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THE APPLICATIONS AND IMPACTS OF NANO TECHNOLOGY ON TEXTILE FABRICS

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ABSTRACT

This is a review of the impacts and influence of nanotechnology on textile fabrics in the past, present, and future expectations of this technology in the field of textiles. Nanotechnology encompasses the study and applications of very small materials, which can be within the range of (1-100) nm. As small as the materials could be, every individual property of the materials will still be engineered to develop the desired characteristics needed to make a fabric an interactive textile. Nanotechnology has a wide range of applications in other fields, but this study is based on the textile field. Nanotechnology impacts its functions on textiles through the incorporation of nano materials, which transforms such textiles into "Smart textiles". The sensing, actuating, data processing, storage, and communication functions make these smart fabrics applicable in areas like health, security (military/defence), and in fashion and entertainment industries. The recent developments of nanotechnology in the textile field are also a vital aspect that is considered in this paper.

Keywords: *Nanotechnology, Interactive textile, Incorporation, Smart textiles.*

1.0 INTRODUCTION

Nanotechnology is a growing interdisciplinary technology often seen as a new industrial revolution. Nanotechnology (NT) deals with materials 1 to 100 nm in length. The fundamentals of nanotechnology lie in the fact that the properties of materials drastically change when their dimensions are reduced to the nanometre scale. Nowadays also the textile industry has also discovered the possibilities of nanotechnology. So, we can define nanotechnology in textile as the understanding, manipulation, and control of matter at the above-stated length, such that the physical, chemical, and biological properties of the materials (individual atoms, molecules, and bulk matter) can be engineered, synthesized, and altered to develop the next generation of improved materials, devices, structures, and systems. It is used to develop desired textile characteristics, such as high tensile strength, unique surface structure, soft hand, durability, water repellency, fire retardancy, antimicrobial properties, and the like (fibre2fashion.com).

Nanotechnology has potential applications in computers (nano chips), aerospace (launch vehicles, nanotubes), colourants, biotechnology and in various other fields. Nanotechnology is, without doubt, the technology of the future. In the field of textiles, nanotechnology has been employed in the synthesis of quantum dots (semiconductor nanocrystals). Dye molecules are used to colour fibres. In nanocrystals, the colour changes with an increase in particle size. It is thus possible to create different-sized particles from a single material having different optical properties that cover the entire visible region (Technicaltextile.net).

Nano stands for one billionth (10^{-9}) of a metre. This defines the length that is, for these materials, important in some way, influencing their mechanical, thermal, electrical, magnetic, optical, and aesthetic properties (Michael *et al.,* 2009).

According to the National Nanotechnology Initiative (NNI) point of view, nano-technology is characterised as the exploitation of structures with at least one dimension of nanometre size for the manufacture of materials, devices or structures with original or significantly improved properties due to their nano-size (Wang *et al.,* 2006). Nanotechnology not only produces miniature structures, but also an expected mechanised technology which can offer thorough, inexpensive control of the structure of matter. Most importantly, nanotechnology can be described as activities at the level of atoms and molecules which have applications in real life. The nanoparticles are frequently used in profitable products in the range of 1 to 100 nm (Sawney *et al.,* 2008).

The incorporation of nanotechnology enables the manufacture of smart and multi-functional textiles with many innovative applications in the areas of health, pharmaceuticals, fashion, sports, military, advanced protection and transportation (Peira *et al.,* 2020; J Cheng *et al.,* 2018). The connection to the 'internet of things' offers yet further potential for advanced uses. Fabrication of microelectronic devices is now at a level where they can be combined into textiles and allow the unique capabilities of nanomaterials to be exploited to add high added-value functionality to fabrics and garments while retaining other desirable properties, such as comfort, flexibility, lightness and aesthetic appearance (Ahmadi, 2019; Fateixia *et al.,* 2019). Smart textiles (Figure 1) are defined as textiles that can sense and react to environmental conditions or stimuli, from mechanical, thermal, magnetic, chemical, electrical, or other sources. They can sense and respond to external conditions (stimuli) in a predetermined way. Textile products which can act differently from an average fabric and are mostly able to perform a special function certainly count as smart textiles. (fibre2fashion.com)

Many textile materials, such as cotton, silk or polyester, are ideal substrates on which to integrate smart, functional nanomaterials (Yetisen *et al.,* 2016). Various approaches have been developed to incorporate nanomaterials into textiles. The 'bottom-up' approach is used during the production of fibres from which the fabrics are manufactured. By contrast, the 'top-down' approach is applied at the finishing stages, for example, by printing technologies, spray coating, or impregnation. Electrospinning is a relatively new method for producing fibres and fabrics from processed raw materials and is ideal for fabricating nanofibres (Pereira *et al.,* 2020; Ahmadi, 2018).

1.1 Historical development

The term nanotechnology was first used in 1974 by Norio Taniguchi to refer to the precise and accurate tolerances required for machining and finishing materials. In 1981, Drexler, now at the Foresight Nanotechnology Institute for Molecular Manufacturing, described a new "bottom-up" approach, instead of the top-down approach discussed earlier by Feynman and Taniguchi 50 years before then. The bottom-up approach involved molecular manipulation and molecular engineering to build molecular machines and molecular devices with atomic precision. In 1986, Drexler published a book, Engines of Creativity, which finally popularised the term nanotechnology. The term nano derives from the Greek word for dwarf. It is used as a prefix for any unit, such as a second or a meter, and it means a billionth of that unit. Hence, a nanometer (nm) is a billionth of a meter, or 10^{-9} meters. To get a perspective of the scale of a nanometer, observe the sequence of images shown in Figure 2 (Michael *et al.,* 2009).

The basic materials needed to construct e-textiles, such as conductive threads and fabrics, have been around for over 1,000 years. In particular, artisans have been wrapping fine metal foils, most often gold and silver, around fabric threads for centuries (Marvin, 1990). Many of Queen Elizabeth I's gowns, for example, are embroidered with gold-wrapped threads. It is impossible to talk about smart textiles without talking about electronic textiles. Electronic textiles are fabrics that have some digital or electronic components in them.

The difference between smart textiles and electronic fabrics is that smart textiles actually need to have a use to them- it has to benefit the person wearing it in some way. Meanwhile, electronic fabrics only need to have a digital component and do not have to benefit the user in any way. Electronic textiles have been around for longer than you would think. By the end of the 19th century, designers started to combine electronics with fashion. For example, there was an evening gown adorned with small electronic light bulbs. This technology continued to develop into the LED t-shirts we know and love today (Elizabeth, 2021).

The start of smart textiles didn't happen until the mid-1990s when a group of researchers from MIT, led by Steve Mann, Thard Starner, and Sandy Pentland, wanted to create wearable computers. Their research led to the development of the Lilypad Arduino, which was one of the first tiny washable computers that could be attached to clothes and power projects. In the beginning, devices like this were also just used to light up clothes. But soon the world of smart textiles began to grow (Gregory *et al.,* 2001).

Table 1 lists other major milestones in the journey of the smart textile, as identified by Global Data.

2.0 HOW TEXTILES ARE MADE

Smart textiles can be made by incorporating smart materials, conductive polymers, encapsulated phase change materials, shape memory polymers and materials and other electronic sensors and communication equipment. These materials interact, according to their designed feature, with the stimuli in their environment. All smart materials involve an energy transfer from the stimulus to the response given out by the material. They are integrated and complex materials. They can do some sort of processing, analysing and responding. They can even adapt to the environment. They have the full ability to change themselves depending on temperature, pressure, density, or internal energy, change (innovationintextiles.com). The amount of energy transferred to make this change is determined by the properties of the material.

Table 1: Innovative Smart Clothing Timeline 1985-2020

Year	Event
1985	Harry Wainwright created a sweatshirt that displayed full-colour cartoon animations.
1994	Jaap Haartsen of Ericsson developed the Bluetooth wireless technology standard.
1995	Harry Wainwright invented the first machine to integrate fibre optics into fabrics.
1997	A computerised machine that implanted fibre optics into any flexible material, including textiles, was developed.
1999	The first consumer Bluetooth device was launched.
2005	Harry Wainwright and his colleague David Bychkov created a jacket that offered electrocardiogram (ECG) readings.
2006	BAE Systems started evaluating infrared displays embedded into fabrics for use in military garments.
2015	Google announced Project Jacquard, part of its Advanced Technology and Projects (ATAP) division.
2016	Arrow launched a smart shirt with a near-field communication (NFC) chip to pair it with Android smartphones.
2017	Google and Levi's launched the Commuter Trucker jacket, featuring conductive fibre and Bluetooth connectivity. Owlet launched smart socks for parents to monitor the sleeping patterns of newborn babies.
2018	Nike applied for two smart clothing patents: a self-cleaning shoe and a sensor-integrated yoga suit. Tommy Hilfiger launched the Tommy Jeans Xplore smart clothing line. Samsung demonstrated its SmartSuit, designed for short-track speed skaters.
2019	Chico's FAS launched a Bluetooth-connected smart bra. Samsung applied for a patent for a smart shirt to track symptoms of diseases like pneumonia and bronchitis. Nike introduced the Adapt self-lacing shoes.
2020	Under Armour launched smart shoes with sensors to provide real-time analysis of running metrics.

This relationship between the amount of energy required and the degree of the specific change governs the behaviour of all materials, including smart ones. If they get energy or any stimuli from the outer environment, they do not make any change to it. They just resist it or absorb it. For example, a material's specific heat (property) will determine how much heat (energy) is needed to change its temperature by a specified amount (Wong *et al.,* 2006).

Adidas partnered with Google to use the Jacquard technology in GMR insoles for football players, and also Xenoma launched smart pyjamas that monitor the user's heart rate and sleep patterns and detect falls or trips.

As with any industry, it's important to learn from the past as we move into a strong future for e-textiles. Thanks to institutions like the University of North Carolina, Drexel and MIT, the future looks bright for innovation in the e-textiles space (medium.com, 2016; fashioninovation.nyc, 2021; fashnerd.com, 2017; retail-insight-network.com, 2023).

The electronic control components of fabrics can be synchronised with each other during finishing. Techniques such as microencapsulation are generally preferred for the incorporation of smartness-imparting material in the textile substrate. These components form an integrated part of the textile structure and can be incorporated into the substrate at any of the levels, namely: fibre spinning level; yarn/fabric formation level; finishing level (Stegmaier, 2012).

3.0 CLASSIFICATION OF SMART TEXTILES

There are several categories of smart textiles in literature, but one of the most widely accepted classifications is based on the aesthetics and performance functions of the garments.

3.1 Aesthetic smart textiles

Because of their capacity to light up and change colour, intelligent aesthetic fabrics are used in the fashion industry. Light-emitting clothing and bright gowns are typical and commercial applications for aesthetic, smart textiles.

3.2 Performance smart textiles

Smart textiles are categorised into three types based on their performance: passive, active, and ultra-smart.

3.2.1 Passive fabrics

Passive intelligent textiles are the initial generation of smart textiles that detect external circumstances, such as UV-protective clothing, conductive fibers, and so on. Because they are merely sensors, passive smart textiles can only perceive their surroundings. Passive smart fabrics sometimes called the "first generation" of intelligent textiles, have functionality beyond standard ones. However, it should be noted that passive materials do not typically adapt due to the information they feel. In other words, when environmental circumstances change, the cloth remains the same. A cooling cloth, for example, may assist in controlling body temperature but does not actively produce coolness. Because of the structure of the fabric, it simply aids in the faster evaporation of liquid. The same is valid for clothing and other items that include UV protection, anti-microbial, and anti-static features.

3.2.2 Active fabrics

Active smart textiles adapt and modify their functioning in reaction to changes in the external environment or human input, such as motion or weather. These fabrics can alter their shape, store and control heat, and perform other functions.

While passive textiles depend on their structure, active fabrics rely on electricity to support actuators and sensors. These actuators and sensors enable the intelligent material to detect touch and temperature and analyze and interpret a wide range of environmental data.

3.2.3 Ultra smart fabrics

Ultra smart fabrics perceive, react, and adapt to environmental situations the same way as active smart textiles do, but they go a step further. Ultra smart textiles are materials that detect, respond, monitor, and adapt to stimuli or environmental conditions such as thermal, mechanical, chemical, magnetic, or other sources. An ultra-smart textile is made up of a unit that functions similarly to a brain, with cognition, reasoning, and activation capabilities" (Thalia, 2021; Kenedy and Bunko, 2019).

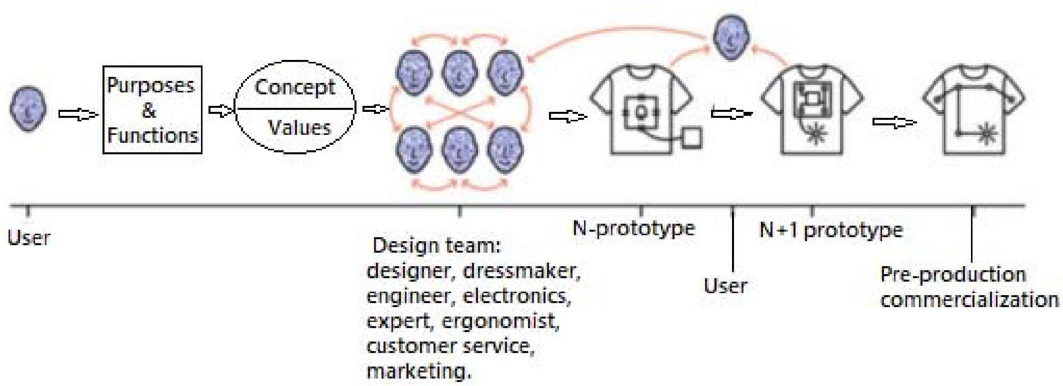

Fig. 1: The making of smart textile (Source: Sable Chaud-Modelab 2017)

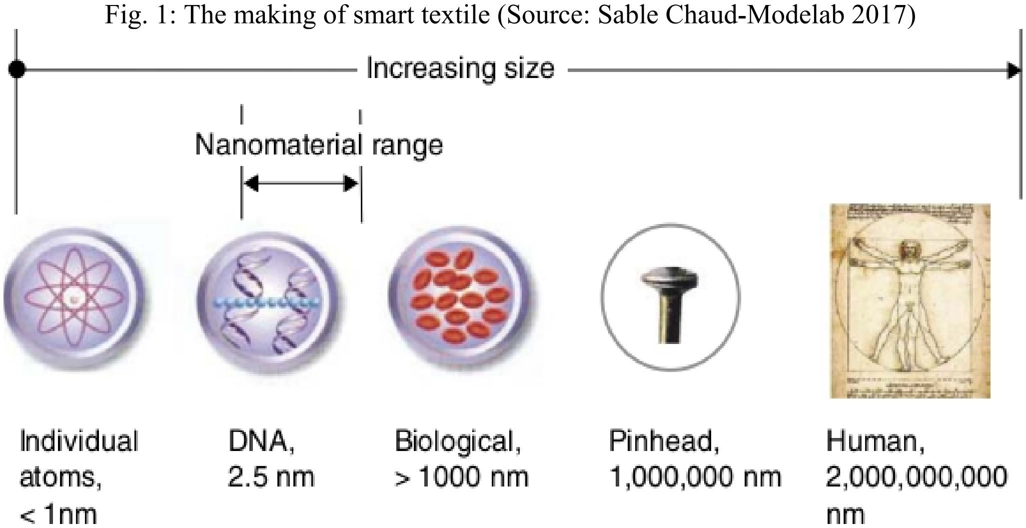

Fig. 2: Sequence of images showing the various levels of Scale. (Adapted from Interagency Working Group on Nanoscience, Engineering and Technology National Science and Technology Council Committee on Technology, "Nanotechnology Shaping the World Atom by Atom." Sept. 1999) (Michael *et al.*, 2009).

4.0 FUNCTIONS OF SMART TEXTILES

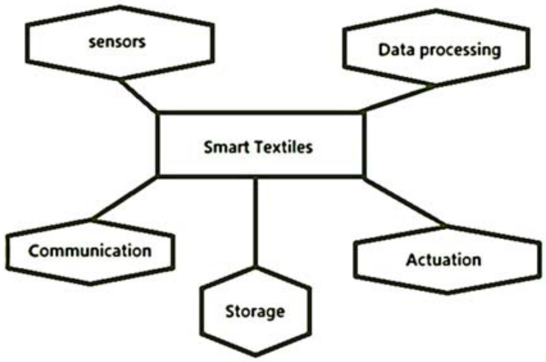

Fig. 3: The five functions of smart textile

Smart textiles function (Figure 3) in a variety of ways, depending on the need for their Production. They can both perceive or communicate the environmental conditions and can detect and process the wearer's condition. They can use electrical, heat, mechanical, chemical, magnetic, and other detection systems to detect them. Smart garments are separated from wearable computing systems by revealing the importance of the garment on which they are integrated. Wearable computing systems are formed by attaching the traditional systems to the garment in some way. The equipment used is placed in non-textile ways without being integrated. Although some electronic materials have been reduced to be used in garments, the actual smart garments should use materials made entirely by textile production. The electronic materials to be placed must not impair the comfort of the standard textile material garment. Therefore, providing this combination is vital for wearability in smart garment and textile manufacturing. It is clear that smart textiles are simple computer systems and have five functions basically as sensors, data processing, actuators, storage, and communication. But it must be compatible with the function of clothing, such as comfort, durability, resistance to regular textile maintenance processes, and so on (Cherenack *et al.,* 2012; Castano *et al.,* 2014)

4.1 Sensors

Sensors are the components that transform one type of signal into another type of signal. There are already systems in textiles that measure heart rate, breath rate, temperature, movement, and moisture, but these systems work with the installation of traditional sensors in textiles. At the present stage of intelligent textiles, the sensors are produced from real textile material, and the heart, breath, and movement sensitive sensors are already produced with satisfactory results. Different materials and structures have the capacity to transform signals:

4.1.1Thermal sensors: a thermal sensor detects thermal change, for example, a thermistor that changes resistance due to thermal change. Another example is the stimuli-responsive hydrogels that swell in response to a thermal change.

4.1.2 Light sensors: these sensors convert light energy into a voltage output, for example, photo-resistors.

4.1.3 Sound sensors: these convert sound into an electrical signal, for example, piezoelectric materials.

4.1.4 Humidity sensors: these sensors measure absolute or relative humidity. An example that can be interesting for textile use is the capacitive device that changes dielectric properties with the absorption of moisture.

4.1.5 Pressure sensors: These sensors convert pressure to an electrical signal. A pressure sensor can be based on simple operations such as opening or closing a circuit. But they may also be based on more sophisticated forms like capacitive or piezoelectric phenomena.

4.1.6 Strain sensors: these sensors convert strain into an electrical signal. Strain sensors may be based on semiconducting materials, strain-sensing structures, or piezoelectric effects.

4.1.7 Chemical sensors: these are a series of sensors that detect the presence and/or concentration of chemical/chemicals.

4.1.8 Biosensor: It is a sensing device that contains biological elements, which are the primary sensing elements. This element responds with a property change to an input analyte, for example, the sensing of blood glucose levels (Kallmayer *et al.,* 2012; Sergio *et al.,* 2003; Cho *et al.,* 2011).

4.2 Data processing

Data processing is one of the components that is required only when active processing is necessary. According to information theory, it is necessary to process every collected information and data and obtain the desired output. Therefore, to obtain the desired output by processing the parameters collected by the sensors, a processor suitable for the relevant purpose is required in smart textiles. The information processing element is only needed when the textile is actively processing information. Textile sensors can provide information to a large extent, but the main problem lies in how the information is evaluated and the processor component comes to the fore. Variation of signals and analysis of signals are the main problems for data processors. Furthermore, the energy required for the processor is another problem encountered today. Since the electronic components required for energy do not have sufficient smallness and flexibility, they differ from the structure of the textile. The waterproofing requirement of these energy units and other electronic units is another problem. However, these problems are generally seen more in the garment-type smart textiles. In the case of vehicles, this is not a problem; the information processing elements can be mounted inside the vehicle (Sergio *et al.,* 2003; Kim *et al.,* 2009).

4.3 Actuators

Actuators are the devices designed to perform the necessary action according to signals from the sensor or processor. These devices are also called actuators. Actuators act by an effect sent from the sensor and possibly by first passing this effect through an information processor to perform actions such as moving objects, releasing materials, and making noise. Shape memory materials are the best examples in this field. Shape memory alloys can be formed in the form of a lattice. Its responsiveness to heat changes enables shape memory materials to be used as an actuator and meets the requirements of intelligent textiles very well.

Another type of actuator is the materials that are capable of releasing certain chemicals under certain conditions, which can be trapped in protective microcapsules or chemically bound to the fibre polymer. Such secretory materials have various commercial applications. Odours, skin protectors, antimicrobial products, and so on. Application studies have been started with active secretion methods and some simple projects have been implemented yet. It is contemplated that the release will be affected by triggering other environment variables such as temperature, pH, humidity, chemical substances, and the like. In one view, a system capable of actively controlling drug secretion would integrate the body with a smart suit capable of receiving simple health findings. For this reason, it is expected that the actuators will have some technological and mechanical components and will bring problems in both fields (Kim *et al.,* 2009; Hasegawa *et al.,* 2007).

4.4 Storage

Storage is another component of smart textiles. Although not a fundamental goal, smart suits are expected to need a storage capacity to operate on their own. While the information to be stored in smart textiles is usually information or energy, examples such as textiles that inject or emit drugs or odours indicate that this storage unit will also serve different areas. Detection, computing, actuators, and communication units generally require energy, especially electrical energy. Efficient energy management is achieved by combining the energy source and storage appropriately.

Examples of the energy sources that can be used in clothing are body temperature, mechanical movement (the energy generated by movement resulting from the elasticity of fabrics or kinetic energy from body movement), radiation (solar energy), and so on. The energy source required for the operation of sensors, processors, and moving systems in smart textiles should be combined with an energy storage capability. Nowadays, very small and light batteries are available, and this solution to the energy requirement is a method that comes to mind first. Even if the flexible ones are manufactured, they are not sufficient in performance and are still under development. On the other hand, the situation is easier and the energy requirement can be achieved by direct contact with clothing or by wireless connection (Engin *et al.,* 2005; Meyer et al, 2006).

4.5 Communication

One of the components of smart textiles is the communication component, which is shaped according to the type and need of communication. There are many types of communication within smart textiles. Some of the basic situations in which smart textiles are contacted are as follows: in one element of the garment itself; can be mounted between two different elements of the garment; and in order to command the garment by the wearer, contact is made to inform the wearer or their surroundings.

In today's prototypes, communication within the garment is provided by optical fibres or by conductive fine wires. They are naturally woven and can be placed in textiles without the use of stitches. A specific communication protocol is followed to communicate with the wearer. The outlines of this protocol can be provided by the technologies described below. Optical fibres are used in the creation of optical screens, and France Telecom has managed to produce several prototypes by producing a sweater and a backpack. On the other hand, since it requires more than one fibre for a pixel, it appears that the present situation needs further consideration. Another communication protocol in smart textiles is pressure-transmission systems. Information can be provided to the garment with pressure-sensitive textile materials, and a data processing element needs to process these entered orders. (Engin *et al.,* 2005; Meyer et al 2006).

5.0 AREAS OF APPLICATION OF SMART TEXTILES

5.1 Health

The development of wearable monitoring systems is already having an effect on healthcare in the form of Telemedicine". Wearable devices allow physiological signals to be continuously monitored during normal daily activities (textilelearner.blogspot.com). This can overcome the problem of infrequent clinical visits that can only provide a brief window into the physiological status of the patient. Representative examples are e.g.: a Wireless-enabled garment with embedded textile sensors for simultaneous acquisition and continuous Monitoring of ECG, respiration, EMG, and physical activity.

The "smart cloth" embeds a strain fabric sensor based on piezo-resistive yarns and fabric electrodes realized with metal-based yarns. Sensitized vest including fully woven textile sensors for ECG and respiratory frequency detection and a Portable electronic board for motion assessment, signal pre-processing, and Bluetooth connection for data transmission. A wearable, sensitized garment that measures human heart rhythm and respiration using a three-lead ECG shirt. The conductive fibre grid and sensors are fully integrated (knitted) in the garment (Smart Shirt) (Langenhove, 2016).

5.1.1 Life belt

A lifebelt (Figure 4) is a trans-abdominal wearable device for long-term health monitoring that facilitates the parental monitoring procedures for both the mother and the fetus. This lifebelt is very useful in case of pregnant women. Pregnant women living in remote areas work during pregnancy and face certain health problems (e.g., high blood pressure, kinetic problems requiring immobilisation, kidney or heart diseases, multiple pregnancies). A lifebelt is a support tool for the obstetrician, who is enabled to monitor patients remotely, evaluate automated preliminary diagnosis of their condition based on collected and analysed vital signs, access patients' medical data at any time and most importantly be alerted (McCane and Bryson, 2009)

5.1.2 Life jacket

A lifejacket is a medical device worn by the patient that consequently reads their blood pressure or monitors the heart rate; the information is transferred to a computer and read by medical staff. A specialized camera in the form of headwear has been developed to be worn by paramedics. Visual information captured by the camera can be transferred directly to medical staff at the hospital, enabling them to advise instantly on appropriate treatment.

5.1.3 The sensory baby vests

The sensory baby vest (Figure 5) is equipped with sensors that enable the constant monitoring of vital functions such as heart, lungs, skin and body temperature, which can be used in the early detection and monitoring of heart and circulatory illness. It is hoped to use this vest to prevent cot death and other life-threatening situations in babies. The sensors are attached in a way that they do not pinch or disturb the baby when it is sleeping (Stegmaier, 2012; Benard and Shea, 2004).

Fig. 4: Life-belt

Fig. 5: Smart baby vest

5.2 Military/defense

Around the world, military forces are exploring how smart clothing (Figure 6) can be used to increase the safety and effectiveness of military forces. In extreme environmental conditions and hazardous situations, there is a need for real-time information technology to increase the protection and survival ability of the people working in those Conditions. Improvements in performance and additional capabilities would be of immense assistance within professions such as the defense forces and emergency response services. The requirements for such situations are to monitor vital signs and ease injuries while also monitoring environmental hazards such as toxic gases. Wireless communication to a central unit allows medics to conduct remote triage of casualties to help them respond more rapidly and safely (stitchprint.eu).

5.3 Fashion and entertainment

As the technology is becoming more flexible, various electronic devices and components clothes becoming truly portable devices. Already, there are textile switches integrated into clothing for the control of such devices. While technology may be hidden through invisible coatings and advanced fibres, it can also be used to dramatically change the appearance of the textile (Figure 7), giving new and dazzling effects. Light-emitting textiles are finding their way onto the haute couture catwalks, suggesting a future trend in technical garments (Van, 2004).

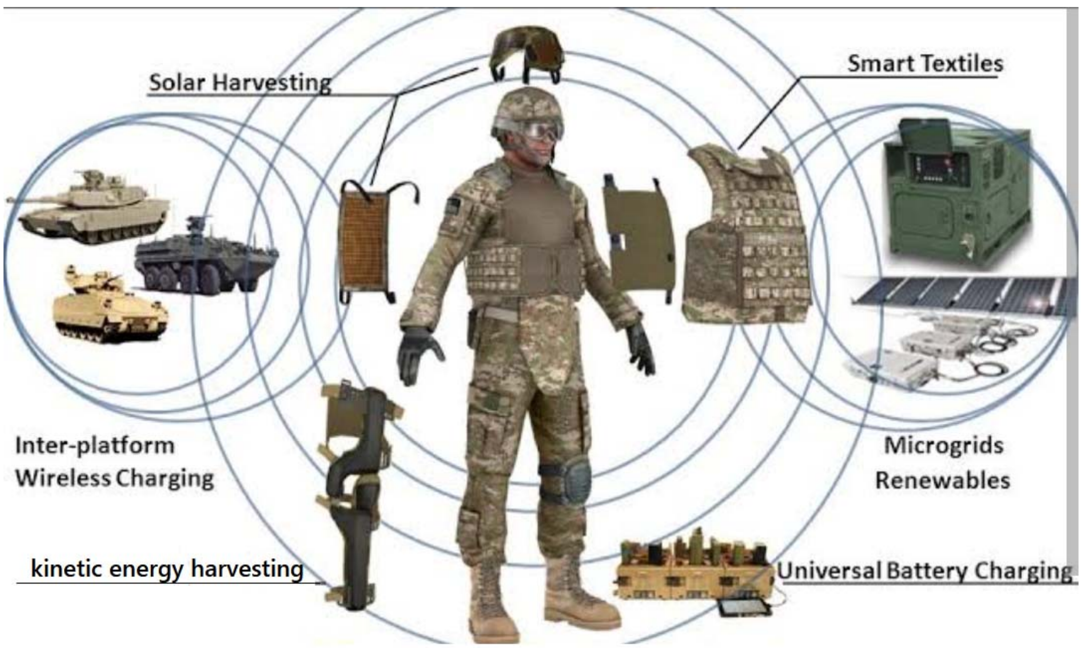

Fig. 6: Smart military uniform

Fig. 7: Smart fashion wear

5.4 Sportswear

Sportswear is an area of important smart clothing developments. In general, a number of important functions can be implemented using smart devices or clothing. These include: Monitoring heart rate, breathing, body temperature and other physiological parameters; Measuring activity, for example determining the number of steps taken, the total distance travelled; Acting to actively stimulate muscles e.g. using electrical muscle stimulation; Work against activity to provide smart' resistance training; Record aspects of performance, such a foot pressure or specific joint movements; Protect against injury (Manshahia and Alagirusamy, 2016).

5.4.1 Smart sports shoe

Global Positioning Systems (GPS) incorporated into walking shoes (Figure 8) which allow the user to be tracked by mountain rescues services. They can also be used to monitor the whereabout of young children. Gloves that contain heaters, or built-in LED's emitting light so that a cyclist can be seen in the dark.

5.4.2 The smart bra

The Australian people have developed a bra (Figure 9) that will change its properties in response to breast movement. This bra will provide better support to active women when they are in action. The Smart Bra will tighten and loosen its straps, or stiffen and relax its cups to restrict breast motion, preventing breast pain and sag.

The conductive polymer-coated fabrics will be used in the manufacture of the Smart Bra. The fabrics can alter their elasticity in response to information about how much strain they are under. The Smart Bra will be capable of instantly tightening and loosening its straps or stiffening cups at excessive movement (Gulden, 2013).

Fig. 8: Smart shoe

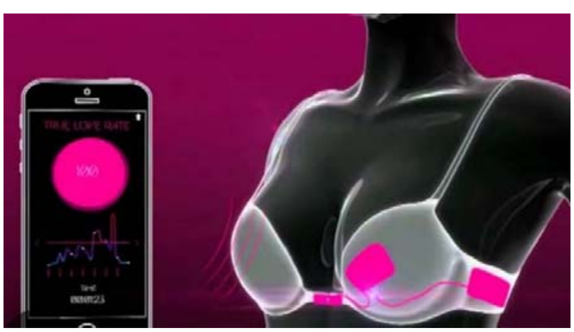

Fig. 9: Smart bra

6.0 RECENT DEVELOPMENTS

6.1 ARTUS (Artificial Uterus)

ARTUS, the Artificial Uterus (Figure 10), was developed by a team of experts at the Hohenstein Institute. It was the first artificial uterus that was designed to help premature babies to develop by providing sensory stimulation.

The premature babies need intensive medical care in incubators for weeks or even months. However, it has been known for some time that these premature babies miss the spatial confinement and prenatal sensory stimuli of the womb (uterus).

ARTUS can recreate the environment and sensory stimulation of a mother's womb in the incubator. Acoustic stimuli like the mother's heartbeat and voice are transmitted to the premature baby, together with mechanical sensations like the gentle rocking experienced in the mother's body.

The aim is to improve the clinical well-being of the little patients. Five components: heart rate, respiration, response to touch, muscle tone and skin colour, are measured at regular intervals. ARTUS will allow the clinical condition of premature babies to be significantly improved.

The artificial uterus will also incorporate a mechanical textile actuator to provide the sensory and motor stimuli and sensation of equilibrium that will promote the development of the infant's brain (Romanis, 2018).

6.2 HRM Garment

Sensoria, a leader in wearable fitness and smart garment technology, is introducing a new smart line of colourful sports bras and t-shirts. The new app called Heart Sentinel, was connected to the heart rate monitoring (HRM) garments and detect certain cardiac irregularities.

This garment was designed to meet the needs of all levels of fitness enthusiasts by including a new medium support sports bra for women and a new short sleeve T-shirt for men. "Heart Sentinel may also locate the person through GPS coordinates.

Each Sensoria garment is made with Emana yarn, the technically advanced and durable fabric that uses far infrared technology which keeps the wearer dry, comfortable and protected from the sun's harmful UV rays, Emana yarn improves skin elasticity to reduce the appearance of cellulite and helps the muscle from fatigue.

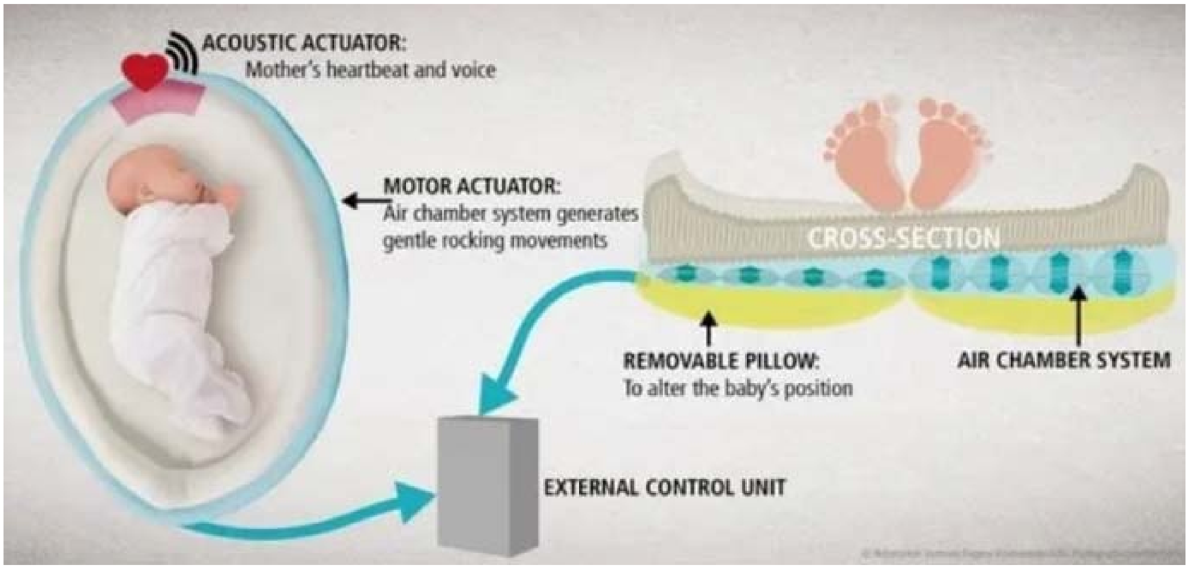

Fig. 10: Artificial uterus

6.3 Anti-cancer Hat

Novocure, a private Jersey Isle oncology company, has introduced a novel therapy for solid tumours in a form of an anti-cancer hat that has been shown to increase patients' chances of survival for two years by up to 50%. The latest data show that the hat in combination with standard temozolomide chemotherapy will extend both progression-free survival (PFS) and overall survival (OS) of the person when compared to temozolomide alone in patients with newly diagnosed glioblastoma.

Glioblastoma is the most common form of primary brain. It is very difficult to treat glioblastoma as it is very complicated because the tumour cells are very resistant and damage the brain in conventional therapies and it has a poor capacity to repair itself.

The anti-cancer is a portable, non-invasive medical device designed for continuous use by patients and reverses tumour growth by inhibiting mitosis, the process by which cells divide and replicate. It creates a low intensity, alternating electric field within a tumour that exerts physical forces on electrically charged cellular components, preventing the normal mitotic process and causing cancer cell death (Laura and Libia, 2022).

6.4 Nano cellular filter

Scientists at Uppasala University Sweden, in collaboration with German virologists, have developed cellulose nanofibre sheets to remove viruses from water. It has a layered structure and it will be able to remove even small sized viruses. This nano cellulose sheets acts as affordable filters which not only can remove viruses but also can have long life. These nano structured filters (Figure 12) have pore structures that can filter viruses that are normally resistant to physical and chemical countermeasure processes.

Nano cellulose consists of cellulose that has been processed in a special way to produce nano fibres or nano structures which are strong and have a large surface area. Their properties depend on how the nanocellulose is produced and the source from which it has been extracted, the surface charge, the molecular groups that are grafted on, and the length and thickness of the fibres may vary (Joshi and Bhattacharyya 2011).

6.5 Self-cleaning textiles

Researchers at the RMIT University have developed a cheap and efficient new way to grow special nanostructures, which can degrade organic matter when exposed to light.

These textiles can spontaneously clean themselves of stains and grime simply by being put under a light bulb or worn out in the sun (Figure 11). The advantage of these textiles is that they have a 3D structure so they are great at absorbing light, which in turn speeds up the process of degrading organic matter. The fabric is treated with copper and silver-based nanostructures, which have the capacity to absorb visible light.

When the nanostructures are exposed to light, they receive an energy boost that creates hot electrons. These hot electrons release a burst of energy to degrade organic matter. When exposed to light, it took less than six minutes for some of the nanoenhanced textiles to spontaneously clean themselves (Chanchal, 2010; Bozzi *et al.,* 2005).

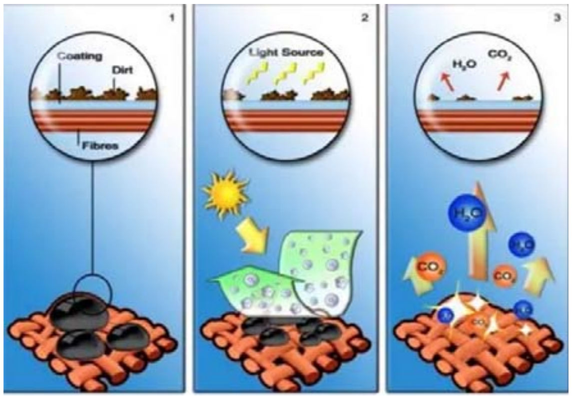

Fig. 11: Self cleaning

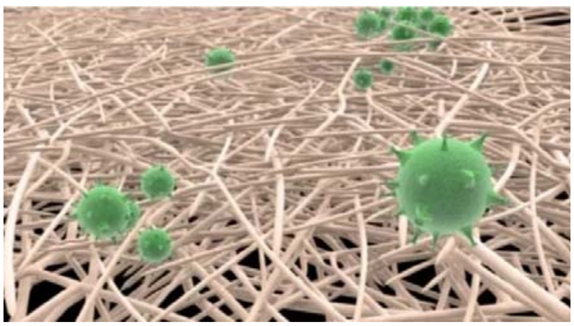

Fig. 12: Self filter

7.0 FUTURE EXPECTANCY OF SMART TEXTILES.

The smart textiles market has been witnessing significant growth over the past years, mainly owing to the advancement and implementation of technologies like artificial intelligence (AI) and internet of things (IoT) in smart textiles and expanding wearable electronics which is expected to grow in the coming years. The global smart and interactive textiles market size is expected to be valued at US$ 2.6 Billion in 2022. With the rising product demand in military/defense, and medical and healthcare, overall demand for smart and interactive textiles is projected to grow at a CAGR of 25.88% between 2022 and 2032, totaling around US$ 26.4 Billion by 2032. (futuremarketinsights.com)

Researchers all over the world are developing "smart" fabrics or textiles that can charge electronics, cool down the body, monitor health, detect human motion, light up like flashlights and more. While most of this technology is still in the lab and won't be seen in stores for years, there is no doubt that the new wave of technology will be lightweight and flexible, and it will rest on your back and legs.

Some of these future expectancies are as bellow:

7.1 Weaving electronics into washable fabrics

Researchers at MIT have developed a way to weave diodes, a building block of modern electronics, into washable, durable fabrics. Previous wearable technologies are usually used as add-ons to existing devices, fibre s or garments. This approach integrates the devices directly to the fibres during weaving, making the textile functional, this development will expand the capabilities of smart textiles, allowing them to be as comfortable and flexible as normal clothing. The end goal is to make a full textile-based system that could work like cell phones and computers.

Integrating other components into fibres in a similar fashion to enable critical components of electronic systems such as energy storing fibres, displays and more, with the hopes to be able to build a textile electronic device such as computer shirt or telephone pants are also being worked upon (textiletoday.com).

7.2 Fabrics that can detect human motion

Engineers from the University of Delaware have developed a way to coat textiles, such as cotton, nylon, wool and others, with carbon-based nanomaterials. The resulting fabrics are equipped with novel sensing abilities that can detect a wide range of pressure, from the light touch of a fingertip to being driven over by a forklift, that could one day be used in clothing or shoes to detect human motion.

These smart garments have applications in the healthcare industry for rehabilitation of patients, assessing movement disorders for the pediatric population and biomedical devices. One of the most immediate applications of the low-cost, flexible sensors could be to measure the forces on people's feet while they walk(tun.com)

7.3 Material that generates electricity through human motion

Researchers at Vanderbilt University have developed an ultrathin device that can generate electricity when it is bent, pressed, or vibrated. If the technology were to be embedded into a piece of clothing, every step, shake or slight movement of the wearer would generate electricity that could be used to charge mobile devices. In the future, it is expected that humans will all become charging depots for their personal devices by pulling energy directly from their motions and the environment (Yi *et al.,* 2022)

These and many more research projects are going on in this field of textiles, giving rise to the market growth and vast opportunities for researchers and lovers of technology all around the world.

8.0 CONCLUSIONS

The efforts made by researchers, engineers and scientists so far on nanotechnology and smart textiles have brought about innovations in the field of textiles, providing added benefits to the user beyond the typical value of the fabric. Textiles can now be made Smart to respond and adapt to their environmental conditions and changes, making different fabric products available to meet the demands and desires of the users. With the recent applications of Nanotechnology in the field of textiles, life has become easier and more comfortable for living, and for a perfectly functional smart textile, the ideas of professionals from different fields of study are of high importance.

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