers to add flash or sparkle to gowns, corsets, suits, ties and light-up bras [22]. A number of designers are currently doing similar one-of-a-kind fashion works [23][24].

Text and imagery. Miniature LEDs or woven POF can display complex and programmable moving images on a garment.

“Galaxy Dress” by Francesca Rosella and Ryan Genz of CuteCircuit is an elegant gown covered with more than twenty-four thousand paper-thin, multi-color LEDs programmed to slowly shift through color spectra to produce a shimmering radiance [25].

Engineer Moritz Waldemeyer collaborated with designer Hussein Chalayan on the “Airborne Video Dress”, utilizing fifteen thousand LEDs to create diffuse video, such as blooming flowers or swimming sharks, on the garment [26][27].

The Nyx Jacket incorporates a flexible, washable LED matrix on its back that displays user-programmable content such as scrolling text [28]. The technology is robust and the jacket is now available for retail purchase [29].

Koncar, Deflin and Weill experimented with POF woven with textile yarns to create thin, flexible, ultra-lightweight screens. Etched optical fibers, illuminated with LEDs, mix colored light to form each pixel. A custom controller directs pixels in the matrix to convey patterns, while wireless networking allows imagery to be downloaded [30].

Non-emissive color-changing textiles. These create visual changes without the use of light. Fabrics treated with chromatic materials can change color in response to changes in stimuli such as temperature, light, pressure, pH, moisture or electrical current [7]. Berzowska used a leuco dye, a type of thermochromic pigment, for “Shimmering Flower”, although due to power requirements the textile was displayed on a wall instead of a body [4]. At Keio University’s Information Design Laboratory (IDL), Wakita and Shibutani developed FabCel using fibers drenched in thermochromic liquid crystal ink. The modular designs can be linked together with other components to create fashion accents [31].

2.2. Output: Tactile, Aural and Kinetic Display

Tactile displays. These devices translate information into a physical sensory experience, usually by means of vibration.

Gemperle, Ota and Siewiorek of the Wearable Computer Group at Carnegie-Mellon developed a tactile display utilizing strategically-positioned miniature motors similar to those that vibrate cell phones. The authors describe ways tactile display “can solve issues of intrusive computers and multiple demands on user visual and audio attention” and emphasize that they “will neither conflict with nor replace audio and visual display but rather support information on these other displays” [32]. Gemperle instigated a series of undergraduate projects to produce non-functional prototypes of tactile devices. Her students imagined such practical applications as a GPS navigation vest for motorcyclists and a sound-driven vest to amplify musical experience for the deaf [33].

Dunne developed and tested various techniques for manufacturing and utilizing vibrating shoulder pads for insertion into almost any garment [34]. She used the same technology to create “Massage Shirt”, which adds relaxation and sensation to the more data-oriented functions of tactile display [35].

Audio output. Miniature speakers and headphones are widely available to express information as sound. Wireless models tend to be bulkier, whereas wired models are more restrictive.

Kinetic output. A variety of components can be used to activate motion-based change: micro motors, linear actuators and solenoids are all readily available. Actuated garments were created by Chalayan and Waldemeyer for the 2007 *One Hundred and One* collection using servo-driven motors, pulleys and wires: one flowing gown wound itself up and disappeared entirely into its own hat, rendering the model naked [26][36]. Perhaps more ideal for clothing application are shape memory alloys (SMA) and shape memory polymers (SMP), which change shape when heat is applied [6][8]. Berzowska and Coelho created “Vilkas”, an animated dress with an SMA called Nitinol woven through the hem. This “muscle wire” autonomously lifts the hemline of the dress via programmed control [37].

2.4. Data Processing

Common microcontrollers such as the Parallax Basic Stamp or Atmel 8051 series chips are often used in clothing applications. So far no one has developed a completely textile- or fiber-based microprocessor [6]. However the LilyPad Arduino, developed by Leah Buechley and SparkFun Electronics, is designed specifically to be sewn into wearable applications [38]. Aniomagic also produces a compact, rigid garment-based controller called “schemer”, intended to work in conjunction with their sensors [18].

2.5. Connectivity

Soft-wired circuits. On-body components can be connected together using conductive threads and yarns [4][6]. Post and Orth coined the term “e-broidery” to describe the use of these materials with traditional hand-sewing techniques to create circuits, and proposed the use of common snaps as connectors between circuits and components [39]. A fabric matrix of connections can be constructed by weaving together conductive and non-conductive threads [6][40]. Soft circuits can also be screen printed onto textiles using conductive inks [7][41]. Park and Jayaraman utilized the light transmission properties of POF to transmit data across the body [42], although Post and Orth note drawbacks when interfacing POF to other components [39].

Wireless PANs and FANs. Untethered and unencumbered networking is possible with wireless personal area networks (WPAN). WPANs are small devices for short-range communication.

Commonly used specifications include Infrared Data Association (IrDA) and Bluetooth, both used widely in mobile phones and laptops [43]. ZigBee is specialized for low data rate, long battery life and security, and is generally inexpensive and less complicated . Other WPANs with potential in wearable applications are Z-Wave and ultra-wide band (UWB) [44]. Alex Hum coined the term Fabric Area Network (FAN) to describe his investigation of radio frequency (RF) signals restricted to the surface of fabric [45].

2.6. Power Source

Readily-available solutions are not ideal: standard batteries are heavy; button cells are underpowered and short-lived; rechargeable lithium-ion batteries have better energy-to-weight ratios [46] but are still bulky and inconvenient for garments. A promising alternative is “energy harvesting” or scavenging power from ambient sources such as photovoltaic (light or sun), thermoelectric (temperature change), or mechanical vibration (kinetic motion). The latter converts body movement to power using various methods [47], the most promising of which are the use of piezoelectric and rotary generators to harness power from walking [48]. Hybrid solutions combining scavenged power with rechargeable batteries have great potential [6][49].

3. Reactive-wear Projects

Smart wear evolves into reactive-wear by automatically collecting data and converting it into meaningful expression. Most of the following projects were created by independent designers and institutional researchers. Many have only been seen in museums, galleries, private collections or on the runway; several were exhibited at the SIGGRAPH fashion show I curated from 2002 through 2005. Most are not robust enough for the commercial marketplace and some utilize only limited working components to create a convincing mock-up of intended functionality. Regardless, all are evocative and suggest a future of functional reactive fashion.

3.1. Projecting Heart-Rate Data

The following three projects were developed simultaneously; such parallel evolution suggests a ripe idea made obvious by available technologies. Besides playing on the obvious metaphor of wearing one's heart on the outside for all to see, they create an intimate link through technology that may at first seem counter-intuitive, but which suggests the potential for a deeply meaningful embellishment.

Psymbiote Visible HeartBeat. The Psymbiote Research collective -- including me, Jesse Jarrell, and D. Evan Brown -- adapts off-the-shelf sensors to drive responsive elements, amplifying the performer’s body with technology to highlight the shifting junction between human and machine. This decorative adornment channels heart rate to an array of LEDs. The system includes a hacked Polar brand sensor that drives three light-up elements: blue wraps each arm to suggest veins and a red medallion lies across the chest. The two colors flash in alternating rhythm with the heart [50].

Your Heart On My Sleeve. Cliff Randell, working with designer Annie Lovejoy and the since-disbanded Wearable Computing Group at the University of Bristol, developed a woman’s jacket which creates a reciprocal relationship between two people. Also built using a Polar monitor, with a heart-shaped segment of EL wire and a red/blue tangle of EL “veins” under sheer fabric on the sleeve, it flashes according to heart-rate data transmitted from another wearer [51]. By sharing these otherwise invisible signals, it creates a new kind of intimacy in which machine awareness promotes human connection.

Lucy Dunne's *Pulse.* Dunne designed a series of evening gowns to detect physiological signals such as laughter, heartbeat, alertness or startle reflex, and convert them to visual displays. “Wearable technology also introduces new social concerns, as it can mediate the ways in which an individual is perceived by others, interacts with others, and manages his/her own physical space." [34]. *Pulse* is an elegantly tailored gown in cream satin that incorporates a large panel of red EL film to create a subtle glow across the chest, delicately pulsing with the wearer's heartbeat [52].

3.2. Biofeedback-Driven Cameras

This concept was suggested by Mann as an effective embodiment of HI [3]: utilizing physiological sensing to capture images at moments of heightened excitement. The potential utility of such a system is thought-provoking: it would allow the wearer to document significant experiences without being distracted from the immediate moment by the act of trying to record it.

***Startlecam* from MIT Affective Computing.** Rosalind Picard and Jennifer Healy developed this device, which senses the skin's electrical conductance to monitor arousal levels and indicate a "startle response". Sensors which measure galvanic skin response (GSR) -- also known as electrodermal response (EDR) or skin conductance response (SCR) -- are used in lie detectors as they are usually good indicators of stress level. When detected by the *Startlecam*, this response initiates the transfer of recently captured video imagery to either on-body or remote data storage [53].

Diana Eng's *Heartbeat Hoodie*. This casual-wear prototype uses heart-rate sensors to trigger a camera embedded in the peak of the hood, so that when the heart rate rises above a pre-set point, images are captured [54]. Eng's recent DIY manual *Fashion Geek* is an excellent introduction for beginners who want to make their own technology-based fashions [55].

3.3. Other Body-Sensing Reactive-wear

GSR gloves from MIT Affective Computing. The *Galvactivator* is a device, also developed by Picard and colleagues, that senses GSR and maps these values to an on-board LED display to indicate physiological excitement or stress. Possible applications include health monitoring, teaching, non-verbal communication assistance for the differently-abled or as a supplement to ordinary communication. "Because the skin conductivity response is not usually visible to others, it raises many questions regarding the psychology of communicating this signal, and what impact this can have on inter-personal relationships." [56]. Extensive research into both the technical hurdles and also the usability aspects of this glove led to the development of a second, more advanced version known as the *HandWave*, a GSR-sensing device that can communicate wirelessly [57]. Continuing research has resulted in the *iCalm*™ wristband, a small, comfortable wireless sensor for detecting multiple physiological signals [58]. One version incorporates responsive LEDs directly on the wearable while another transmits data to mobile devices [59].

Childrens' wear. Two concurrent but distinct prototypes promote the enhancement of children's communication as a safety device and tool for parents. Jacki and Nancy Morie of Skydeaminds and Kip Haynes of the USC Institute for Creative Technologies collaborated with SMARTlab London to create *Technokids*. Combining BodyMedia's *Sensewear* armband and a purse decorated with LEDs, the system is designed to "help keep kids of the future connected to vital bases of safety in a world fraught with potential dangers" [60]. A similar garment to inform parents of a child's emotional space and physiological stress is *Dog@watch Kids-wear* from the *Aware-wear* collection [61] by the Advanced Institute of Wearable Environmental Information Networks (NPO-WIN), a Japanese organization of over forty institutions [62].

***Company Keeper* from Am-I-Able Designs.** Di Mainstone, Sara Diamond and colleagues at Banff New Media Institute created a whimsical prototype that incorporates unusual sensing. They describe this hooded dress as providing "an antidote for every social inadequacy." Mood is assessed via sound and body language: a microphone measures environmental sound levels while touch sensors and an accelerometer in a hanging tassel measure nervous energy. Soundscapes customized to fit the detected mood are then played through headphones in the hood, talking to the wearer "like a humorous and absurd" companion [63].

3.4. Visualizing Sound

The visual translation of aural data can enhance communication and comprehension of verbal expression, or reveal useful information about environmental sound. Potential applications might help to augment a speaker's effectiveness, or to create devices that automatically protect hearing.

Psymbiote VisualVoice. Another reactive-wear project from Psymbiote Research channels vocal cadence to an array of lights reminiscent of a traditional stereo EQ. *VisualVoice* uses a piezoelectric contact microphone against the larynx to capture the vibration of the vocal chords, and translates that rhythm to an LED display embedded in the collar itself, wrapping the throat with lights that dance in sync with the voice [64]. Such a system could be a useful aid in presentation contexts, creating a secondary sense to augment the performer's vocal expression.

Smart Wear Research: sound-responding photonic jacket. Researchers at Yonsei University developed a method of using etched plastic optical fiber (POF), woven into fabric and combined with LEDs, to create programmable illumination. A microcondensor sensing ambient sound frequencies drives a control module that lights up the surface of this jacket like an elegant EQ display [6].

Flashwear's *T-Qualizer*. One of the first reactive-wear garments to be available on the retail market, this t-shirt has a simple EQ-styled, sound-reactive EL panel mounted to the front, powered by AAA batteries. A similar model detects and displays the strength of nearby WiFi networks [65].

3.5. Engaging Physical Rhythms

This group of projects incorporates on-body motion sensing to display our physical rhythms in a visceral and integrated manner. Like the sound-responsive projects, they augment our awareness by incorporating supplementary visual feedback.

CuteCircuit's *KineticDress*. Francesca Rosella and Ryan Genz designed and engineered this motion-activated Victorian gown. Rings of EL wire lie under layers of sheer black, animated when the wearer walks or interacts with others. The light-up elements signify activity: when the user is still and alone the skirt appears black. As movement increases, so too the number of rings which light and the frequency with which they flash [66]. The behavior of the gown might be seen as a metaphor for the emotional state of the wearer, and the ways we are sometimes invigorated by the energy of those around us.

***Twinkle Toes* by Diana Eng.** These sparkling pumps are reminiscent of Dorothy's ruby slippers in the *Wizard of Oz*. Eng employs an off-the-shelf pedometer, disassembled and hacked to drive LEDs so that they flash in time with her footsteps. Step-by-step instructions to build your own pair are included in *Fashion Geek* [55].

***Lumiloop* from mintymonkey / Ratstar Labs.** Elise Co and Nikita Pashenkov collaborated on *Lumiloop*, a system of program and display modules that can be configured into different reactive bracelets. Each display features an LED matrix, and interchangeable program modules contain sensors to dynamically drive the displays. In one, an accelerometer translates wrist gestures into illuminated patterns [67].

***Wearable Synthesis* from Keio IDL.** Akira Wakita and Midori Shibutani created this collection of responsive and elegant modular garments. In one skirt, lights within the pleats not only pulsate with the wearer's pace, but also change color according to built-in body temperature sensors [68].

3.6. Networked Garments

These garments are distinctive in the way that they incorporate built-in wireless connectivity to enable communication between a wearer and nearby networks. Such linking allows for the display of an unlimited array of data possibilities, harvested from online sources or nearby devices.

Paul Davies' *DHS Safety Vest*. This web-enabled vest incorporates a five-color display that changes with real-time data from the US Department of Homeland Security, obtained by connecting and retrieving the "Threat Advisory Level" from the XML file on the DHS website using WiFi networks [69]. Although the artist may have intended the garment as political commentary rather than practical application, it does suggest a fertile realm for reactive-wear experiments: subtle displays that reveal live-updates of the most pertinent need-to-know data. A more pragmatic example might be an umbrella that updates its color according to the weather forecast.

***Wearable Synthesis* from Keio IDL.** Another garment from the set discussed above, a matching jacket, communicates wirelessly with the skirt to enable on-the-fly color-coordination. *Wearable Synthesis* also enables communication between individuals: one jacket lights up when its sensors detect another garment from the set worn nearby [70]. Such a set might function to effectively keep track of one's companion in crowded public venues.

<*exhale*>: Thecla Schiphorst and whispers[s] research. "Body-area networked garments" developed at Simon Fraser University, <*exhale: breath between bodies*> is a collection of sensuous skirts and sleeves linked to elastic breast-bands that "listen to collective breath". The data collected by these bands is passed across the network of individual garments to actuate small fans, vibrators and pulsating light embedded within the skirts. Thus <*exhale*> "creates a shared public space of breath, revealing sensation, sound and light, exploring the notion of intimacy accessed through physiological data" [71].

***Emotional Ties* from Am-I-Able Designs.** Mainstone, Diamond and their team at Banff created a second set of prototypes that whimsically incorporates unusual sensing. This pair of matching outfits uses strategically placed touch sensors to monitor body language. Preening gestures by one wearer trigger reciprocal audiovisual display on the other outfit, taking "inspiration from the subtleties of the unsaid word." For example, if the male adjusts his tie or the female smoothes her waist, an LED animation and melody play on the other's garment [72].

4. Conclusion

By amplifying the body and mind via augmenting the senses, we may enable ourselves to simplify the complex relationship between our data and our bodies. Everyday use of reactive-wear could affect interpersonal interactions and also promote a deeper understanding of ourselves and the domains we inhabit. As the field of reactive fashion grows, the implications of its potential to enrich our lives with both beauty and utility will become more apparent, hopefully spurring further innovation.

The possibilities of pervasive computing embedded into clothing, jewelry and other wearable devices -- transforming data into aesthetic and meaningful displays -- are limited only by our imagination and willingness to expose ourselves using a new language of subtle signals. Reactive-wear may bring profound re-negotiations at the interface that connects us to our computing, enabling powerful links between people, information, awareness and expression.

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