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Recent Trends in Wearable Electronic Textiles (e-Textiles): A Mini Review

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ABSTRACT Wearable electronic textiles (e-textiles) have the ability to sense, respond, and adjust in multiple environmental stimuli, which can interact with the human brain's capability for cognition, reasoning, and activation. Moreover, they have the ability to generate and store energy, keep track of the wearer's health, and react to varying situations. Conductive polymers, metal-wrapped yarns, as well as, carbon nanotubes with silver, copper, and gold nanoparticles are used in a variety of yarn structures to design circuits, switches, and fabrics directly. Knitting, stitching, embroidery, and other integration techniques are used to combine electronic components and electrical interconnects to develop flexible electronic clothing and smart wearables. For this purpose, controlled sensors, actuators, conductive embroidered or printed fabric, planer yarn, data transfer devices, conductive inks, electromagnetic shielding, power supply, and other components are incorporated in e-textiles design. Despite the progress made so far, wearable e-textiles still, lack the required performance and device features along with the issues related to complex fabrication techniques, end-of-life processing and sustainability. Hence, this review aims to discuss the recent developments, which address the future challenges concerning electronic (e-textiles).

INDEX TERMS e-textiles, functional yarns, recent trends, wearable electronics

I. INTRODUCTION

In addition to their conventional features, modern textiles are expected to serve new purpose as well. Electronic textiles have been named as intelligent or smart textiles, electro-active textiles, textronics and wearable electronics. Smart textiles respond to thermal, optical, mechanical, electrical, chemical or magnetic stimuli, which makes them appropriate substrates for the integration of optical, electronic, and nano-tech-supported components. A smart textile, unlike conventional electronics,

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which are mostly rigid, is able to withstand complex impairments. Additionally, such textiles are flexible, light, and permeable, which enables integrated electronics to be embedded into curved material surfaces, which can be worn conveniently. Based on the materials used, three categories of these textiles include active, passive, and intelligent textiles. Passive smart textiles can just observe the conditions or stimuli, however, active are those smart materials, which would automatically sense and react to them in time. Very smart or intelligent textiles have the ability to perceive, respond, and adjust as required for their environment.

In fact, materials that can perform a function, while manually or automatically being programmed can develop a higher level of intelligence. The three basic components of smart textiles are sensors, actuators, and the controlling units. Since sensors act as a peripheral nervous system that would detect the signals, they are required in passive smart materials. Active smart textiles require both sensors and actuators; the actuators can either directly react to the detected signal or do so via a central control unit. The highest level is intelligent textiles, which require a central processing unit with reasoning, cognition, and activating capacities. Smart textiles may carry out a number of functions, such as detecting, actuating, communicating, data processing, and supplying power, in order to establish a smart system. However, it is crucial to maintain the flexibility of clothings' to be comfortable to wear, stretchable, and washable [1].

Electronic textiles have integrated electronic components, which can provide active electronic functionality [2]. Figure 1 shows a summary of multidisciplinary approaches that can be used to integrate various functions in modern e-textiles. Due to their higher surface area, greater wearability, ease of integration, and manufacturing flexibility, modern wearable e-textiles exhibit high efficiency and sensitivity, increased mechanical stretch ability, and flexibility, extended lifespan and serviceability, enhanced wearing comfort and long-term biocompatibility and so on.

FIGURE 1. Various Functions of Advanced e-textiles

II. THE EVOLUTION OF E-TEXTILES

The first-generation of e-textiles is best illustrated by the simple integration of electronic circuits into clothing by utilizing concealed wires and soft interconnects. Even while the electronic garment illustrates the idea of transitioning from rigid circuit boards to on-body electronics, its obvious disadvantage was that it was too heavy, unpleasant, and difficult to integrate comparatively. Since they are still in the early stages of development, wearable e-textiles are yet confronting a number of difficulties. Most electrical devices were noticeably fragile that limited their frequently washing activity and shorter lifespan. Another problem is the weaker adhesion of conventional electronic devices, which are inconvenient and might quickly slide off while being used [3]–[6].

The second-generation primarily focused on the fabrication of textiles with functional properties, by incorporating switches and sensors. Thin-film electronics may be attached to traditional textile fabrics by using thermoplastic adhesives and lamination technologies. Additionally, by utilizing printing processes like screen printing and inkjet printing, electrical devices may also be made directly on textile substrates when solution-processable functional ingredients are used. Significantly, this level of study improved the electronics to textiles conformability, while also obtaining the degree of pliability of traditional textiles via use of thin-film electronics. Since these thin-film devices were frequently sealed by packing materials to avoid the wear-induced loss of the structural components, the permeability, that's crucial for long-run wearing, was also of much relevance [7].

In recent years, the third-generation of e-textiles developed and employed a functional yarns and fibers as building blocks to develop smart devices and systems. This bottom-up approach may make optimal use of the advantages of highly scalable and proven textile technologies, such as braiding, knitting, weaving and embroidery, in order to construct complex patterns and structures that are desirable in various settings, while maintaining the textile properties. So far, e-textiles have been used in everything from tiny implantable and surgical devices, wearable electronics, and robotics to larger smart interiors, interactive surfaces, and robots [8]–[12].

III. INTEGRATION OF CONDUCTIVE, FUNCTIONAL, AND SMART COMPONENTS

Carbon nanotubes, illuminating components, thermocouples, or shape memory materials can be employed in a variety of sensing applications in various fields including advanced textiles. Chromic materials can be employed for the environmental pollution monitoring and medical diagnostics since a number of factors can alter their optical properties [6]. In this context, halochromic pH sensors become important for identifying alkaline or acidic situations in evaluating pollution levels, food quality, and health concerns. For instance, alterations in sweat pH might affect the causes of skin conditions and function as a moisture indicator in smart medical textiles. Due to their increased electrical conductivity, carbon nanotubes, graphene, and conductive polymers are potential options for developing e-textiles through integration of sensors and actuators. Incorporating electrical components into these materials might result in an entirely new line of wearable accessories. Innovative uses for optical light emitting diodes, nano-electronics, liquid conductive metals, and others may be produced by fusing optical, opto-electronic, flexible, and stretchable electronics [13]–[15].

The integration of photonic materials with opto-electronics in advanced textile fibers enables the clothes to change colour in response to environmental conditions including moisture, heat, externally stimulated light, airborne pollutants, pollen, or even dust. Additionally, extremely reflective, vibrant, and sensitive 3D visual impressions were added to textiles using holographic film and optical fiber coatings consisting of periodic multilayered dielectric materials. A wearable pH meter can be produced by combining an opto-electronic circuit with fabric tinted with a halochromic chemical that emits visible light [16]. Halochromic dyes were immobilized on textiles using nanotechnology or even the conventional dyeing methods, giving the functional fabric an excellent durability because of the nanoparticle assisted high surface energy. Due to this, washing cycle-resistant and optical pH monitors have been made possible [17]. The sol-gel technique is simple to use and produces porous coatings with no cytotoxic activity. It is frequently used in hybrid films' production onto smart textiles with stimuli-responsiveness or technical capability, like antibacterial activity, water repellency, and flame retardancy. Reportedly, results from the current research indicated that prepared materials displayed exceptional performance capacities, while maintaining their conventional textile properties. Coupling electro-conductive carbon nanotube tracks also showed interesting outcomes with an electrical system intended for real-time observation of temperature and relative humidity [18].

Conducting fibers are the basis for many wearable e-textiles. Recent reports on MXene and graphene-based nanocomposites investigated the production of a range of e-textile materials from fibers and yarns to smart textiles, by fusing two-dimensional materials like MXenes and graphene with metals, conducting polymers, carbon nanotubes, and others. They also demonstrated how various semiconducting, conducting, and electrochemically active phenomenon might result from the combination of these selected elements. Biological comprehensive analytic systems and physical sensing stimuli like strains were notably mentioned in description of the smart wearable electronics. The investigation of sweat-detecting patches was also done using samples from smart bandages and smart sutures [19]. The media lab at MIT in the United States created a flexible and robust fabric-keyboard with embroidered panel for Levi's musical jacket. It was prepared using a polyester composite cloth and conventional embroidery techniques using low-conductive stainless-steel thread. This keyboard is extremely responsive to touch and turn a regular denim jacket into a wearable musical instrument, which enable the user to play notes, chords, and rhythms. Prof. Kim's research team in South Korea created a textile platform with multifunctional user-interface techniques and body-motion sensors by utilizing fibers covered with polymerized PEDOT, which was poly(3,4-ethylenedioxythiophene). By incorporating PEDOT fibers into a fabric using a pattern, textile sensors have been developed with multifunctional capabilities, such as extremely sensitive and reliable strain sensors, touch sensors, body-motion sensors, and multilayered strain-recognition unified information devices. Textile antennas are necessary components in this industry, which includes wireless communication as well as sensing activities, whether they are incorporated inside or inside the garments. For the placement of many antennas and other electrical equipment, the vast area, which is available in textiles can be examined for further research [16].

Recently, smart surgical masks, personal protective, light therapy equipment, wound dressings, flexible textile-based sensors, and actuators have all been developed using e-textiles. A team of researchers created electronic sports gear that can monitor a user’s heart rate, breathing, and movement. The data is then sent to a smartphone for instant processing through Bluetooth Low Energy. A self-powered PU electric mask was able to produce the sufficient power to halt viral transmission when it came into contact. Another study, disclosed a mask containing a wireless readout circuit and a pressure sensor to investigate the wearable-based smart system. For wearable healthcare, particularly for uses muscle stimulation, a user-friendly electronic sleeve with a variety of integrated printed electrodes was developed. In a likewise manner, another work used a vacuum-assisted layer-by-layer manufacturing method to create a superhydrophobic and electrically conductive silk fabric in order to track and trace the moisture levels for highly vigorous mouth breathing. A group of researchers found that wearable electronic textiles with heartbeat (pulse) and breathing signal monitoring might wirelessly transmit health information to a smartphone application for analysis. This might be used to assess a person's sleep conditions, to track, and identify their sleeping patterns. To increase surface area of aforementioned antennas, the energy harvesters or batteries could be positioned above the radiation spot. Even so, when the flexible textile modules were used for wireless communication and included into the textiles, the device become susceptible to distortion because of the user activities and motions, resulting to damage and malfunction- related activities.

Therefore, an energetic design approach is necessary to ensure a consistent and efficient antenna performance under these circumstances. Utilizing textile antenna materials is also essential since they offer remarkable radiation qualities as well as superior user comfort. The materials must have both conductive and insulating components, and the right production method requires antenna incorporation into the e-textiles. In order to address the variation in antenna operation under diverse climatic circumstances, hydrophobic materials with the least amount of moisture recapture must be utilized for the process. One of the three techniques for making textile antennas, is the modest technique, utilizing knitting, interlacing, embroidering conducting wires, and tapes or yarns into a piece of clothing. The second popular technique uses thermally activated thermal sheets to fuse e-textiles. Finally, other manufacturing processes like advanced ink-jet printing, 3D printing or even screen-printing may be used to set up the antenna, reflector, and base plane on the e-textiles. Presently, a cutting-edge substrate wave-guide technique may be used to create a totally textile-based wearable antenna. Hence, the automotive, retail, military, fashion, and entertainment industries would all have niche application areas in the future. Stretchable, flexible sensors can offer remarkable tracking capabilities for human movement and physical activity. With careful analysis of the acquired data, these e-textiles can be utilized to identify human motions in a practical way and give accurate movement tracking. These electronic textiles might be used for real-time body measurements in retail settings and for self-defense.

Briefly, e-textiles have a variety of beneficial elements as well as certain hazardous heavy metals and organic halogenated chemicals that are harmful to both human health and the environment. These hazardous materials may seep into the environment when recycling, while being burnt if coupled with municipal waste streams, or while leaching off land surfaces. From the total energy recovery perspective, it was also asserted that recycling these materials should be challenging. Instead, researchers suggested that future work should concentrate on developing hybrid models that could easily be broken down into the basic components without losing electronic, electrical, and electrochemical properties. It may be useful to restrict the variety of materials mixed in order to permit fully sustainable e-textiles [19], [20].

IV. CONCLUSION

To enhance the wearable technology, soft actuators must be integrated with textiles, ideally during production. In other words, actuators should be created to mimic the threads or fibers that might be appliqued to, knitted into, or woven into smart fabrics. It would be more user-friendly if conventional assistive technology could be disguised as a piece of clothing, such as a pair of tights with built-in textile actuators that support the wearer's pace. It is commonly predicted that textiles would be able to mimic the shapes and subtle movements of both living creatures and machines, as opposed to just electrical output, by opening up a broad range of exciting possibilities. Furthermore, the use of these smart material technologies in financially feasible applications would determine the viability of the e-textile sector. In order to satisfy emerging market' needs for pricing and product quantity, and scaling-up the production of smart materials is necessary. The integration of smart technology has forced an ideological change from considering textiles to be just consumable for the sustainable products. The manufacture of textiles would soon be supported by parallel developments in semi-automated and automated production, encouraging several novel strategies for the development of future textiles.

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