

Smart Fabrics Technology Development

Final Report

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A NASA Innovation Fund Project

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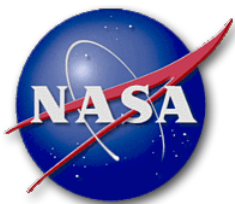


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1. Abstract

Advances in Smart Fabrics technology are enabling an exciting array of new applications for NASA exploration missions, the biomedical community, and consumer electronics. This report summarizes the findings of a brief investigation into the state of the art and potential applications of smart fabrics to address challenges in human spaceflight.

2. Executive Summary

The goal of the project was to evaluate the current state of the art in Smart Fabric technology, find what new devices and applications are around the corner, and investigate how NASA collaboration can increase the TRL of Smart Fabric technologies. A long-term goal is to encourage the use of Smart Fabric technology where appropriate in future space missions.

“Smart Fabric” is defined by this project as traditional fabric with integrated active functionality. “Traditional fabric” includes materials (e.g. cotton, polyester, Nomex, Kevlar, etc), treatments (e.g. dyes, polyvinyl alcohol, etc), and manufacturing techniques. Active functionality could include power generation and storage, human interface elements, sensing devices, Radio Frequency (RF) functionality, or assistive technology.

The state of the art in commercially available Smart Fabric technology is somewhat limited. The most commonly available Smart Fabric elements are conducting and semiconducting yarns and swatches. These elements allow manufacturers and hobbyists to attach and interconnect rigid electronic devices to traditional fabrics. Conducting swatches can also be used for electrical switching and contact biosensing applications (e.g. ECG or heart rate). Fabrics that are sensitive to deformation are also available, and these can enable several elements including user interfaces, biomedical sensing, or other monitoring applications.

Current laboratory and university research relevant to the field revolves around more complex integrated sensing devices (such as carbon electrodes), flexible silicon-based electronics, piezoelectric fibers, and printed carbon nanotube films. These are the technologies (currently at TRL 3 – 5) that will enable the Smart Fabrics of science fiction – human interfaces, computing power, and more that are seamlessly integrated into clothing and other textile features.

Smart Fabric technology can find useful application in NASA’s human and robotic space exploration programs: comfortable, reliable, and unobtrusive monitoring of crew members; compact and lightweight sensors, controls, power generation and storage; cleaner and more reliable integration of electronic elements into Extravehicular Activity (EVA) garments; extremely lightweight and compact monitoring and feedback for robotic probes. At the mission level, the use of Smart Fabric technology will result in reductions in upmass and volume requirements. There is great potential for NASA spinoffs to the private sector at both the technology and application levels. Smart Fabric technology is worth pursuing at the agency level.

3. Background

3.1. Introduction to Smart Fabrics

The term “Smart Fabrics” refers to a broad and somewhat ill-defined field of study and products that extend the functionality and usefulness of fabrics. Humanity has used various types of fabrics for thousands of years to keep warm, provide comfort, and protect from the elements of nature. For most of recorded history, fabrics have also provided a means of self-expression through colors, patterns, cuts, and other stylistic elements.

Aside from the vagaries of fashion and variations in practical application, humanity’s use of fabric has not extended far beyond the basic needs of protection, comfort, and expression. Recent times (within the last 100 years) have seen the use of specialized, synthetic fabrics that are suitable for specific applications (e.g. Nomex, for its fire-retardant capabilities, or Kevlar, for its high strength), but these fabrics are still passive elements.

There is some disagreement over the scope of Smart Fabrics, but a broad definition would state that Smart Fabric is traditional fabric with integrated active functionality. Active functionality could include power generation or storage, human interface elements, sensing devices, radio frequency (RF) functionality, or assistive technology. The basic technological elements of smart fabric are conductive or semiconductive threads and yarns, nanoelectronics applied directly to fibers, yarns, or woven elements, and chemical treatments that provide different features.

Smart Fabrics differ from Wearable Electronics in that wearable devices are merely contained and carried by clothing, where Smart Fabrics have the functionality of wearable devices actually integrated into the fabric. This is an important distinction to make, because several commercial products marketed as “Smart Fabric” are actually “regular” fabric that envelopes traditional electric, electronic, and/or electromechanical (EEE) devices.

Power Generation & Storage

All electronic devices require power, and this is a significant design challenge for Smart Fabrics. Researchers at Stanford University [1] have developed a method for treating paper with carbon-nanotube inks to create batteries and electrodes. Paper’s fibrous structure allows the inks to permeate the material to create a strong, flexible bond – the same technology could be applied to fabric substrates rather than paper, to create a fabric-based energy storage device. Power generation can be achieved through piezoelectric elements that harvest energy from motion or photovoltaic elements.

Human Interface Elements

Human interfaces to active systems can be roughly grouped into two categories: input devices and annunciation or display devices. Input devices can include capacitive patches that function as pushbuttons, or shape-sensitive fabrics that can record motion or flexing, pressure, and stretching or compression. Capacitive patches can also be used to sense physioelectric signals, which allow for user input via electromyogram (EMG) or electroencephalogram (EEG). Annunciation and display devices may include fabric speakers, electroluminescent yarns, or yarns that are processed to contain arrays of

organic light emitting diodes (OLEDs). Fabrics can also include elements that provide electrotactile feedback or simply vibrate.

Sensing Devices

Fabric-based sensing has been a large field of research in the biomedical and safety communities. Capacitive swatches can be used for electrocardiogram (ECG), EMG, and EEG sensing; fabrics incorporating thermocouples can be used for sensing temperature; luminescent elements integrated in fabrics could be used for biophotonic sensing; shape-sensitive fabrics can sense movement, and can be combined with EMG sensing to calculate muscle fitness. Carbon electrodes integrated into fabrics can be used to detect specific environmental or biomedical features such as oxygen, salinity, moisture, or contaminants.

RF Functionality

Fabric-based antennas are a relatively simple application of Smart Fabrics. Simple fabric antennas are merely conductive yarns of specific lengths that can be stitched or woven into non-conducting fabrics; more complex antennas may be woven into specific shapes and utilize conductive fabrics for shielding and directional use. The use of fabric antennas has already been explored at length by many parties; such antennas are available for cellular and satellite phones, and have been integrated into NASA's Extravehicular Mobility Unit (EMU) EVA suit and the KORONA-M communications system for the Russian Space Agency's ORLAN-M EVA suit.

Assistive Devices

Fabric with integrated shape memory alloys could stretch, shrink, and bend on command; making it easier to don or doff clothing, maintain the shape of soft packaging, or encourage correct posture. Resistive elements woven into fabric can provide active heating (this is frequently seen in ski gloves).

3.2. Potential Impact

There is a keen interest in Smart Fabric technology in the medical, sport, fashion, and artistic communities, but Smart Fabric technology presents several challenges. Creating successful smart fabric products requires expertise in many disciplines – textiles, semiconductor physics, nanotechnology, chemistry, physiology, analog and digital electronics, wireless communication, human interfaces, signal processing, ergonomics, and others. According to Smart Garment People, a Danish consulting company, some manufacturers are very experienced with electronics and others with textiles, but few do both well. Research in flexible electronics that could be applied to the Smart Fabrics field has generally occurred in academic environments, with little to no coordination with commercial entities creating Smart Fabric products.

Research by NASA could have wide-ranging benefits for the industry. Most obviously, NASA-sponsored research would lend credibility to a nascent industry whose most visible products so far have been somewhat impractical. NASA's strict requirements for safety, reliability, and low resource utilization would be directly applicable to successful commercial products, so any advances made here

would benefit the entire industry. NASA involvement can also serve as a bridge between the disparate research efforts that have happened so far, and bring together all of the expertise needed to create pure Smart Fabric devices.

Smart Fabric technology has the potential to radically change the mobile computing industry – imagine pants that are also batteries to power various mobile devices; hats with cellular antenna boosters; shirt sleeves with data storage; gloves that contain controls for your cellular phone, so they can stay on when it’s cold. Other industries would benefit as well: restaurant tablecloths that display menus, daily specials, and allow patrons to page their waiter or waitress; hospital bed sheets that monitor patients; medical monitors that are impossible to forget because they are part of your clothing. These are all potentially huge commercial successes with real relevance for human spaceflight at NASA.

4. Approach

4.1. Project Goals

The goals of this project have been to understand the state of the art of smart fabrics and to identify potential applications of smart fabrics to human spaceflight. We have sought to characterize both the commercial and research status of smart fabric technologies. When identifying applications to human spaceflight we have focused on technologies that can reduce the mass, power, and crew effort required to complete a task. We have considered improvements to existing systems and the creation of new systems for future missions.

4.2. Process

Initial research gave us a good picture of what the commercial state of the art is today. Beyond that, we chose a dual focus; partly on current Smart Fabric R&D efforts, and partly on enabling technologies that are not necessarily specific to Smart Fabrics (such as flexible electronics). We viewed this as important because many of the technologies that will make Smart Fabrics successful are still in early development.

4.3. Hardware Demonstration

Through the course of our research and contact with other parties (commercial and academic), we have developed a collection of Smart Fabric elements that are representative of the state of the art in commercially available Smart Fabrics. To demonstrate these building blocks, we have prepared some basic examples of the application of Smart Fabrics. The examples are not intended to be comprehensive or polished; they merely hint at the possibilities of the technology; polished demonstrations are left as an exercise for a future project. The demonstration is shown in a short video that accompanies this report.

5. Findings

5.1. Overview of Findings

Investments in both commercial and academic research have been driven mainly by entertainment, healthcare, sport, and military applications. There has also been interest in the fashion and performing arts industries, where designers are exploring the possibilities of luminescent and color-changing clothing.

Practical issues have hindered the wide adoption of Smart Fabric technology. The process for mass producing traditional textiles does not translate well to smart textiles – cutting patterns from large rolls of cloth and sewing them together to make garments breaks and reforms electronic connections in an uncontrolled manner. Because of this, Smart Fabric elements are generally integrated by hand into textiles produced by standard methods.

Clothing and some other textile products (such as tablecloths) must be washable, which subjects the smart elements to water and chemical immersion, physical stress, and extreme temperatures – the current state of the art tends to be too fragile for this treatment. The state of the art in flexible electronics and nanotechnology, required to integrate power and computer processing elements into fabric, has not advanced to the point that analog processing or digital logic can be integrated into fabrics.


The result of this is that many products marketed as Smart Fabrics are really just traditional electrical and electronic components glued or sewn in to traditional fabrics, or inserted into pockets and channels in the fabrics. Even though some smart fabric elements are readily available (such as buttons, conductive swatches, and conductive wires for interconnects), they are not in widespread usage because of the manual effort involved to integrate them.

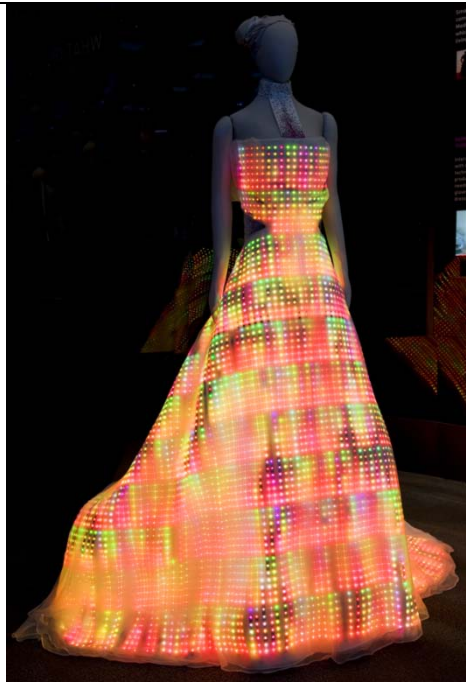
5.2. Commercial State of the Art

Despite these challenges, many companies are exploring potential commercial applications for smart fabric technologies. Consulting agencies have been created to assist in the design, development, and marketing of new products and technology owners are often taking an active role in product development. As the enabling technologies mature and more companies develop the necessary expertise, smart fabrics will move from novelty and niche commercial markets to more mainstream applications.

While there are many commercial items that suggest the future use of Smart Fabric technology, currently available consumer smart fabric products are not highly integrated – most can be better described as Wearable Electronics; rigid electronics and standard wiring mounted on fabric. They generally gather user actions or sensor data and in some cases are marketed on the novelty of the technology rather than the functionality of the product. Power from an external source is usually required or standard consumer batteries are used. No commercially available product integrates flexible displays, though some incorporate lighting and indicator LEDs. The most advanced smart fabric systems that are commercially available are physiological monitoring garments. These are used for medical and sport applications where they must be comfortable and take accurate measurements for

long periods of wearer movement. These systems have benefitted from significant research funded by European governments.

Examples of Commercial Products	
	<p>Fibretronic soft electronic products http://fibretronic.com</p> <p>Fibretronic is a provider of wearable electromechanical interfaces such as joysticks and pushbuttons used in outdoor wear (such as jackets and gloves). These devices provide users access to traditional electronic devices such as smartphones, GPS receivers, and portable music players. The interfaces are specifically designed for integration into textile products, but do not represent Smart Fabric technology per se. Examples of commercial products incorporating Fibretronic’s interfaces are Kombi Sport Gloves.</p> <p>A Smart Fabric evolution of this technology could involve replacing the electromechanical pushbuttons and joysticks with Quantum Tunneling Composite (QTC) fabric, and electrical interconnects using integrated conductive yarns.</p>
	<p>NuMetrex biological sensing garments http://www.numetrex.com/about/the-system</p> <p>NuMetrex heart monitoring apparel incorporates patches of conductive fabric into tight-fitting areas of sports garments to provide capacitive sensing of heart rate in a more comfortable configuration than existing products. Sensing and RF electronics are contained in a rigid plastic module that is attached to the garment using conductive snaps.</p> <p>The NuMetrex heart monitoring garment represents a midpoint in the evolution from Wearable Electronics to Smart Fabrics – Smart Fabric elements (capacitive sensing fabric) are beginning to replace traditional “hard” electronic components.</p>



CuteCircuit Galaxy Dress

<http://www.cutecircuit.com/products/galaxydress/>

The CuteCircuit Galaxy Dress was made as a proof of concept for the fashion possibilities of integrating electronic components into textiles. The dress includes 24,000 surface-mount multi-color LEDs integrated into layers of silk; the LEDs display animated patterns on the dress.

Though the Galaxy Dress was never worn by a person, the company has made smaller scale illuminated clothing for celebrities and fashion events.



International Fashion Machines ESSENTIAL™ Wall Dimmer

http://www.ifmachines.com/products_essential.html

The ESSENTIAL Wall Dimmer is an example of a fabric-based user input device. Using a tuft of conductive fabric acting as a capacitive sensor, the wall dimmer senses the touch of a capacitive object (like a finger) to turn on, turn off, and adjust the brightness of household lighting.

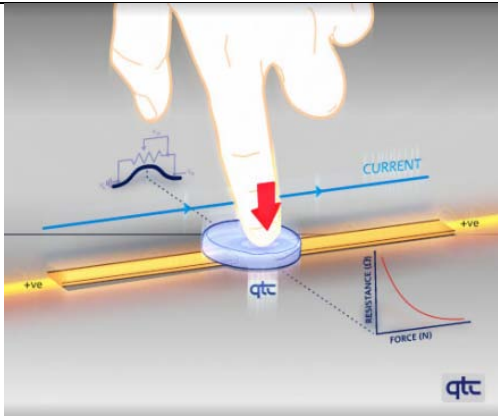


The Peregrine glove

<http://www.theperegrine.com>

The Peregrine glove uses swatches of conductive fabric and strings of resistive elements (coiled steel wire) to provide up to 18 programmable “button” locations on the glove surface for user input into a computer.

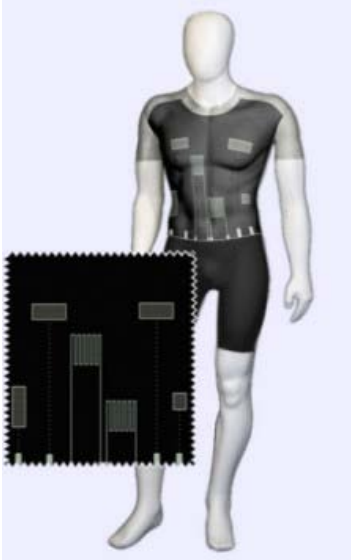
The glove is a good illustration of the complexity of mass manufacturing smart fabrics – the fabric used to create a glove must be cut into complex patterns, so a traditional fabric glove is created first, then smart fabric elements (the conductive patches and integrated wiring) are added on by hand.



Peratech Quantum Tunneling Composite sensing material

<http://www.peratech.com>

Peratech's Quantum Tunneling Composite (QTC) material is a semiconducting material: while in an unstressed state the material acts as an insulator; when deformed, the material starts to conduct – resistance drops as pressure on the material increases. A commercial product using this material is the ElekTex Keyboard, a fabric-based keyboard that can be rolled up for easy storage and transport.



SmartLife HealthVest

<http://www.smartlifetech.com/technology/Health-Vest->

The SmartLife HealthVest is designed for physiological monitoring in healthcare, sport, military, and hazardous environments. The shirt uses Smart Fabric technology for sensing (ECG, respiratory data, heart rate, and skin temperature) as well as electrical interconnects. Like the NuMetrex garments, electronic components are housed in removable modules.



Exmovere Exmobaby biosensor pajamas

<http://www.globenewswire.com/newsroom/news.html?d=200247>

Exmobaby biosensor pajamas are based on a washable, conductive fabric-based biosensor garment. Electronic components are housed in a removable pouch.

5.3. Smart Fabric Research

Ongoing research, highlighted below, has the potential to address some of the major challenges in developing smart fabric systems and the expansive, ongoing efforts to more fully integrate electronics and fabrics into functional systems.

Smart Fabrics and Interactive Textiles Projects, European Commission [2], [10]

The textile and clothing industry has traditionally been very important to the economies of the European Union (EU). Recently, the industry has been relocating manufacturing and production facilities to low-wage countries, leading the EU to invest in research and technology that will ensure the European textile industry retains a competitive edge. The promising findings of a 2002 project led the European Commission's 6th and 7th research frameworks to provide significant research and development funding for personal health monitoring through smart wearable systems and for projects targeting the integration of sensors, energy sources, processing, and communication into clothing. These projects seek to develop technologies and processes that can be commercialized in the textiles and clothing industries through collaboration with academia, research institutions and industry.

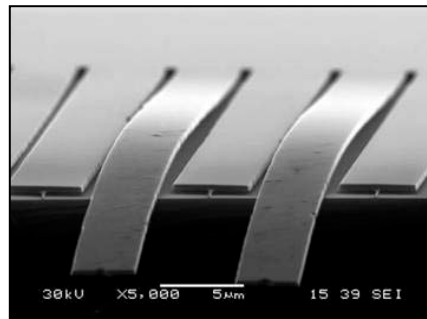
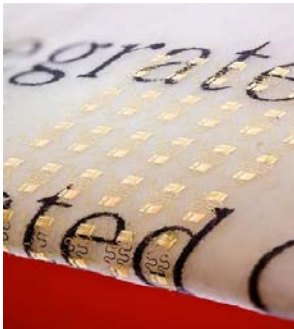
Below is a list of projects funded by the European Union's 6th and 7th Frameworks for Research and Development that have focused on smart fabrics and interactive textiles [3]:

Project Title	Description
<p>WEALTHY Sept 2002 – Feb 2005 http://www.wealthy-ist.com/</p>	Pioneering research to develop and test comfortable smart fabrics for biological monitoring – ECG and respiration.
<p>MyHeart Jan 2004 – Oct 2007 http://www.hitech-projects.com/euprojects/myheart/</p>	Development of Intelligent Biomedical Garments for monitoring, diagnosing and treatment of medical conditions
<p>BIOTEX Oct 2005 – Feb 2008 http://www.biotex-eu.com/</p>	Sought to develop biochemical-sensing techniques that could integrate into textiles. Project aimed to develop textile sensing patches to target bodily fluid sensing.
<p>PROETEX Feb 2006 – Jan 2010 http://www.proetex.org/</p>	Developed smart wearable garments for emergency disaster intervention personnel to improve safety, coordination, and efficiency.
<p>STELLA Feb 2006 – Jan 2010 http://www.stella-project.de/</p>	Sought to develop flexible and stretchable textile substrates with electrical interconnects.
<p>OFSETH Mar 2003 – Jun 2009 http://www.ofseth.org/</p>	Focused on how silica and polymer optical fibers can be used for sensing vital parameters while being compatible with a textile manufacturing process.

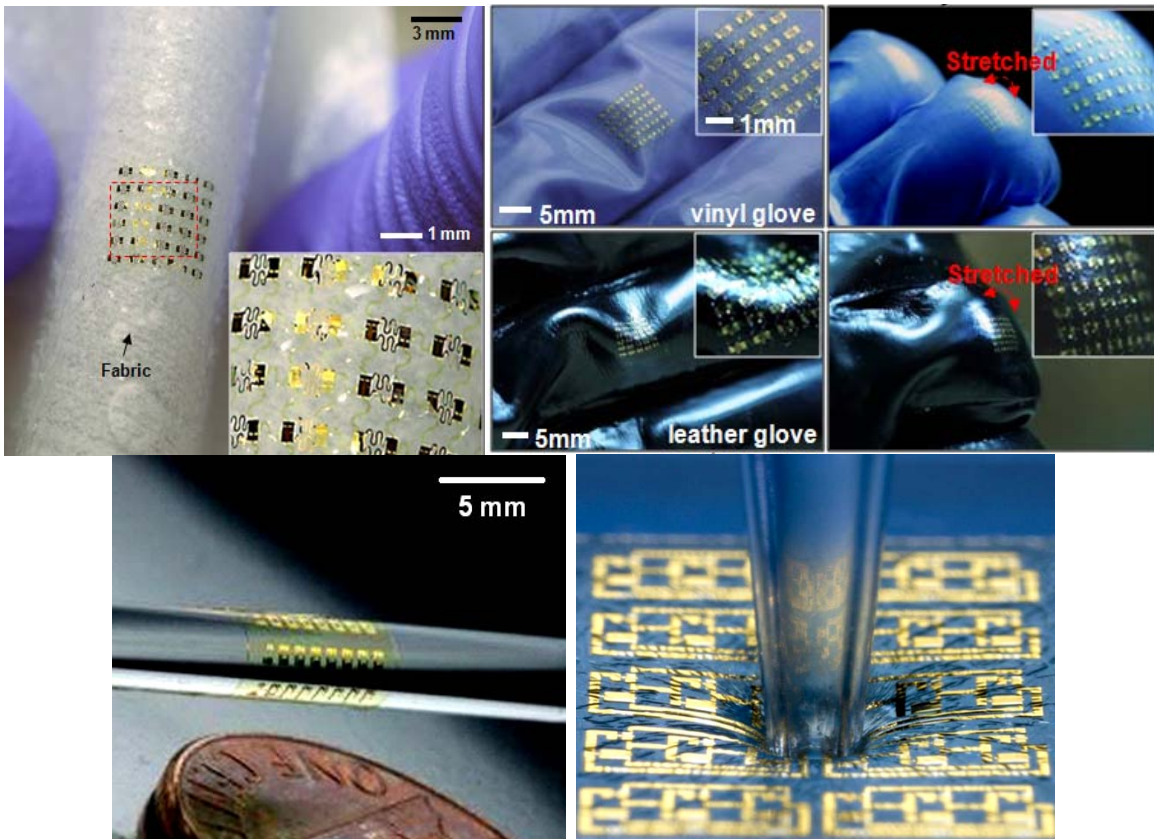
<p>CONTEXT Jan 2006 – Jun 2008 http://www.context-project.org/</p>	<p>Focused on development of contactless sensors in textiles for monitoring ECG and EMG.</p>
<p>WearIT@Work Jun 2004 – Nov 2008 http://www.wearitatwork.com/</p>	<p>Aimed to prove the applicability of computer systems integrated to clothes, creating wearable interfaces for various industrial environments.</p>
<p>MICROFLEX May 2008 – May 2012 http://microflex.ecs.soton.ac.uk/</p>	<p>Development of flexible materials in the form of high added value smart fabrics/textiles which are able to sense stimuli and react or adapt to them in a predetermined way.</p>
<p>DEPHOTEX Nov 2008 – Oct 2011 http://www.dephotex.com/</p>	<p>Research and develop flexible photovoltaic textiles based on novel fibers</p>
<p>PLACE-it Feb 2010 – Jun 2013 http://www.place-it-project.eu/</p>	<p>Development of a technology platform for lightweight, thin and conformable opto-electronic systems interconnect technology</p>

Flexible Electronics, Rogers Research Group at University of Illinois

The Rogers Research Group (University of Illinois at Urbana-Champaign) has expended significant effort to develop materials and manufacturing processes that offer the performance and convenience of conventional, wafer-based silicon devices with the ability to bend and stretch. By combining monocrystalline Silicon nanoribbons (ultrathin, flexible silicon ribbons) with a unique interconnect structure, the Rogers Research Group has demonstrated a way to apply common integrated circuit (IC) manufacturing techniques to deformable (flexible, stretchable, and bendable) substrates. The Group has also developed encapsulation techniques that allow for moisture and environmental resistance.



A major focus of the Rogers has been in applications of the technology. Though the work was not originally targeted for Smart Fabric applications, the technologies and processes are applicable to Smart Fabric technologies at the levels of individual yarns or woven fabrics, as well as other wearable materials.



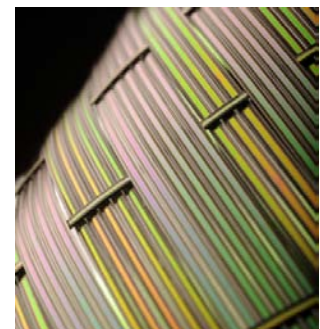
Biosensors in Clothing, University of California San Diego [4], [11]

The University of California San Diego's Laboratory for Nanobioelectronics has demonstrated a method for direct screen-printing of biological sensors onto clothing. By printing the sensors on the elastic bands in men's underwear, the researchers ensure the sensors maintain tight contact with the skin. The sensing electrodes detect hydrogen peroxide and the enzyme NADH, which are associated with numerous biomedical processes. Testing indicated the sensors could withstand the mechanical stress of a wearer's daily activity (flexing and stretching) with minimal effect on the measurements.



Multifunction Fibers, Massachusetts Institute of Technology [5], [12]

The Research Laboratory of Electronics at the Massachusetts Institute of Technology has created multifunctional fibers that add useful properties to traditional textile fibers. The lab has demonstrated fibers that produce and detect sound – leading the way for clothing that acts as microphones or speakers. In 2006, the lab created light-sensitive fibers that could replace lenses and sensors in cameras and lead to clothing that continuously watches its surroundings.



US Army Natick Soldier Systems Center SBIR Projects

Over the past 15 years the Army Natick Soldier Systems Center (NSSC) in Natick, Massachusetts has funded several studies on the integration of data and power networks into soldiers' clothing. According to their textile technologists, one of the most difficult challenges in mass manufacturing of smart garments is that the textiles must be cut and sewn to create garments – a process that would break and reform any electrical channels in the fabric. The NSSC-funded projects have worked to address these problems and have developed prototype technologies that carry data and power for soldier health monitoring, wearable antennas, and other electronics a soldier might require.

5.4. Promising NASA Applications

Smart fabric technologies are especially appealing for use in NASA's human spaceflight missions in low Earth orbit and beyond. There are several foreseeable applications that show potential to improve crew safety, reliability, and efficiency, and to reduce mass, power, and volume requirements of existing support hardware.

5.4.1. Extravehicular Activity (EVA)

Crew Controls

Currently, astronauts control the cooling and pressure systems of their EVA suits using a set of controls mounted on the chest. The pushbuttons and sliders are mechanical switches that must be large enough for an astronaut's gloved hand to access. Using Smart Fabrics, controls could be integrated seamlessly into any location on the EVA outer garment and conductive textiles could replace the traditional wiring. This would reduce the EMU's mass and potentially make the controls more accessible.

In 2005 ILC Dover, producer of the ISS and Space Shuttle crew pressure garments, partnered with the University of Maryland and NASA to evaluate a series of advanced robotic interfaces for astronauts in the EMU. The evaluated devices included a control pad made of pressure sensitive fabric that was mounted on the suit lower arm and later on the wrist. The controls functioned well as the user controlled a robot, but the lower arm position caused unacceptable arm fatigue because it required the user to keep both arms raised during operation. Users also experienced hand fatigue from pushing the buttons too hard – the team discovered that without tactile feedback, subjects did not know when the button was activated and pressed harder than was necessary. The findings highlight that while integrating smart fabrics into the space suit is appealing, life-like evaluations are an important tool for identifying usability issues. [6]



Smart Fabric technology could be combined with electromyography (EMG) to address this issue in another way: by integrating capacitive sensors into the EMU's inner garment, electromyography

could be used to detect muscle contractions. The system would allow an astronaut to make slight arm or hand movements to initiate commands rather than requiring them to reach for external controls. Combined with an appropriate head-up display, this approach could enable the astronaut to command off-suit systems in addition to the EMU's onboard systems.

Cuff Checklist

A cuff checklist is used to remind the astronaut of the tasks that are to be performed on the current extravehicular activity, and may contain diagrams and procedure steps. As future missions become more complex and require astronauts to operate with more autonomy due to the communication lag with Earth, the cuff checklist (or a system with similar capacity to inform the astronaut) becomes critically important. The current cuff checklist is merely a set of laminated cards that the astronaut flips through to find a particular task. While this system is reliable, it is severely limited in the amount of information it can contain and the speed at which an astronaut can find specific information.

Advances in flexible electronics are leading to wearable displays that could be integrated into the outer garment of the EMU. Flexible display research has not resulted in appropriate commercial products yet, but display industry leaders are investing heavily to bring the technology to market. A flexible, wearable display could provide dynamic, complex visual output in addition to detailed checklists – it could support mapping and navigation, real time status indicators, images and video from robots and other astronauts, or animations to complement text instructions.

Tactile Feedback

EVA suits severely limit the tactile feedback that we normally take for granted. This can cause problems because it requires the astronaut to visually locate, identify, and operate tools and other objects when a non-suited person would do these things by touch. When performing simple actions such as grabbing or pressing, astronauts performing EVA activities do not have the benefit of tactile response to gauge their actions. By wearing an inner glove embedded with vibrotactile or electrotactile aids, contact between the glove and other objects could be “passed through” the gloves, giving astronauts the ability to “feel” what they touch. The same inner glove could allow the astronaut to “feel” virtual controls by simulating button edges, tactile response, or different surfaces.



In January of 2010, Barron Associates and the University of Washington began work on a Tactile Data Entry System for astronauts wearing the bulky EMU gloves. Under the NASA Phase I SBIR, Barron and the University of Washington will show the feasibility of a glove-mounted tactile feedback system

for EVA data entry and quantify the benefit of such feedback. This system will use smart fabric technologies to integrate vibrotactile elements into the EVA glove. [7]

More EVA Applications

- Covering the exterior of the EMU or EVA suit with flexible solar cells would generate additional power, limiting the size of the fuel cells, batteries, or umbilical connectors currently required to operate the suit.
- Integrating piezoelectric elements at strategic locations in the fabric could harvest additional power from the EVAer's movements.
- Integrating a flashlight, laser pointer, rangefinder, or other tool into the glove of the EMU could improve efficiency and add capabilities.
- Integrating environmental sensors into the exterior of the EMU could keep help astronaut be more aware of their surroundings.
- Integrating biosensors onto the EVA suit's cooling undergarment would allow for more detailed physiological monitoring of crew members during stressful EVAs.

5.4.2. Intravehicular Activity (IVA)

Health Monitoring

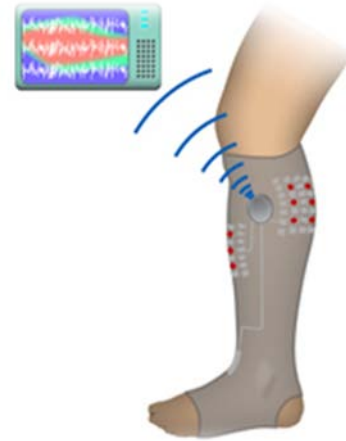
One of the major scientific goals of the International Space Station (ISS) is to understand how long duration exposure to the space environment affects the human body. Additionally, the challenges of treating illness in space make it critical for astronauts to monitor their own health and identify potential health problems early. Systems are currently in place on the ISS for astronauts to manually check and report important physiological data, but continuous health monitoring is only available in a limited capacity with some exercise equipment.

The Smart Fabrics research community has invested significant effort in the development of continuous, accurate, and comfortable physiological monitoring systems. As described in Section 5.2, commercial products for medical and sport applications have begun to enter the market over the past several years. The European Space Agency has invested in research to extend this capability to space through the Long Term Medical Survey (LTMS) and Intelligent Sock projects. QinetiQ North America, in partnership with the US Army, has also made important advances in the comfortable integration of physiological sensors into garments.



Through a partnership with the Swiss Centre Suisse d'Electronique et de Microtechnique (CSEM), ESA has developed and tested multiple iterations of the LTMS. This system is designed to be comfortably worn for up to 24 hours and to record ECG, respiration, pulse oximetry, core body temperature, blood pressure, and activity/posture. Since 2008, a prototype has been used by crewmembers of the Concordia Station in Antarctica during winter over months and if the latest prototype evaluations prove successful, the LTMS is expected to require very little modification to be used for human spaceflight. [8]

ESA has partnered with a small smart fabric design company in Denmark called Ohmatex to develop the Intelligent Sock project. This system is designed to monitor the effectiveness of various training aids and astronaut workout methods. The sock will map the electrical and metabolic activity in astronauts' leg muscles as they exercise, taking advantage of wearable sensing technologies developed under the European Commission's Smart Fabrics and Intelligent Textiles research. A prototype will be evaluated in late 2010 and early 2011. [9]



Wearable Control and Feedback

Smart Fabrics could enable astronauts to remotely communicate, control, and receive feedback from systems they would otherwise need to physically approach. Using flexible electronics integrated into their clothing, astronauts could have continuous access to critical functions, science experiments, or simple conveniences. In darkness or low visibility, the astronaut would still be able to locate critical controls if they were attached to his or her clothing.

Smart Fabric technology could also lead to a practical wearable voice communication system to communicate with other crewmembers and mission control (similar to the communicator on the “Star Trek” series). Astronauts' clothing might also integrate a speaker and tactile feedback to announce caution and warning alarms. The same shirt could allow the astronaut to control exercise equipment, monitor science experiments, change the song on their music player, monitor time remaining for an automated task (e.g. data downlink or cooking), or know when the toilet is available.

5.4.3. Inflatable Habitats

A major part of an inflatable habitat's structure is a series of durable fabric layers that make up the outer wall. The layers are tightly folded at launch and then inflated at the habitat's destination to create safe living and working quarters. Outer fabric layers must withstand MMOD (micro-meteoroid/orbital debris) impacts and block radiation, while the inner layers must support the daily activities of the occupants. By integrating Smart Fabrics into the wall instead of traditional electronic components, engineers can install some systems on the ground and reduce the need for assembly in space. Additionally, flexible electronic systems make more efficient use of spacecraft volume – especially the irregular shapes of an inflatable habitat – than traditional, rigid electronics.

Without the constraints of a rigid exterior structure, Smart Fabric technology will have a profound impact on the construction, deployment, and capabilities of inflatable spacecraft modules. Conductive yarns woven into interior, intermediate, and exterior fabric layers can carry power and data and reduce the volume requirements of conductors. Textiles that sense distortion (e.g. flexing or stretching) can be integrated into fabric layers to provide real-time monitoring of MMOD impacts, inflation pressure, and deployment status. These monitors could also warn crew members about everyday hazards such as condensation or objects rubbing against the walls.

Lighting and crew controls could also be integrated into the fabric structure – organic or inorganic LED elements or electroluminescent wiring can be woven into interior layers, and capacitive or pressure-sensitive fabrics could be used for crew controls – these elements might otherwise have to be stowed and launched separately, then installed after the spacecraft module has been inflated. Integrating controls into fabric also negates the need for bulky, heavy enclosures, connectors, and wiring harnesses. The exterior layers of the spacecraft could have integrated photovoltaic cells, and intermediate layers could integrate carbon nanotube battery films for energy storage.

6. Future Expectations

Smart Fabric technologies are rapidly evolving from hobbyist toys and impractical stylistic elements into real, useful components that can change the way we interact with our environment. As collection of and access to data becomes more and more critical in space missions, Smart Fabric technologies can enable previously impossible capabilities. From ubiquitous sensing of spacecraft and crew members to considerable mass and volume savings, the technology has the capability to reshape the design of space missions.

Now is the time for NASA centers to begin serious research and development of Smart Fabric technologies and applications. Sustained collaboration with university research centers and small manufacturers of Smart Fabric devices will yield devices ready for flight in 5-10 years.

6.1. Potential Collaborations

Collaboration must occur at various levels to ensure that enabling technologies keep pace with applications. This means collaboration with researchers in the fields of nanoelectronics, flexible electronics, encapsulation technologies, printing technologies, carbon nanotubes, and textile manufacturing. Some possibilities include:

- DARPA – There have been dozens of DoD-sponsored projects researching wearable electronics and Smart Fabrics. Use of these outcomes and further collaboration with involved parties will yield advanced results with relatively little NASA resources.
- NASA Research Centers – Ames Research Center (ARC) and Langley Research Center (LaRC) both maintain contacts in the worlds of commercial and academic research and can serve as “ambassadors” that find technologies, manage research projects, and contribute results at the TRL 3-4 level, ready for application and integration.
- Academia – Penn State and the University of Illinois both have research centers that are working in fields relevant to Smart Fabrics. The Georgia Institute of Technology has human factors and

textile engineering programs that will provide valuable contributions to manufacturing techniques and usability.

- Private Corporations – There are dozens of companies that work with directly with Smart Fabrics or tangentially related fields. The bulk of these companies are European; NASA collaboration with US companies could help to level the playing field after a decade of heavy EU investment.

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