

# Designing & Evaluating E-Textile Applications

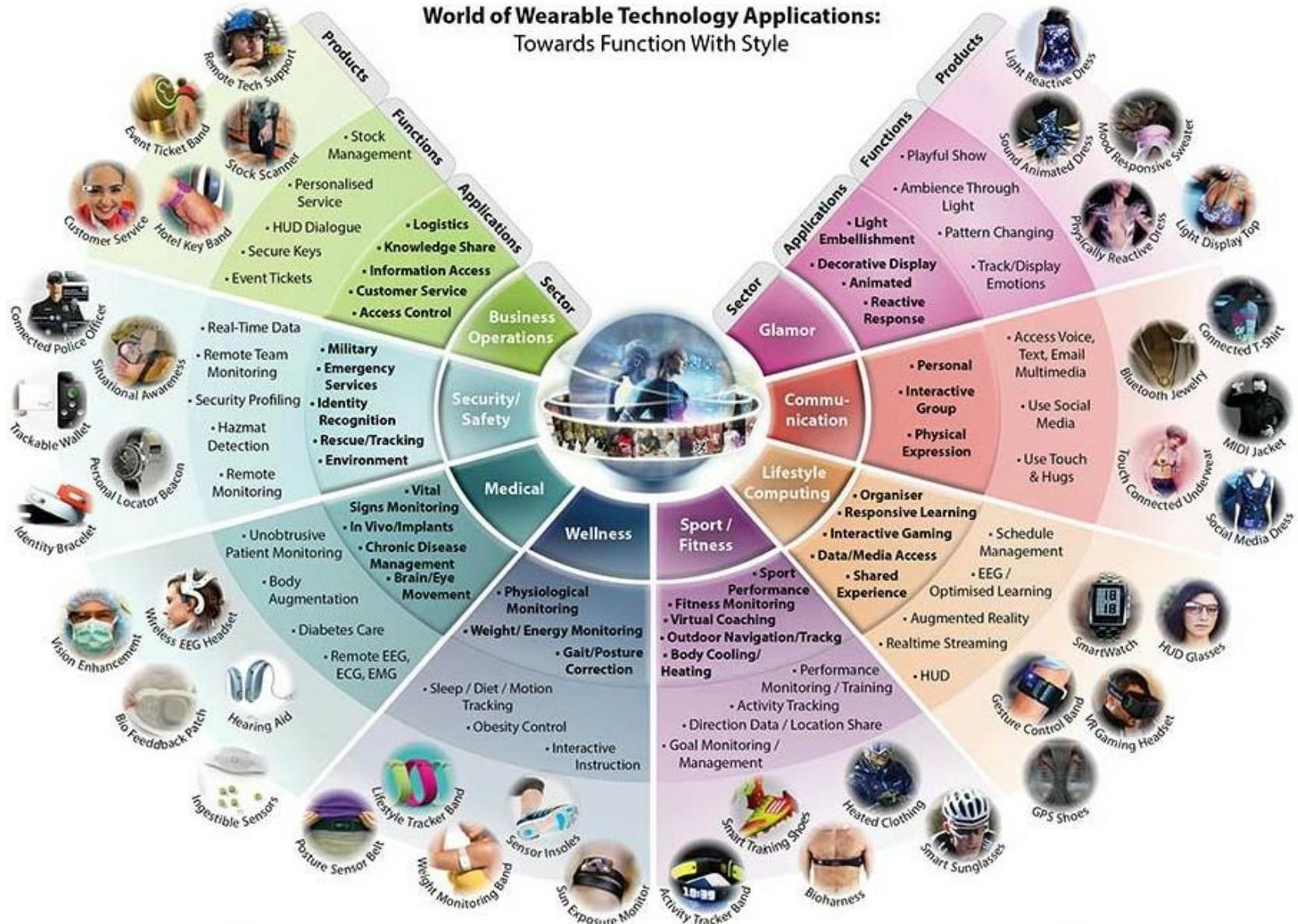
H. Lee Wainwright

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# World of Wearable Technology Applications: Towards Function With Style



# Categorical Evolution

Generally... E-Textiles fall into two categories:

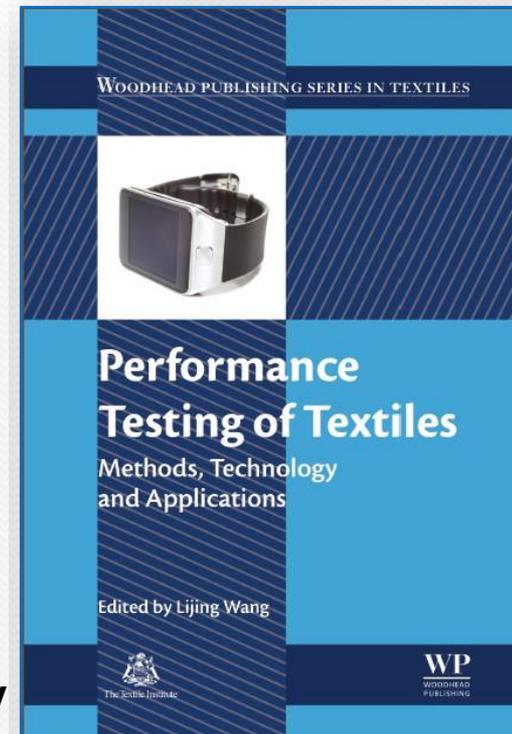
1. Electronic devices embedded into garments
2. Electronics integrated directly into textile substrates

In the textbook, "*Performance Testing of Textiles*", I define two E-Textile categories a little differently...

1. Apparel with "added" electronic components
2. Apparel that employs "smart" technologies using electronics

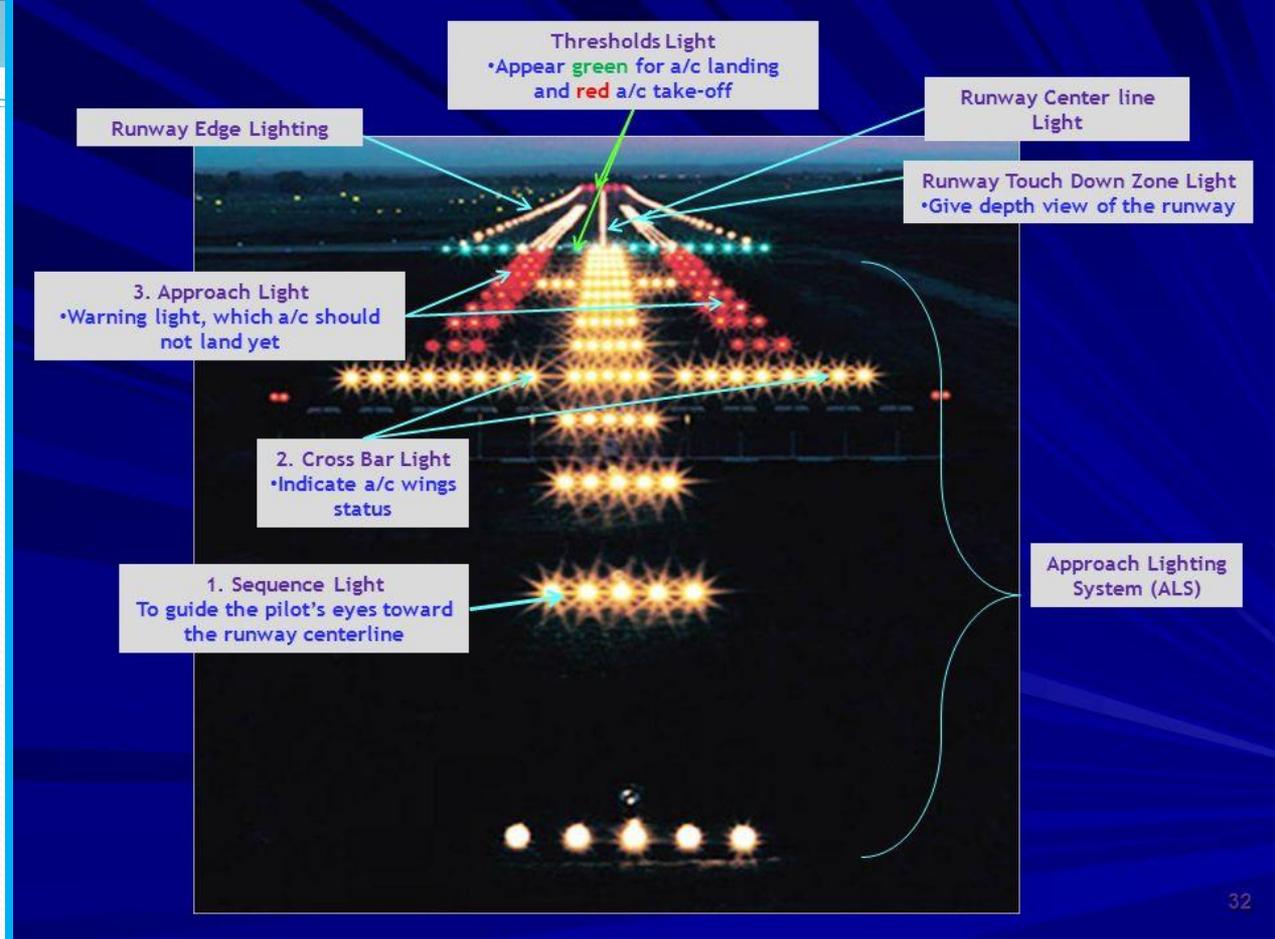
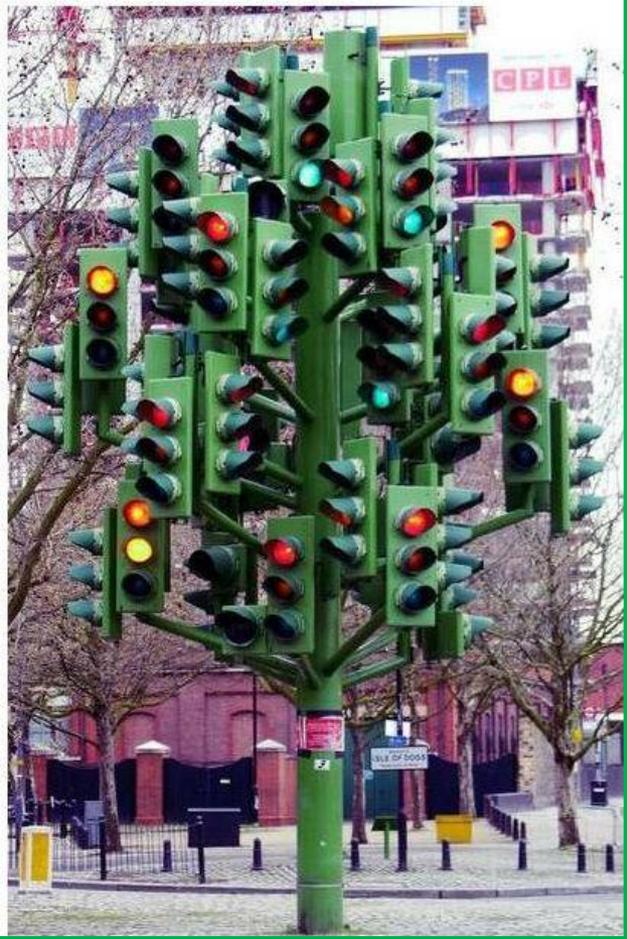
As with any new technologies, additional categories will evolve as creative approaches are invented to address government regulations and issues that new E-Textile products bring to the marketplace. To that point, I've added a third category:

3. Apparel employing electronics that conforms to regulatory issues with regards to safety, disposal, durability, and functionality



# **Evolution of Modern Functional Textiles to Responsive E-Textiles**

- **1972 Antimicrobial fabric (Life Materials, Situ Biosciences, Fab Industries...)**
- **1978 Gore-Tex**
- **1983 Lycra (Spandex)**
- **1985 Programmable E-Textile (HLW)**
- **1986 Coolmax by Dupont Textiles (Invista)**
- **1998 Conductive thread (Amberstrand)**
- **1993 Insect repellent fabric (Insectshield LLC)**
- **1997 Inter-active flexible LED/Optic displays (HLW)**
- **2005 PV energy producing fiber (Konarka Technologies)**
- **2006 Bio-sensor feedback to fabric display (Exmovere/HLW)**  
**Interactive Hugging Shirts (Cutecircuit)**
- **2010 IR energy output fabric (Celliant)**
- **2013 Programmable OLEDs embedded into textiles (Cutecircuit)**
- **2015 WIFI/Bluetooth color-controlled LED/Optic textile (HLW)**



# Colored patterns help guide our decisions every day



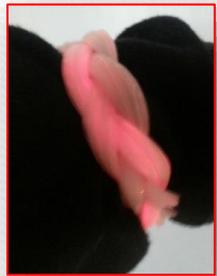
# What if...



- We could match accessories to our apparel by a simple touch on a smart phone or see who's calling our phone by the color routine tagged to their name?



**Could that be convenient & save time?**



Color indicates caller ID



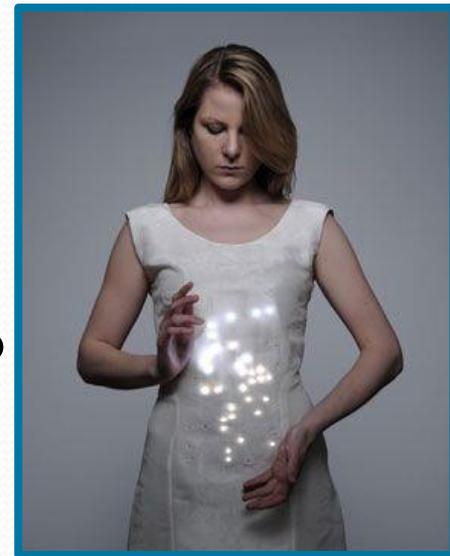
Use any smart phone to change the color of logos, accents and/or areas on a purse!

# What if.....

- We could tell if someone needed immediate medical attention by watching their clothing change colors?



***Could we save lives?***



(In 2004, the CDC reported that the average patient spent 3.3 hours in the ER. Almost 400,000 patients waited 24 hours or more.)

# What if...

**We could know if someone was dead or alive needing help on the battlefield by simply looking at fatigues with FLIR equipment?**

**Could we prevent soldiers from placing themselves in harm's way for no reason?**

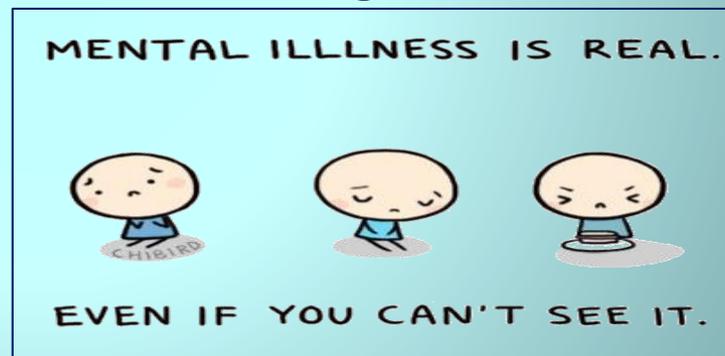




# What if....



- We could determine compatibility with someone or see another person's mood by simply observing their clothing?



***Could we meet that special person or prevent possible suicides?***

(USA: 121 suicides per day - over 44,100 per year)

# What if.....



- We could tell if a person was lying simply by watching their cap change colors?

*Could we stop people from lying?*

*...more importantly... would anyone wear it?*

*Probably not!*



I'm always  
disappointed when  
a liar's pants don't  
actually catch  
on fire.

(According to a 2002 study conducted by the University of Massachusetts, **60%** of adults can't have a ten minute conversation without lying at least once. )



**The answer to all of these  
“What if?” questions is “YES!”  
by implementing E-Textile  
technologies available today!**

# Integrating 'Smart' Wearable Technologies

## Overview, Obstacles and Breakthroughs

- Most promising potential
- Advantages and limitations of E-Textiles
- Light, Heat, and Reactive Inks & Dyes
- LED/Optic flexible textile displays
- Manufacturing challenges

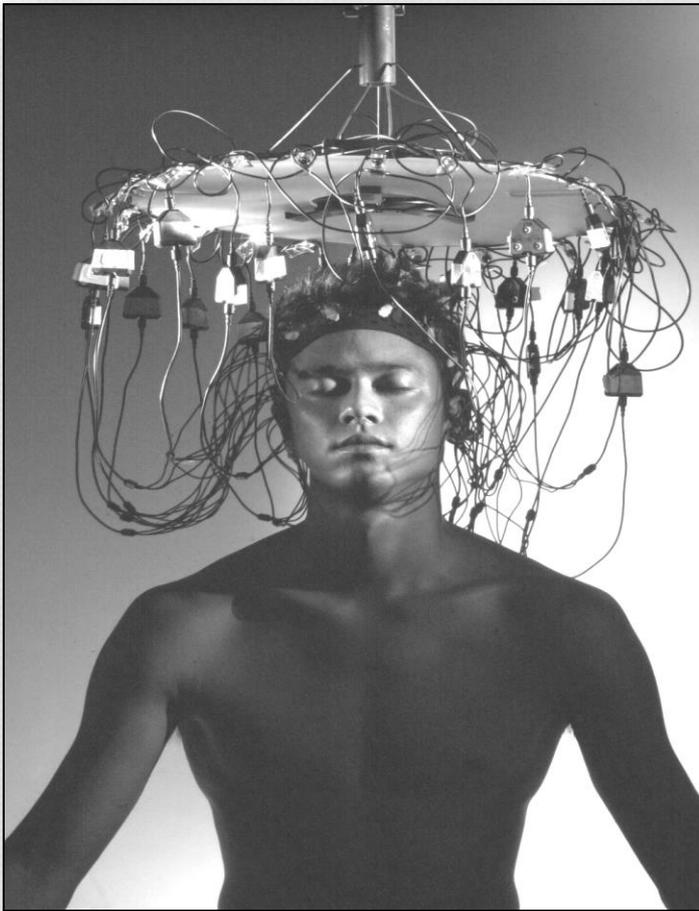
# Integrating 'Smart' Wearable Technologies

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# OPERATOR ACCEPTANCE

## THE CRUCIAL BARRIER TO PSYCHOPHYSIO MONITORING



- Most body sensors are not wireless
- Some 'State-of-the-Art Sensor Systems' require implantation
- Few methodologies offer a sense of "Value-Added" to the operator
- No one wants to work while attached to a "Hospital-Style" apparatus
- The public is wary of technologies associated with 'Lie Detection' and 'Brain Fingerprinting'

**"Fitness and Health remains the leading application for wearable technology." (FORTUNE magazine)**

# Physical Sensor Applications



ECG  
Respiration  
Temperature

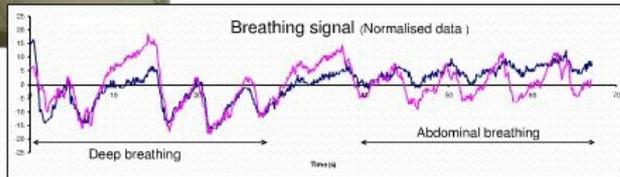
Wireless control unit  
GPS, accelerometer

## Breathing monitor t-shirt



Sensor 1  
Sensor 2

Applications in sport, also pulmonary illness.  
Diaphragmatic breathing - increased oxygen delivery.



## Foster-Miller



Graphical display of heart rate, respiration rate, temperature, activity

## Smart fabrics

### - Bend/stretch sensor

- Conductive elastomer (CE), piezoresistive sensor
- Screen-printed onto fabric
- Resistance varies depending on bend/strain
- Can be used to detect body movement e.g. joint flexion, breathing signals



CE sensor

## BIOTEX

Bio-sensing textile for health management



Pulse oximetry

Respiration

ECG

## BIOTEX

Bio-sensing textile for health management



Wireless control unit (Bluetooth)

Textile patch with sweat pH, sodium, conductivity and temperature sensors

Sweat rate sensor

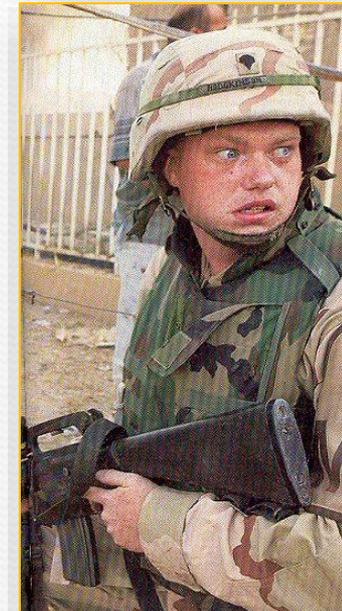
# STRESS AND FATIGUE

## THREATS TO PERFORMANCE

- Every operator has a unique optimal “Stress/Performance Ratio”
- Increases of pilot stress are necessary to survive under certain ‘G-Force Loads’
- Overload of heart, skin and muscle activity decreases situational awareness
- Fatigue can exasperate other adverse states: Distraction, Task Saturation, Low Confidence and Anxiety



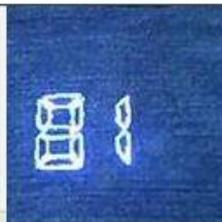
**Service.** Sensitive Feet represents a crucial new way to monitor animal fatigue, pain and activity. By monitoring animal sensitivities and data, it is possible to better train and deploy bomb-sniffing dogs, racing animals and seeing-eye dogs.



May 2007



# Bio-Physical Monitoring via Bluetooth & GSR Sensors



Reporting Sensors:

Alert Notification:  Alert Types:

Report Duration:   Real time

Buttons: Connect, Start Report, Stop Report

2007 Smart Fabric Conference, Washington D.C.

**Coaching.** Monitoring the physiological data from the Sensitive Feet of a team and its individual players enables maximum usage of energy and adaptation of strategies in real-time.

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# Lighted Fabric Requirements

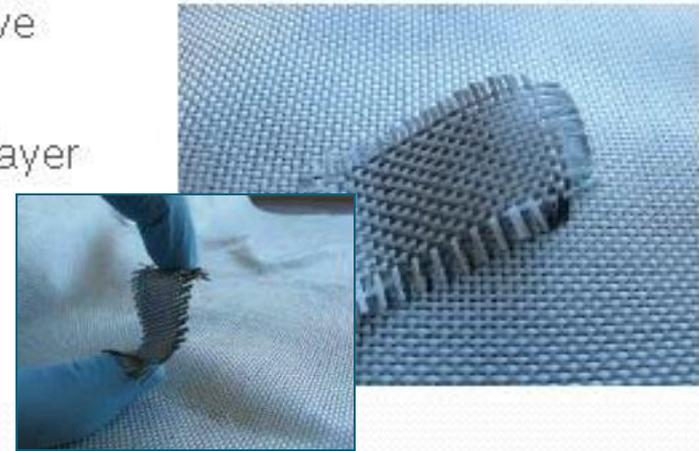
- **Connectivity (Wiring Method)**
- **Waterproof Flexible Power Switch**
- **Power Source Positioning**
- **Sensor Activation Mechanism**
- **Flexible Output Display Method**



# Connectivity

## “Smart” path to lower costs

Researchers at North Carolina State University (NCSU) have been focusing on the formation of functional inorganic nanocoatings on textiles, using a process called atomic layer deposition. The coatings have been applied toward new electronic devices based on a textile framework and protection of textiles from UV radiation and chemicals.

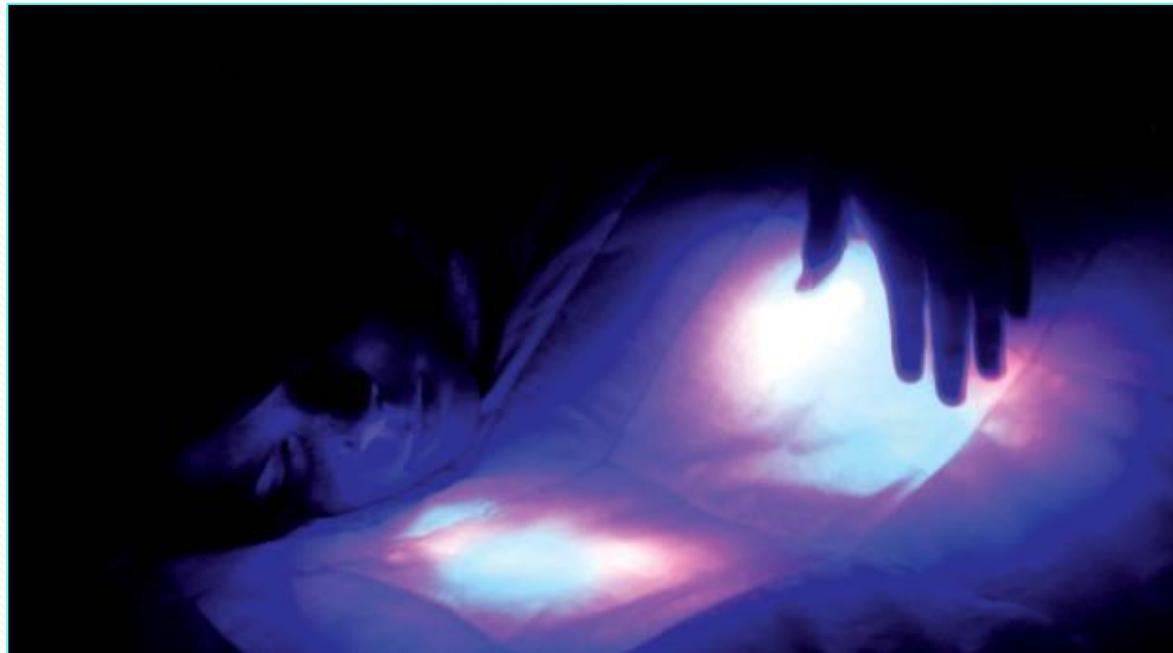


**“Most conductive fibres are so flexible they do not crack or snap if repeatedly bent, unlike metal wires. This means they can be fed into a loom or embroidered directly onto cloth that can be worn and washed as normal. With costs falling and use increasing, the threads are a rapidly growing business...”**

**says Hugo Trux, head of the Conductive Fibres Manufacturing Council (CFMC), an American trade group.**

# Power Switch

*Using CONNECTEDwear™ it's never been easier to add cutting edge technology to your garments!*



# Power Source Positioning

- Battery Life vs. Power Requirement**

(Based on 20ma. Average Current Draw or 1 LED on constantly)

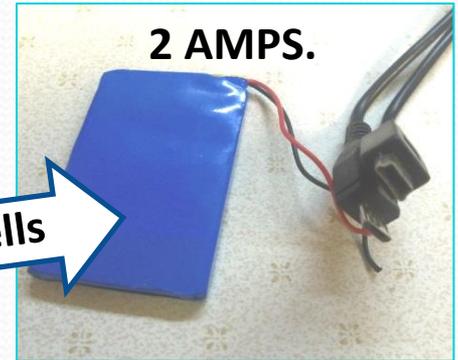
Lithium 2032 Coin Cells = 7.5-20 hours

Alkaline Batteries (AAA) = 60-100 hours

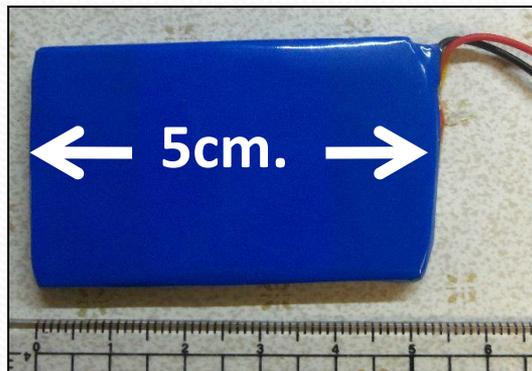
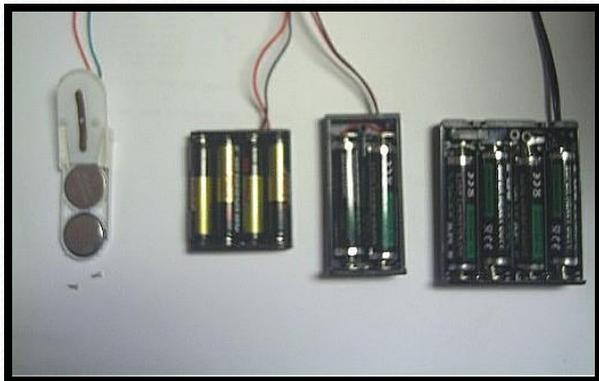
Alkaline Batteries (AA) = 100-200 hours

Alkaline Batteries (C) = 400-600 hours

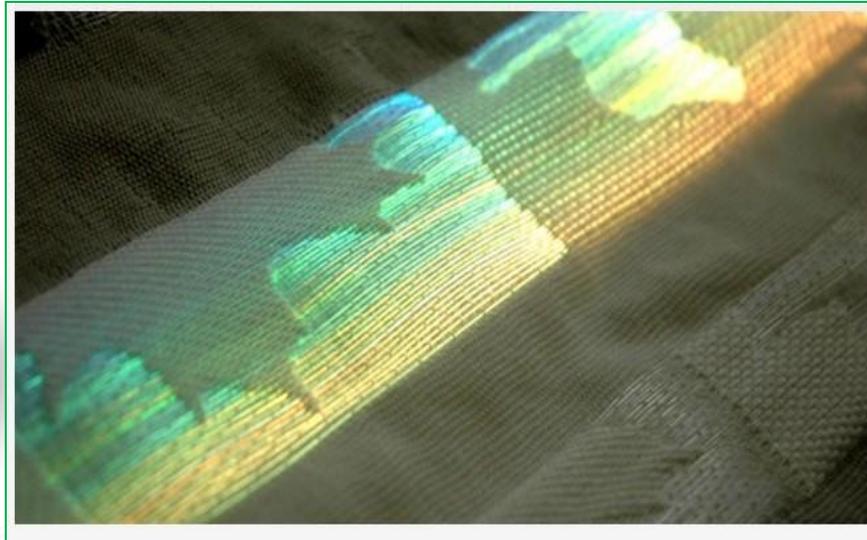
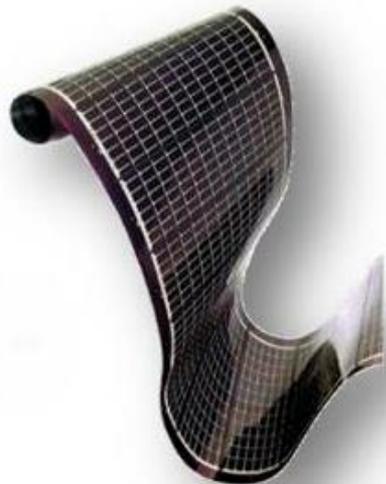
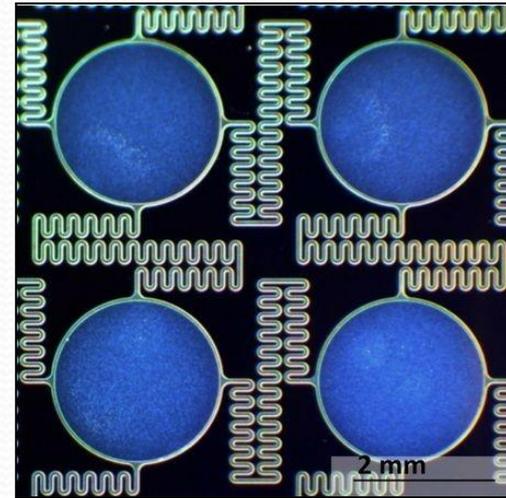
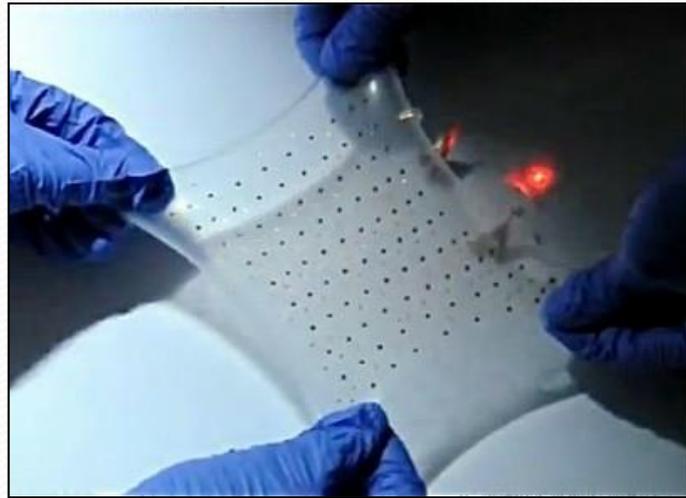
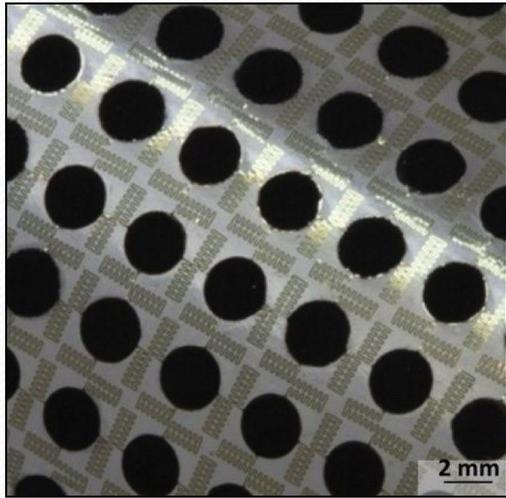
3.7 VDC Li-Ion Polymer Rechargeable Battery



(Above numbers do not take into account current needed to drive speakers for audio output or other LEDs used in additional areas for WIFI or Bluetooth requirements)



# Flexible POWER SOURCES



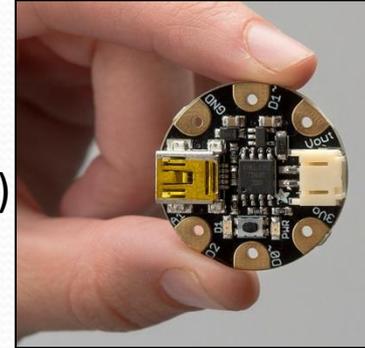
**“Karma Chameleon” is the term given to the new fiber process under development by Concordia University in Montreal, Canada for the human body to supply the power for light-emitting displays.**

# Future Power Source?

Nicola Formichetti, Lady Gaga's stylist, is preparing to launch his collection inspired by solar-powered technology. The idea is to have the ability to charge phones on the go. Other designers such as Paulin van Dongen are working to create more fashion integration with flexible solar film technologies.



# Electronics



- **Adafruit's GEMMA** Miniature wearable electronic PCB (Printed Circuit Board)  
<https://www.adafruit.com/>

- **Lilypad XBEE** is a radio transceiver that can be sewn into clothing to create wireless wearables.  
<https://www.sparkfun.com/>



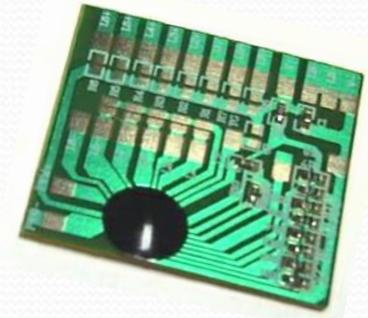
- **Arduino PCB** is a generic platform that can be adapted to many applications including Bluetooth, Zigby, and RF applications.  
<http://www.arduino.cc/>



- **Pre-programmed drivers** RGB COBs, Blinking LEDs, Sewable LED Piping, Bonded LEDs, and "Canned" generic PCBs available through Technology Suppliers  
[www.inventables.com](http://www.inventables.com)



- **Winbond, PIC chip, and other generic microprocessor based development boards...** PCBs require programming experience to create more complex displays... [www.mouser.com](http://www.mouser.com)



# Sensor Activation Mechanism

- Motion
  - Digital Thermometer
    - Body Temperature
  - GSR
    - Heart Rate
    - Emotional State
    - Lie Detection
    - Excited State
    - ECG
  - CO2 Concentration
  - Methane Levels
  - Light (Activation/Deactivation from outdoors to indoors)
  - UV Exposure (Avoid Sun Overexposure)
  - Audio Levels (Avoid Damage to Eardrums)
- Monitoring physiological and environmental parameters
  - Wound Monitoring
    - Infection monitor
      - ❖ Using blood and body liquid
  - Sweat Monitoring
    - Relative Quantity
    - Salinity
    - pH

**BIOTEX**  
Bio-sensing textile for health management

# A Few Output Display Technologies



**The PING dress**

Vibration on shoulder alerts wearer of incoming calls



**Side-fire plastic optic fibers (POF) woven into textiles by Lumigram™**



Holding hands activates scrolling message on **OLED arrays under fabric**



**Exposed Side-Fire POF belt**



**LEDs under fabric displaying level of excitement via color**



**20,000 LEDs attached to black textile support layer displaying colors and tweets...**

# More E-Textile Based Display Examples

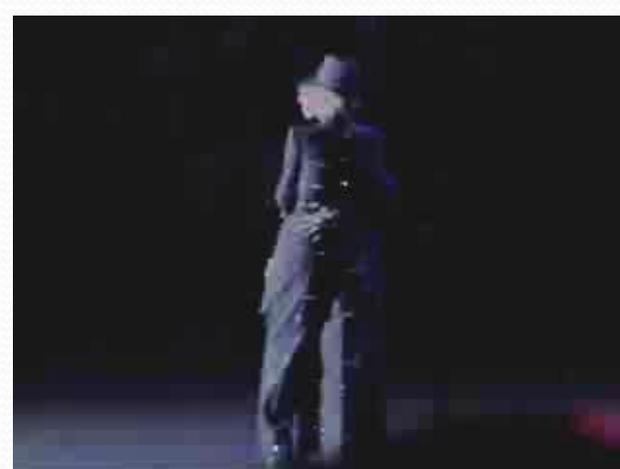
Embedded OLED Arrays

LED strips

Audio responsive LED/Optics



Bonded LEDs



Fiber Optics



EL (Electroluminescent)

# Limitations and Issues

- **It's really cool until you try to walk through a TSA checkpoint**

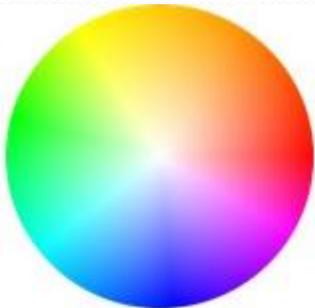
Wires, electronics, and batteries in clothing can become a serious problem in airports. I know because I was stopped wearing an E-Textile jacket with a digital sleeve display I created. Everything from bomb sniffing dogs to men in long trench coats interrogated me and I barely made my flight!

- **Do I put it in the trash or re-cycle bin when it stops working?**

To address these problems two pieces of legislation have been put in place: The Directive on waste electrical and electronic equipment (WEEE Directive) and the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive)

- **Are there any recyclable E-Textile technologies?**

To address these 3 issues, I created a new technology that is Blue tooth controlled and removable from apparel that will allow for smart phone control of medical, safety, military, utility, and aesthetic E-Textile applications leaving no wires, batteries, or other components in garments to cause any problems



Color coordinate shoes or purse to apparel at the touch of a smart phone screen!

# **Integrating 'Smart' Wearable Technologies**

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- **LED/Optic flexible textile displays**
- **Manufacturing challenges**

# Inks and Dyes...Think "Out of the Box"



Combining reactive inks with E-Textile technologies can add another dimension for designers...



Creatively combining various technologies can provide more than simply the sum of the parts...

**Hallcrest Inc.** 1911 Pickwick Lane, Glenview, IL 60026

(USA supplier of Non-Toxic Dyes and Inks)

Photochromic, Thermochromic, and Hydrochromic Inks)

*UV Light Activated*

*Heat Activated*

*Water Activated*

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1985

# First LED/Optic E-Textile Display



Multiple LEDs feed multiple bundles forming separate image frames



Sequential timed activation results in surface movement of images



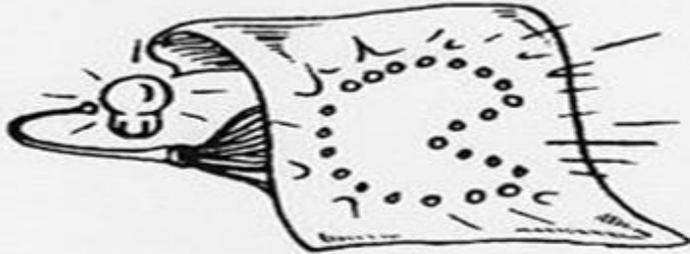
Processor controls pulse timing



Plastic Fiber Optic "light pipe" with fluorinated polymer coating



Single LED light source feeds multiple light pipes which in turn define dotted images



Quiescent "current saving" method strobes LEDs @ 160+ Hz. To achieve <10% duty cycle to prolong battery life



## 2018 LED/Optic E-Textile Displays w/Bluetooth Control

**The “Opti-Coupler”™** is a removable smart phone accessory remote control device removing all metal from E-Textile products which addresses such problems as:



- Waste fill issues (i.e. wires, batteries, LEDs, & more)
- Airport Security problems with metal detectors
- Wash-ability (Machine Washable)
- Extreme Durability (No break point issues with wiring or connections)
- Maintenance-Free products (Minimal failure points... greater MTBF)
- Warranty issues (Eliminates need for returning products for repairs)



# October 12, 2017 "Dress Code" Event in LA featuring Cierra Ramirez in a "Smart Dress" by H. Lee Wainwright, E-Textile Consultant, and Dalia MacPhee, a celebrity designer for "Dancing with the Stars"



FRI, 13 OCTOBER 2017 AT 12:46 PM [Tweet](#)

## Cierra Ramirez Makes Her Dress Light Up With Code at Google Event



**Cierra Ramirez** shows off her tech dress at the **Google CS+X Series: Dress Code** event held at the Google offices on Thursday afternoon (October 12) in Venice, Calif.

*The Fosters* actress modeled one of **Dalia MacPhee's** designs, which was equipped with LED lights inside the skirt that were turned on using coding technology.

**PHOTOS:** Check out the latest pics of **Cierra Ramirez**

"Dresses are even prettier when technology is involved," **Cierra** wrote on Instagram at the event. "It can change any color you want, just by the

touch of your smartphone! What color would you make my dress?"

So cool!

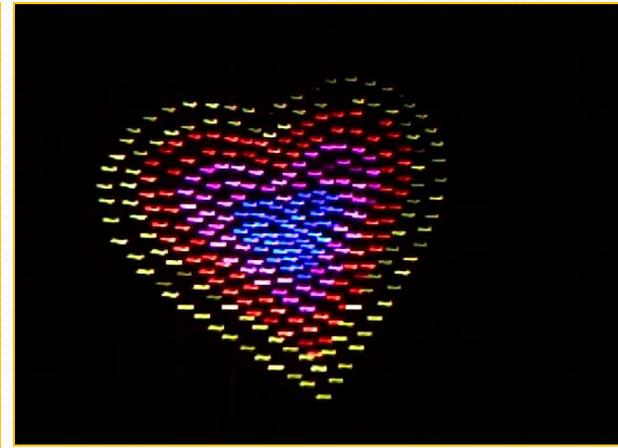
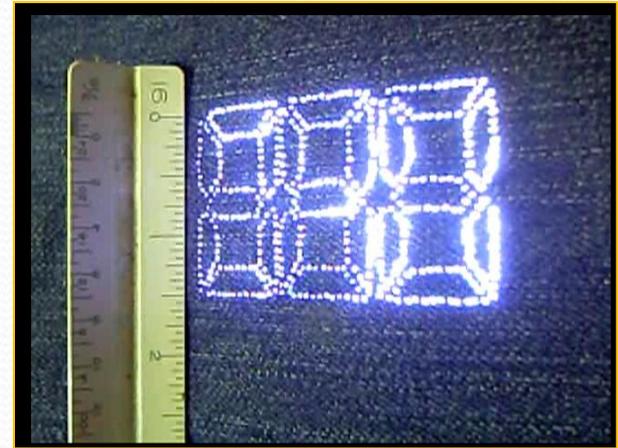


**cierraramirez** [Follow](#)

▶ 307.6k views 240 comments

Dresses are even prettier when technology is involved ☐☐ check out this LED dress I had the honor of wearing tonight designed by the talented @daliamacphee while hosting tonight's @google Dress Code event. It can change any color you want, just by the touch of your smartphone! What color would you make my dress?

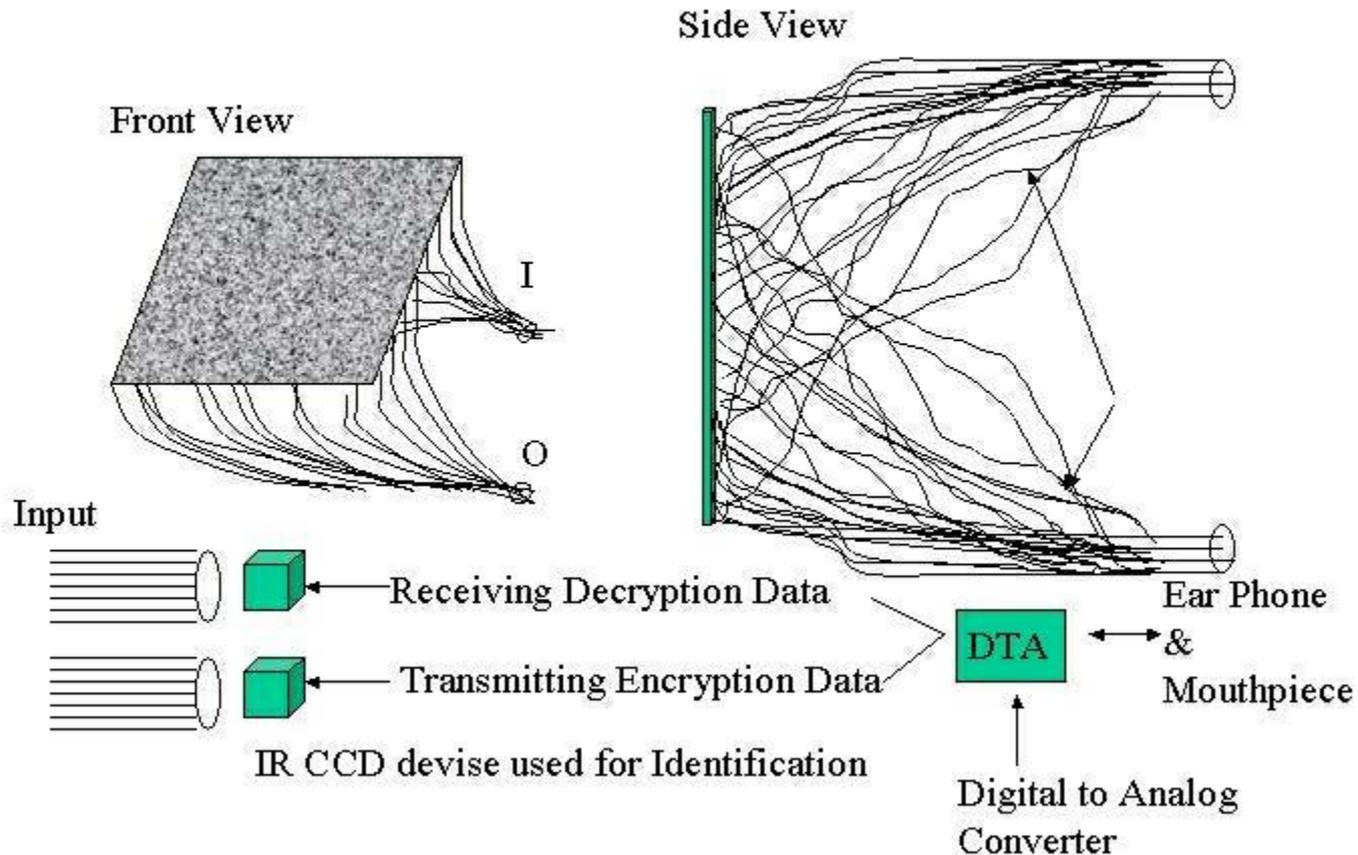
# LED/Optic Machine Washable Displays



Designed for Entertainment, Utility, Medical, Bio-Physical, and Military applications.....

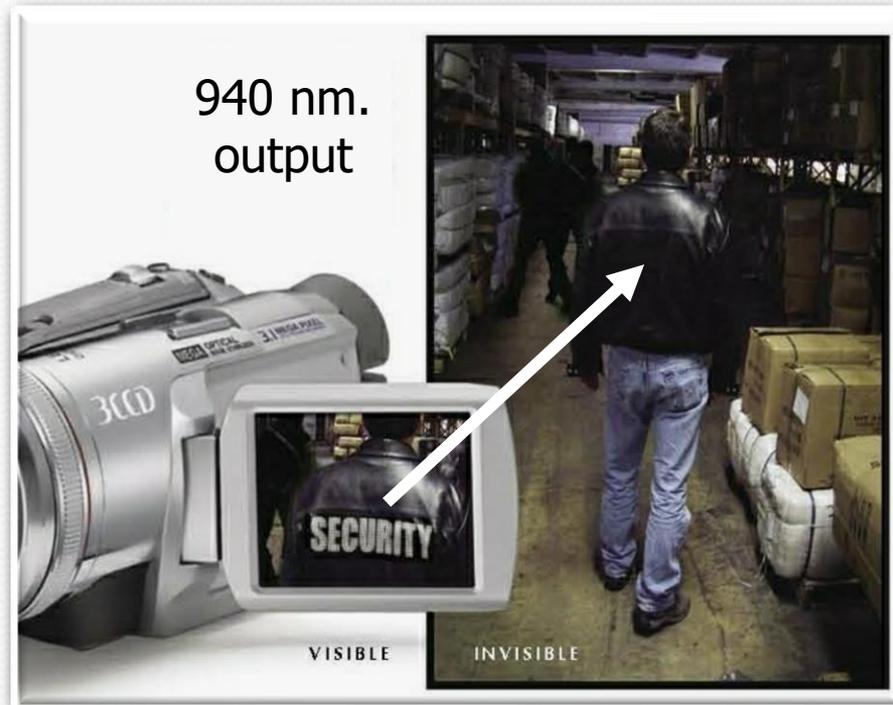
# 2-Way IR Data Transfer via LED/Optic Fabric Displays

## 4. 2-Way Communication/Identification Fabric



# Conceal or Reveal with “User-Selectable” Modes

- Switch on “**Stealth Mode**” to be seen only by security cameras!
- Turn on “**Visible Mode**” graphic displays from fabric surfaces at will to be seen from a distance!



**Stealth** (Invisible to the unaided eye, but seen with FLIR equipment and security cameras)

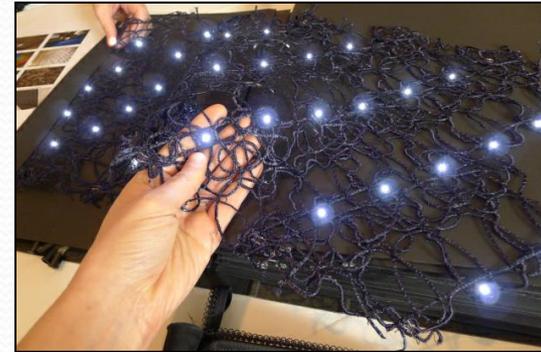
**Visible Modes**  
(Visible in any selectable color)

# Manufacturing challenges

- Due to the complexity and placement arrangements of LEDs in apparel applications, most creations have been done by hand....
- Sportswear companies like **NIKE** and **REEBOK** are using **GSR** sensors on watches, chest bands, and pressure sensors inside shoes to display bio-physical data on watches, but none have employed lighted displays in their designs to date. ... **WHY?**

**Answer:** Manufacturing and Behavior Modification obstacles

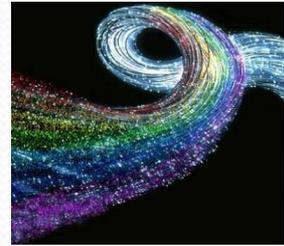
1. Hand made is inconsistent, not precise enough for quality assurance
2. Consumers hate to change batteries and often forget to charge products using rechargeable batteries
3. None of the LED array applications are machine washable
4. LED arrays are VERY expensive limited to Haute Couture, celebrity special events, and costumes for theatrical productions due to power and comfort issues.
5. Wiring harnesses tend to be bulky and uncomfortable





# Manufacturing challenges

## (LED/Optic Display CNC Machines)

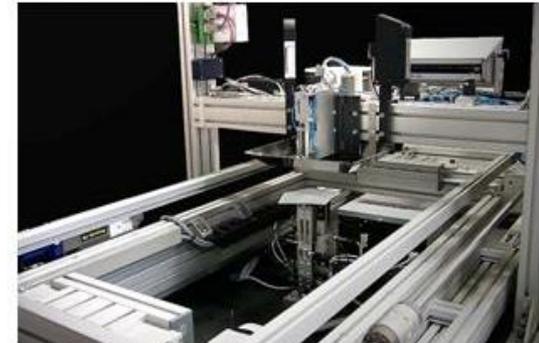


The marriage between functionality and comfort can be addressed by employing fiber optics.

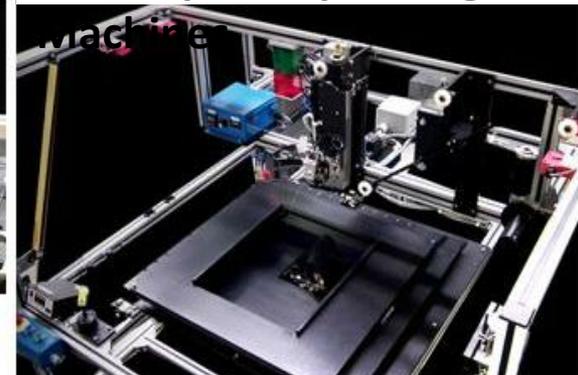
The keys that unlock the door to success with any product are its manufacturability and price point acceptance in multiple international markets.

There are two Fiber Optic based technologies that use CNC machinery to mass produce apparel related displays.

Woven hair-like optical fibers emitting light from their perimeters (**Lumigram**) & machine washable digital displays and animations in fabric (**Me**).



**Fiber Optic Implanting**



# The Future of E-Fashion:

## The Journey from Novelty to Utility

“The market for (Smart Fabric) wearable's business exceeds \$2 Billion, according to a report from Juniper Research.” (FORTUNE MAGAZINE)



### Mitsubishi ESKA (PMMA) Plastic Optical Fiber

<http://www.pofeska.com/pofeskae/contact/index.html>



Lumitex, Inc. produces flexible fiber optic backlighting for displays. [www.lumitex.com](http://www.lumitex.com)

**We live in a world of constant change, a morphing diorama to tickle our senses providing immediate gratification. Striving to keep up with these changes in the fashion industry is a creative process requiring cooperation from many levels of industries that; prior to the creation of E-Textiles and Smart Fabrics, didn't exist. The challenge needs to be addressed as designers and engineers come closer to combining their creative talents blurring the line of distinction between electronics and fabrics into a coherent presentation worth considering to enhance and change our daily routines for the future.**

# Sourcing for E-Textile Products, Materials, & Prototyping parts

## Source LINKS:

<http://www.adafruit.com/products/1643> (Neo-Pixel Ring- Rainbow Ring leds)  
<http://cutecircuit.com/> (Company examples of celebrity costumes using OLED arrays)  
<http://fashioningtech.com/> (Hair extensions) (Monitor Movements)  
<http://www.talk2myshirt.com/blog/archives/5617> (List of E-textile companies engaging in research, prototyping, and applications)  
<http://etextilelounge.com/> (Conductive Thread evaluation comparisons with instruction videos)  
<http://www.ifmachines.com/> (Apparel Soft Switches)  
[http://www.ifmachines.com/products\\_faqs.html](http://www.ifmachines.com/products_faqs.html) (Apparel electronics)  
<http://www.adafruit.com/category/92> (User-friendly accessories for building E-Textile projects)  
<http://www.plusea.at/?p=4203> (textile sensor demonstrations)  
<http://www.visijax.com/about-us/our-technologies> (Raise arms to activate turn signals in fabric)  
<http://www.rainbowwinters.com/videos.html> (Photochromic, lenticular, and ambient driven color inks)  
<http://highlowtech.org/?cat=5> (MIT Media Lab Instructional books on Lilypad Arduino applications)  
<http://whisper.iat.sfu.ca/> (Whisper project 2007)  
<http://www.ife.ee.ethz.ch/research/groups/PlasticElectronics> (Electronics Laboratory and wearable computing, Zurich, Switzerland - Thin film flexible electronics and sensors, smart textiles, and company spin offs)  
<http://subtela.hexagram.ca/index.html> (Subtea project with scrolling jackets and flexible led sleeve digital displays, Concordia University, Canada)  
<http://www.ita.rwth-aachen.de/3-f-und-d/3-01-08-smart-textiles.html> (Textile switching and functional control testing)  
[http://www.izm.fraunhofer.de/en/abteilungen/system\\_integrationsinterconnectionstechnologies/arbeitsgebiete/elektronikintegrationinalternativmaterialien/projects/integration\\_von\\_elektroniktextilien.html](http://www.izm.fraunhofer.de/en/abteilungen/system_integrationsinterconnectionstechnologies/arbeitsgebiete/elektronikintegrationinalternativmaterialien/projects/integration_von_elektroniktextilien.html) (E-Textile testing and qualifying lab)  
<http://research.ocadu.ca/socialbody/projects> (Social Body Projects at OCAD University, Toronto, Canada)  
Flexible Display Conferences: <http://flextech.org/>  
<http://www.hleewainwright.com/resources/celebrity+examples.pdf> (E-Textile Examples created by H. Wainwright)  
<https://www.smartfabricsconference.com/> (Conference covering Smart & E-Textile Research)  
<http://burningman.org/> (LED Event in Nevada Desert)

## (Conductive thread suppliers)

<http://fashioningtech.com/profiles/blogs/conductive-thread-overview> (Comparison analysis of several conductive threads)  
<http://www.fine-silver-productsnet.com/shmeya2.html>  
<https://www.sparkfun.com/search/results?term=conductive+thread&what=products>  
<http://members.shaw.ca/ubik/thread/order.html>  
<http://soft-circuit.com/shop/conductive-materials/conductive-thread-sample/>  
<http://www.kobakant.at/DIY/?p=379>

## (Thin Film PV Suppliers)

<http://www.dunmore.com/products/thin-film-photovoltaic.html>  
<http://www.powerfilmsolar.com/>

## **Sourcing of PCBs and other Materials:**

Adafruit's GEMMA Miniature wearable electronic printed circuit board

<https://www.adafruit.com/>

Lilypad XBEE radio transceiver for wearable's:

<https://www.sparkfun.com/>

Arduino PCB for Bluetooth, Zigby, and RF applications:

<http://www.arduino.cc/>

Pre-Programmed Drivers for RGB COBs, Blinking LEDs, Sewable LED wire, and parts for entrepreneurial designers:

<http://www.inventables.com>

Winbond, PIC Chip, and other generic processors:

<http://www.mouser.com>

PMMA Spooled Optical Fiber:

<http://pofeska.com/pofeskae/contact/index.html>

Side-Fire Flat Optical Fiber:

<http://www.lumitex.com>

MSDS Criteria: [http://www.ilpi.com/msds/osha/1910\\_1200\\_APP\\_A.html](http://www.ilpi.com/msds/osha/1910_1200_APP_A.html)

## **CREDITS:**

### **Karma Chameleon**

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### **Joanna Berzowska Website:**

<http://design.concordia.ca/people/full-time-faculty/joanna-berzowska.php>

### **XS Labs Catalogue:**

[http://xslabs.net/catalogue-pdf/XS\\_catalogue.pdf](http://xslabs.net/catalogue-pdf/XS_catalogue.pdf)