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10. Smart Textiles

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Abstract:

In every area of engineering and technology in the twenty-first century, product development has advanced significantly. In the race of such progress, textiles are not falling behind. The most interesting development in the textile and apparel industries is smart textiles.

The responses that can be sensed and intelligently analyzed by smart textiles include electrical, thermal, mechanical, chemical, magnetic, and responses from other sources. Three subcategories of intelligence exist, including passive smart textiles, active smart textiles, and very smart textiles. Sensors, data processing, actuators, accumulator and communication are the main five functionalities that can be distinguished in smart textiles.

However, it must be consistent with the purpose of clothes, including comfort, toughness, resistance to standard textile upkeep procedures and so forth. The possibility for it to enter our daily lives is enormous. It is now widely employed in a variety of industries, including those that involve healthcare and safety apparel, firefighting apparel, intelligence apparel, military apparel, e-textiles, bio-medical applications, sports apparel, protective apparel and space exploration.

Therefore, it is sometimes referred to as next-generation apparel. The purpose of this chapter is to provide an overview of smart textiles, including their varieties and uses.

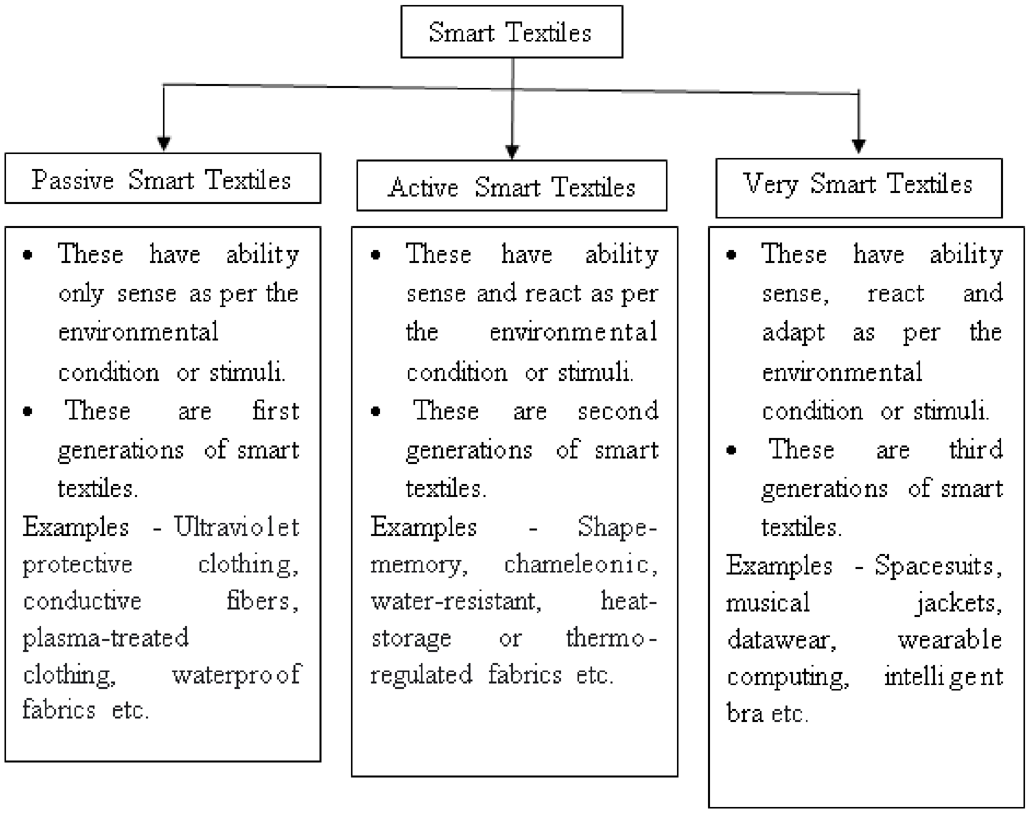
Keywords: Active smart textiles; passive smart textiles; smart textiles; very smart textiles.

10.1 Definition:

Smart textiles are textile items that can perceive and respond to changes in the environment or outside stimuli (from chemical, thermal, mechanical, or other sources, for example)[1]

[1] Koncar, V. (2016). Introduction to smart textiles and their applications. In V. Koncar, *Smart Textiles and their Applications* (pp. 1-8). Cambridge: Woodhead Publishing Series in Textiles.

10.2 Classification of Smart Textiles[2]:



10.2.1 Stages of Incorporation in Textiles:

Smart textiles must have a sensor, an actuator (for active smart textiles) and a controlling unit (for very smart textiles). These components may be fibre optics, phase change materials, shape memory materials, thermo chromic dyes, miniaturized electronic items etc. These components form an integrated part of the textile structure and can be incorporated into the substrate at any of the following levels –

a. Fibre spinning level: Components are incorporated in spinning dope or polymer chips prior to spinning.
b. Yarn/fabric formation level: The smartness of a textile can be improved by enhancing the smartness of yarn and by introducing active materials, sensors and activators etc. during fabric formation.

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[2] *https://www.uc.edu/content/dam/uc/ce/docs/OLLI/Page%20Content/Smart_textiles%20sm.pdf.* (n.d.). Retrieved 06 07, 2022

c. Finishing level: The smartness of a textile can be improved by applying some active finishes and synchronizing the electronic control units with each other can improve the smartness of textile material.

10.3 Functions of Smart Textiles[3]:

In general, smart textiles can be distinguished by five features. These include sensors, data processing, actuators, accumulator and communication. Although they all have a clear purpose, not every function is present at once in smart fabrics. They must be made of appropriate materials and have appropriate structures, and they must perform similarly to conventional clothing in terms of being long-lasting, pleasant, and resistant to standard textile upkeep procedures (washing, dry cleaning, drying, pressing, etc.).

A. Sensors:

A sensor converts a signal into another signal that a predetermined reader can read and comprehend (real device or person). In terms of actual equipment, the majority of signals eventually become electric ones. There are some real-world textile sensor examples for motion, respiration rate, and heart rate that produce results which are at least tolerable.[4]

B. Data Processing:

When active processing is required, data processing components are needed. Textile sensors provide enormous amounts of data, but the current challenge is in interpreting the data. The attachment of active components to fibres is the subject of research.[5] Real computer fibres won't be available on the market until a number of practical issues, like fastness to washing, deformation, interconnections, etc. are resolved.

C. Actuators:

Actuators react to an impulse produced by the sensor function, potentially after data processing. Actuators do a variety of tasks, such as moving objects, releasing chemicals, creating noise, etc. The most well-known examples in this field are shape memory materials. The Italian firm, Corpo Nove, in cooperation with d'Appolonia, developed the Oricalco Smart Shirt.[6]

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[3] Das, S. C. et al. (1-3 November,2013). Smart Textiles- New Possibilities in Textile Engineering. *International Conference on Mechanical, Industrial and Materials Engineering* . RUET, Rajshahi.

[4] Van Langenhove, L. et al. (25-27 June 2003). The use of textile electrodes in a hospital environment. *World Textile Conference-3rd Autex Conference* (pp. 286-290). Gdansk-Polen: ISBN 83-89003-32-5.

[5] *https://www.ibm.com/docs/en/zos-basic-skills?topic=channels-fiber-connection-ficon*. (n.d.). Retrieved 06 26, 2022

[6] https://www.researchgate.net/publication/330295435_Development_and_Applications_of_a_Smart_Textile_Actuator_by_Flat_Knitting_Technology. (n.d.). Retrieved 06 26, 2022

D. Accumulator:

Data or energy is typically accumulated by smart textiles. Energy is typically required in the form of electrical power for sensing, data processing, actuation, and communication. An optimal mix of energy supply and energy storage capability will make up efficient energy management. Sources of energy that are available to a garment are for instance body hear (Infineon[7]), mechanical motion (elastic from deformation of the fabrics, kinetic from body motion), radiation (solar energy[8]), etc.

E. Communication:

For intelligence textiles, communication can take many different forms. It may be necessary for a suit's constituent components to communicate with one another, for the wearer to give orders to the suit, or for the suit to communicate information to the wearer or his environment. Optical fibres[9] or conductive yarns[10] are currently used in the suit to facilitate communication. For example, the following technologies can be used to communicate with the wearer: optical fibres are a logical choice for the construction of a flexible textile screen. France Telecom[11] has managed to realize some prototypes (a sweater and a backpack).

10.4 Applications of Passive Smart Textiles:

A. Ultraviolet Protective Clothing:

The clothing that has the potential to reflect or absorb the harmful ultraviolet (UV) rays by the use of UV-absorbing compounds, bulked and microfibre constructions and passive heat retention with plentiful pores in textile products. Wearers of UV protective clothing may have a gradient Ultraviolet Protection Factor (UPF)[12]

B. Conductive Fibres:

A non-conductive or less conductive substrate, such as cotton, polyester, nylon, stainless steel, or high-performance fibres like aramids and polybenzoxazole (PBO), is the basis for conductive fibres. Electrically conductive materials, such as carbon, nickel, copper, gold,

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[7] Lauterbach, C. et al. (13–15 May 2002). Smart clothes self-powered by body heat. *Proceedings of 2002 2nd International Avantex Symposium.* Frankfurt, Germany.

[8] Chapman, K. (2002, September). High Tech fabrics for smart garments. *Concept 2 Consumer* , 15-19.

[9] Park, S.and Jayaraman, S. (9-11 July 2002). The wearable motherboard: the new class of adaptive and responsive textile structures . *International Interactive Textiles for the Warrior Conference.*

[10] Van Langenhove, L. et al. (1-3 July, 2002). Intelligent Textiles for children in a hospital environment. *2nd Autex Conference : Textile Engineering at the Dawn of a New Millenium.* Bruges, Belgium.

[11] Deflin, E., et al. (13-15 May 2002). Communicating Clothes: Optical Fiber fabric for a New Flexible Display. *AVANTEX Proceedings*

[12] Haerri H. P. and Haenzi D. (2002). UV absorbers for sun protective fabrics. *International Textile Bulletin* , 65-68.

silver, titanium, or poly3,4-ethylenedioxythiophene (PEDOT) are then coated or embedded into the substrate. Metals can be applied via physical vapour deposition techniques, printed using conductive nanoparticle inks or chemically deposited using autocatalytic chemistry.

Static dissipation, EMI shielding, signal and power transfer in low resistance versions and heating element in higher resistance versions are some applications for conductive fibres and fabrics[13].

C. Plasma-Treated Clothing:

As a highly reactive material, plasma can be used to change the surface of a particular substrate, impart desired qualities and remove contaminants. This process is known as plasma activation or plasma modification (plasma cleaning or plasma etching). Cleaning, activation, grafting and deposition are the four general processes that can be used to classify plasma processes. Using plasma technology, the adhesion properties of several polymers like polypropylene, polyethylene, polyamide and Teflon, can be enhanced to ensure the best possible contact with the adhesive or coating. Plasma will eliminate invisible oil films, tiny rust, and other impurities that frequently develop on surfaces as a result of stocking, previous manufacturing processes, or cleaning procedures. A substrate surface can be made hydrophilic using a carefully designed plasma activation method. Non-wovens and other textiles can have their surfaces plasma polymerized to make them hydrophobic. The use of gas plasmas to disinfect the surfaces of medical components or equipment is on the rise[14].

D. Ceramic Coated Textile:

Ceramic coating is a protective thin film that can significantly extend the useful life of all sorts of parts. As a result, production rises by lowering maintenance downtime and extending run durations between repairs. Ceramic coatings are formed of inorganic, non-metallic, solid, thin layers that are inert and may even be crystalline that are deposited, heated, and afterwards cooled. In other words, inorganic crystalline thin films are typically included in the definition of ceramic coatings. Physical deposition (such as magnetron sputtering deposition and plasma spraying process) and chemical deposition, such as electrochemical deposition, are the two main techniques used to create ceramic coatings. These techniques can have an impact on the microstructures and properties of the ceramic coatings. Currently, fluid ceramics are used as ceramic coatings for both heat protection and thermo ceramic construction[15].

10.5 Applications of Active Smart Textiles:

A. Shape Memory Materials:

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[13] https://en.wikipedia.org/wiki/Conductive_textile (n.d.). Retrieved 06 16, 2022
[14] Sisodia, N. and Bhargava, A. (2016). Plasma technology in textiles. Asian Journal of Home Science , 261-269.
[15] http://www.issp.ac.ru/ebooks/books/open/Ceramic_Coatings_Applications_in_Engineering.pdf. (n.d.). Retrieved 06 16 , 2022

Shape memory materials (SMMs) can withstand two or more different temperature states. After the application of an external stimulus, such as an increase in temperature, SMMs are able to memories a second, permanent shape in addition to their true, temporary shape. Shape memory polymers, such as polyurethane, polyester ether, styrene-butadiene copolymer, etc., have both hard (austenite phase) and soft (marten site phase) segments. This is such that the shape memory materials can be used in many ways in smart systems. These innovative performances include sensitivity, actuation, damping, and adaptive responses to outside inputs including temperature, illumination, stress, and field. Below and above the temperature (transformation temperature) at which it is active, a shape memory material has distinct features. In most shape memory materials, this phase transition can be triggered by a temperature change of just a 10ºC. The air spaces between neighboring layers of clothing are enlarged to provide better insulation when these shape memory materials are activated in clothing. As a result, the adaptability of the garment's ability to protect the wearer from excessive heat or cold is increased by the use of shape memory materials in clothing.[16]

B. Chameleonic Textiles:

Chameleonic textiles (are also called chromic textiles) are intelligent fabrics that adjust their color based on the surrounding environment. The term "chromic materials" refers generally to substances that emit color, obliterate color, or simply alter color as a result of external stimuli. Depending on the stimuli that affect them, chameleonic textiles can be categorized as follows:

a. Photochromic:

The external stimulus energy in these chameleonic textiles is light. Photochromism is the name of the phenomena that underlies these materials. Two categories can be used to distinguish photochromic fibres. The first group of fibres emit color when activated by visible light, and another group of fibres emit color when activated by UV radiation. Organic materials are the most popular because they are colorful, have a high density, and have a wide range of applications, even if both inorganic and organic materials can be employed in the first group.

Typically, organic photochromic materials don't exhibit this property when they are in their crystallized state; instead, they do so after melting in a solvent. The issue is that the nature of the solvent has a significant impact on both good and negative aspects of material behaviour, including color emission, reaction speed, resistance, density, etc. This makes it crucial to think about the appropriate solvent to employ before applying these components to fibres. While maintaining their original color when exposed to natural light, some fibres generate fluorescent colors like red, green, or blue when exposed to ultraviolet radiation in a dark environment. During the spinning process, the inorganic fluorescent paints used for this purpose are incorporated into the liquid at a rate of around 10%. It is significant to note

[16] Hayashi, S. (1995, 12 3-4). Properties and application of polyurethane-based shape memory polymer. University of Washington: US-Japan workshop on smart materials and structures.

that the color can be flexibly adjusted by combining different inorganic paints or by adding the paint to the thread's natural color.

b. Thermochromic:

The application of thermochromic dyes, whose colors change at specific temperatures, causes thermochromic materials to change their color in response to heat (external stimulus energy is heat). Two thermochromic system types that have been used successfully in smart textiles are liquid crystal and molecular rearrangement. Both times, the dyes are applied to the fabric of the garment in the form of microcapsules, much way a pigment is put to a resin binder. The so-called cholesteric kinds of liquid crystal, in which nearby molecules are organized to form helices, are the most significant types of liquid crystal for thermochromic systems. The liquid crystal's selective light reflection causes thermochromism. The liquid crystal's refractive index and the pitch of its molecules' helical arrangement control the wavelength of the reflected light. Temperature modifies the pitch length, which alters the wavelength of the reflected light and causes color changes. A different way to produce thermochromism is to cause a dye's molecular structure to rearrange due to a change in temperature. Although other forms have been developed, spirolactones are the most prevalent types of dye that display thermochromism by molecular rearrangement. Both a color developer and a precursor to a colorless dye are dissolved in an organic solvent. At lower temperatures, the solution becomes solid after being microencapsulated. At the mixture's melting point, the system either gains or loses color as it is heated. If the combination is then cooled, the change goes the other way. The general process underlying the changes in color is far from clear-cut and is still very much up for speculation, despite the fact that thermochromism through molecular rearrangement in dyes has generated some level of economic interest.

A. **Electrochromic:** In these chameleonic textiles, external stimuli energy is electricity.
B. **Piezorochromic:** External stimuli energy is pressure in these chameleonic fabrics.
C. **Solvatechromic:** External stimuli energy is liquid, like water, in these chameleonic textiles. Swimwear is made from these materials.
D. **Carsolchromic:** These chameleonic textiles use electron beams as external stimulus energy.

S. Nato[17] of Toray Industries announced the creation of a temperature-sensitive fabric in 1988 under the trade name SWAY by using microcapsules with a diameter of 3–4 m to contain heat-sensitive dyes that are uniformly covered with resin over the fabric surface. The microcapsule was made of glass and contained dyestuff, an electron acceptor (chromophore agent), and a color-neutralizer (alcohol, etc.), which reacted and changed color depending on the temperature of the surrounding air. SWAY featured a multicolor fabric with a base palette of 4 colors and 64 mixed colors. SWAY operates between -40 and 80ºC and can reversibly change color at temperatures greater than 5ºC. These textiles color-changing properties are created to complement the intended use, such as skiwear's 11–19°C

[17] Nato, S. (1989). Temperature-Sensitive Colouring Materials SWAY. *Sen-1 Kikai Gakkaishi* , 435-439.

operating range, women's clothing's 13–22°C operating range, and temperature shade 24-32°C operating range.

A cloth that changes color from white to blue when exposed to UV light with a wavelength range of 350–400 nm was created by T. Hongo and GO Philips for Kanebo Ltd.[18] The chemical compounds of the spropiran type that are utilized to make this sort of photochromic material are photolyzed, changing their color. Kanebo employed the stable compound spiropiran as a photochromic material due to the limited stability of spiropiran, and a T-shirt made of photochromic prompted fabric was released on the market in 1989.

An endothermic fabric was utilized in a Japanese Patent[19] to shift colour from green (below 15° C) to colorless (above 15° C). Within a specified temperature range, the cloth can stably change color, successfully absorb near-infrared rays solely in the color-changed state, develop heat-absorbing characteristics, and impart a sense of warmth. Hanks, Samuels, and

Gregory[20] investigated how tunable molecular and oligomeric devices could change colour dynamically. They came up with a quick, low-cost method of attaching chromophores to the surfaces of polymers, particularly polyaniline, polypyrrole, polythiophene, and poly (ethylene-dioxythiophene). The researchers only looked at how an electric field affected a substance that was either coated on a fibre or contained one.

A garment created by Danial Cooper is practical for shielding the wearer from smog. Monitors for nitrogen oxide, sulphur dioxide, and ozone are woven into the nylon fabric that makes up the front panels. The fabric's colour shifts from blue to orange in the presence of pollution.[21]

C. Heat-Storage or Thermo-Regulated Fabrics:

Heat storage or thermoregulated textiles also known as innovative comfort textiles can absorb, distribute, and release heat through phase shift in low melting point materials in response to changes in ambient temperature. National Aeronautics and Space Administration NASA intended to warm the pilot's hands by encasing the phase change materials (PCMs) in gloves. On the basis of heat-absorbing and temperature-regulating technologies, NASA created textiles that aimed to increase the protection of sensors and astronauts against high temperature variations in space.

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18 Russel, D. A. (1999). Potential uses of Shape Memory films in clothing. *Technical Textile International* , 17.
19 Koji, I. (1993). Reversible Colour Changing Endothermic Fabric. *JP 5009868* .
20 Gregory, R., & Samuels, R. a. (M-98 C01). *Chameleon Fibres.* US National Textile Centre Annual Report.
21 Bradock, S. E. & Mohony, M.O. a. (1999). *Techno-Textiles Revolutionary Fabrics for Fashion and Design.* Thomes and Hudson Annual Report.

In order to create a thermally active fabric with a 30–50% additive, Vigo et al.[22] completed a polyester/cotton fabric with polyethylene glycol (PEG) as PCMs and dimethyloldihdroxy-ethyleneurea (DMDHEU).

In the 1980s, The Triangle Research and Development Corporation USA[23] reported in a patent that the surface of woven, knitted, and nonwoven fabrics may be treated with solution-containing microcapsules.

Lennox K. P.[24] inserted 6-7 percent by weight of PCMs microcapsule during wet spinning poly-acrylonitrile (PAN) fibre.

Because the melt viscosity of textile grade PCMs is still lower than necessary, it is exceedingly challenging to make composite fibre by melt spinning with PCMs as the sole component. They are incapable of having the necessary spinnability. Heat-absorbing and temperature-regulating fibre can be spun via core-sheath spinning after PCMs and PEG with an appropriate molecular weight are combined. Micro PCM-containing melt-spun thermo regulated fibre has been researched by Watanabe.[25]

10.6 Applications of Very Smart Textiles[26]:

E. Spacesuits:

In order to minimize overheating, the initial versions of the Apollo spacesuits had an inner layer of nylon fabric and a network of thin-walled plastic tubes that circulated cooling water around the astronaut. A three-layer system later, the pressure garment was created. The inner layer was a comfort layer made of thin nylon with fabric ventilation ducts. Then, four spacing layers of Dacron were combined with aluminized Mylar for heat protection. These were protected from abrasion and flame by a Teflon-coated beta cloth covering. Teflon communication cloth made up the top layer. A life support system including oxygen, water, and radio communications was built within the backpack unit.

F. Musical Jackets:

An ordinary jacket is transformed into a wearable musical instrument via a musical jacket. Any instrument that is available in the general musical scheme can be used to play notes, chords, rhythms, and accompaniment when wearing a musical jacket. To power these components, it incorporates a fabric keypad, a sequencer, a synthesizer, amplifying speakers, conductive organza, and batteries. The smart suit is made up of electrically heated fabric panels for warmth, a global mobile system for communication, and a functional

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[22] Vigo, T. L. (1986). *Patent No. US 81857C.* US Patent.
[23] Colvin, D. (26-28 April 2000). A concept for cool microclimate garments for Triangle R & D Corp. USA. *2nd International Conference on Safety & Protective Clothing.*
[24] Lennox, K. P. (1998). Space-age technology to keep us comfortable. *Technical Textile International* , 25-26.
[25] Watanabe, T. (1993). Endothermic and Exothermic Conjugate Fire. JP 5-5215 .
[26] https://www.technicaltextile.net/articles/smart-textile-2592. (n.d.). Retrieved 06 19, 2022

architecture for navigation. The sensor system consists of two impair detecting sensors, an electrical conductivity sensor, a heart rate sensor, three position and movement sensors, ten temperature sensors, and a sensor for measuring temperature. A user interface (UI), a central processor unit (CPU), and a power source are needed for the implementations and synchronization. Except for the sensors and the user interface, every major module is installed inside the supporting vests. Group communication is simple, quick, and economical with this elegant outfit. The belt has a microphone, loudspeaker, and cell phone built in. Groups of individuals can communicate by pulling a tag off this belt.

G. Data Wear:

Each bodily joint has sensors built into the data wear that plot the position of each joint on a graph that a computer can calculate. Conductive elastane is used to create the sensors. The TCAS (maker) system examines the angle of each of these joints to determine the absolute position of the data wear clothing's magnetic position sensors (i.e. of each of the limbs). The placement of the sensors can be tailored to the needs of each application. The coats, pants, and gloves that make up the data wear body unit are electrically circuited or wired to communicate with computers. Data wear is used to monitor limb position in computer data, medical imaging, measurements, ergonomics, biomechanics, robotics, and animation. Data wear can monitor the entire body, which has special application in the study of sports injuries and biomechanics.

H. Wearable Computing:

Researchers at MIT in the USA have developed electronic circuits that transfer power and data solely via fabrics. They are capable of touch detection and employ passive electronic components as well as those made of conductive yarns. This produces interactive electrical gadgets like graphic input surfaces and musical keyboards. In the future, complete computers could be constructed from clothing-related textiles. In that regard, these electronic circuits represent a modest first step. Silk organza, which has two different types of strands, was the first conductive fabric tested. A plain silk thread runs on the warp, and a silk thread covered in thin copper foil runs in the opposite way on the weft. This highly conductive metallic yarn is manufactured similarly to cloth-core telephone cable. The silk fibre core can endure high temperatures and has a high tensile strength. This makes it possible to use commercial machinery to stitch or embroider with the yarn. Because of the distance between the threads, each one may be cared for separately, making a strip of this fabric similar to a ribbon cable. Organza-based circuits merely need to be shielded from folding contact with one another, which can be done by covering, supporting, or backing the fabric with an insulating layer that is also made of cloth. Additionally, conductive yarns made expressly for making filters for processing tiny particles are available.

Conduit and textile fibres are scattered among these threads. Different resistivities result from different ratios of the two constituent fibres. These fibres can be stitched together to make resistive and conductive parts. Although some parts, such resistors, capacitors, and coils, can be sewed into fabric, other parts still need to be attached to the fabric. Soldering straight to the metallic yarn will do this. It is simple to solder surface mount LEDs, crystals, piezo transducers, and other surface mount components into the fabric if their pad spacing is more than 0.100 inch. After the components are joined, it might be necessary to mechanically reinforce their connections to the metallic yarn. Acrylic or another flexible coating can be used to accomplish this. Specifically formed feet could be created to make it easier to sew components with regular leads straight into circuits on fabric. Gripper snaps work well as connections between the electronics and the fabric.

A fairly strong electrical contact is made when the snap pierces the yarn. Additionally, it offers a nice surface for soldering. Subsystems can be quickly snapped into garments or taken off for washing in this fashion.

To date, a number of circuits have been created on and with fabric, including touch-sensitive microcontroller systems, all-fabric keyboards, and buses to link different digital devices. This kind of system construction makes it simple because parts can be connected directly to the conductive yarn. Fabric is an excellent material for prototyping since it can be easily cut where signal lines should stop and its conductors are addressable. Capacitive sensing, which uses a collection of embroidered or silk-screened electrodes as the points of touch, can also be used to create keyboards in a single layer of fabric. The rise in the electrode's overall capacitance can be used to detect when a finger makes contact with it. It is important to note that this can be accomplished using a leakage resistor sewed in highly resistant yarn and a single bidirectional digital I/O pin for each electrode. Because the signal changes with pressure, capacitive sensor arrays can also be used to determine how well a piece of clothing fits the wearer.

The keypad is adaptable, strong, and touch-sensitive. The parts required to perform capacitive sensing and output key press events as a serial data stream are supported by a printed circuit board. Only at the bottom of the electrode pattern does the circuit board establish physical contact with the electrodes at the circular pads. Sewing machines or textile factories may make all of the input devices out of fabric. It is simple to scale the size of these textile-based sensors, buttons, and switches. In contrast to most current, delicate touch sensors, which must remain flat to function at all, they may also adapt to any required shape. Typical textile snaps and fasteners can be used to join together subsystems. When exposed to grime, they can be cleaned by washing them like conventional clothes.

I. Intelligent Bra:

The University of Wollon in Australia is creating a smart bra that can alter its characteristics in reaction to breast movement. When active women are in motion, this bra will offer better support. Smart bras have adjustable straps and cups that may be stiffened and relaxed to limit breast movements and prevent soreness and sagging. In order to make smart bras, conductive polymer coated materials are used. The conductive polymer deposited on the primary cloth can detect the strain being applied to it. Depending on the amount of strain they are under, the textiles' elasticity may change. When it detects excessive movement, the smart bra can rapidly tighten and loosen its straps or stiffen its cups.

10.7 References:

1. https://www.sciencedirect.com/topics/engineering/smart-textile accessed on 07 June 2022
2. https://www.uc.edu/content/dam/uc/ce/docs/OLLI/Page%20Content/Smart_textiles%20sm.pdf accessed on 07 June 2022
3. S. C. Das, D. Paul, S. M. M. Hasan, N. Chowdhury, M. E. H. Nizam, Smart Textiles-New Possibilities in Textile Engineering, International Conference on Mechanical, Industrial and Materials Engineering 2013 (ICMIME2013)1-3 November, 2013, RUET, Rajshahi, Bangladesh, Page no. 514-519
4. L.Van Langenhove, C. Hertleer, M. Catrysse, R. Puers, H. Van Egmond, D. Matthys, “The use of textile electrodes in a hospital environment”, *World Textile Conference-3rd Autex Conference*, Gdansk-Polen, ISBN 83-89003-32-5, pp. 286-290, 25-27 June 2003.
5. Ficon project (http://www.fibercomputing.net)
6. http://textile.t4tech.com/Application.asp#
7. C. Lauterbach et al, Smart Clothes self-powered by body heat, *AVANTEX Proceedings*, 15 May 2002.
8. K. Chapman, High Tech fabrics for smart garments, Concept 2 Consumer, pp. 15-19, September 2002.
9. S. Park, S. Jayaraman, The wearable motherboard: the new class of adaptive and responsive textile structures, International Interactive Textiles for the Warrior Conference, 9-11 July 2002.
10. L. Van Langenhove et al, Intelligent Textiles for children in a hospital environment, *World Textile Conference Proceedings*, pp. 44-48, 1-3 July 2002.
11. E. Deflin, A. Weill, V. Koncar, “Communicating Clothes: Optical Fiber fabric for a New Flexible Display”, *AVANTEX Proceedings*, 13-15 May 2002.
12. H. P. Haerri and D. Haenzi, UV absorbers for sun protective fabrics, International Textile Bulletin, 5/2002, 65-68.
13. https://en.wikipedia.org/wiki/Conductive_textile accessed on 16 June 2022
14. Nidhi Sisodia and Abha Bhargava, Plasma technology in textiles, *Asian Journal of Home Science,* Volume 11 | Issue 1 | June, 2016 | 261-269
15. http://www.issp.ac.ru/ebooks/books/open/Ceramic_Coatings_Applications_in_Engineering.pdf accessed on 16 June 2022
16. S. Hayashi, “Properties and application of polyurethane-based shape memory polymer”, US-Japan workshop on smart materials and structures held at University of Washington, Dec. 3-4, 1995.
17. S. Nato, Temperature-Sensitive Colouring Materials SWAY. Sen-1 Kikai Gakkaishi (1989) 42 (9) 435-439
18. 7 D.A. Russel Potential uses of Shape Memory films in clothing Technical Textile International October 1999, 17
19. I. Koji, “Reversible Color Changing Endothermic Fabric”. JP 5009868 (1993)
20. R Gregory, R. Samuels and T. Hanks “Chameleon Fibres" US National Textile Centre Annual Report M-98 C01
21. S.E. Bradock, MO Mohony "Techno-Textiles Revolutionary Fabrics for Fashion and Design" Thomes and Hudson Annual Report 1999, 34, 141
22. T.L. Vigo, C.M. Fost, "Temperature Adaptable Textile Fibres" US Patent US 81857C (1986)

23. D.P. Colvin "A concept for cool microclimate garments for Triangle R&D Corp USA, 2nd International Conference on Safety & Protective Clothing, April 26-28, 2000
24. K.P. Lennox, "Space-age technology to keep us comfortable" Technical Textile International 1998, 7(7) 25-26
25. T. Watanabe "Endothermic and Exothermic Conjugate Fire" JP 5-5215 (1993)
26. https://www.technicaltextile.net/articles/smart-textile-2592 accessed on 19 June 2022.