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Electrically Conductive Yarns (ECY) for Health Monitoring: A Review

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Abstract

Electrically conductive yarns (ECY) possess the property of carrying the signal from one end of the yarn to the other to work as sensors, actuators, and communication devices. Conductive yarns in health monitoring applications are used for disease diagnosis and assessment of patient condition by sensing and transmitting the signal. In this paper, only human body health monitoring is the main target to discuss specifically the products and technologies based on conductive materials. In the medical field, polymeric conductive yarns are found with some superior properties of sensitivity, and flexibility, and have high strain monitoring. Smart textiles having electronic devices are embedded into the structure for transmitting; and receiving signals are suitable for products with technical features, and monitoring of health. Conductive yarn properties depend on wire types, diameters, and material characteristics. Polyaniline-coated polyester yarns are stable environmentally with excellent flexibility. The usability of the whole health monitoring system increases by using wireless technologies. Furthermore, making conductive yarns with zero resistivity, low cost, and multiple features is of great interest in the future smart textiles market.

Keywords: Electrically Conductive Fibers; Yarns; Fabrics; Health Monitoring; E-Textile

Introduction

Smart Textiles

Smart textiles are intelligent textiles that can sense and react to environmental stimuli. The E-textile system is fabricated by the development of electrical devices like sensors, energy harvesting, actuators, storage items, etc. and applications are shown in Figure 1 [1,2]. Smart textiles interact with the environment and such e-textiles exist in different shapes and compositions (woven, knitted, or non-woven) [3]. The term e-textiles represents the class of fabric structures that sense and respond to environmental changes and the multificated environment for smart textiles is represented in Figure 2 [4,5].

Smart textiles can perceive and respond to a specific stimulus by embedding various components/parts of electronics into structures (yarns, fabrics, or garments) [6]. Smart textiles with the perspective of energy conduction, and transformation, as well as serve the function of protection from environmental hazards [7]. The parts having considerable weight and interest in e-textiles are sensitive sensors, flexible transistors, and stretchable electronic tools integrated into yarns, fabrics, or garments [8]. The great potential of smart textiles in the medical area has many end uses like early recognition, treatment, compliance monitoring, physical therapy, and many others [9]. Further integration of electronic devices within clothing has increased the growth of e-textiles due to developments in materials science and electronics [10]. Moreover, the market of smart textiles currently close to \$100m and is expected to grow towards \$5bn in 2027 [11]. Smart textiles have many phenomenal uses in the medical field by using pressure sensors [12]. The origin of the stimulus may be electrically powered, heat, chemical reaction, or other [13]. E-textiles sensing ability can be made through both intrinsic and extrinsic means [14]. Smart textiles often used well-specialized materials, to realize the sensor function [15]. Smart textiles monitoring systems with sensor materials containing the design and development, the coated yarn has the potential to contribute significantly [16]. In the field of research value for applications in health monitoring, the sensors with high sensitivity and stretchability are of great importance [17].

Figure 1: (a) Musical jackets with fabric keypad on one side and (b) fabric keypad (Reproduced with the permission of [2]).

Figure 2: Multifaceted surroundings for smart textiles (Reproduced with the permission of [5]).

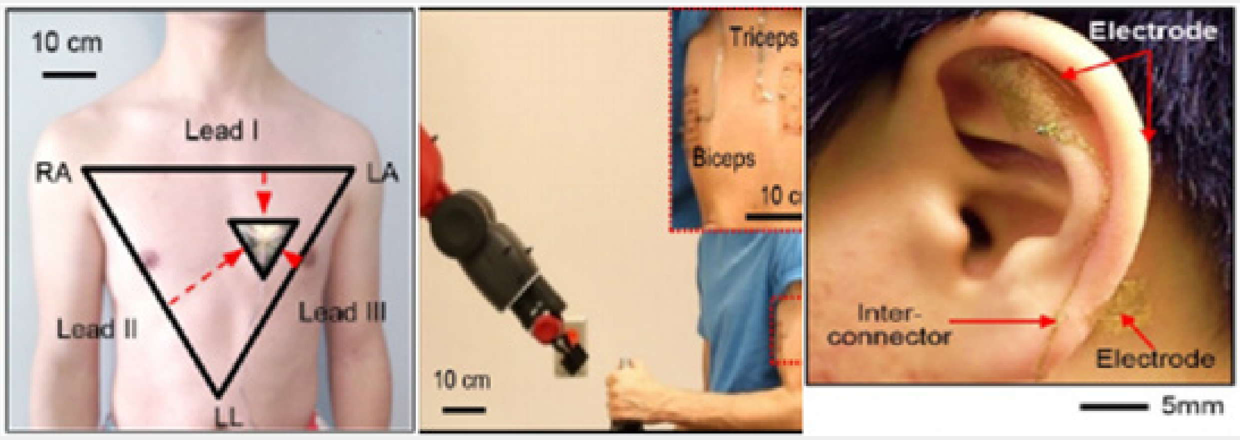

Figure 3: Electrocardiogram electrode attachment on the chest, robot arm angle controlling for the elbow, and electroencephalogram electrode overlay on the auricle and mastoid respectively (Reproduced with the permission of [26]).

Health Monitoring Systems

Wearable health monitoring system provides real-time medical monitoring services, and is the combination of computer, communication, medical, and technologies that integrates many characteristics. Wearable Healthcare systems need electrodes that are skin adhering to provide maximum comfort for the patients and to process, carry the signals with low resistance [18]. Growing inhabitants are infected from various kinds of infections

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while some are chronic age-related disorders. To deal, ensure the monitoring of all those disorders by using conductive materials in wearable healthcare systems is the evolution of diagnostic technologies in the field of medicine [19]. There are two types of health monitoring from both construction (structure), and individual (human) body. Telecommunication and information technologies allow patients and medical staff to communicate easily, and reliably and move the data from one end to another in real-time remote health monitoring systems [20]. Structural health monitoring has very simple uses due to its multimodal nature [21]. There are various techniques/approaches in the structural health monitoring research field like the acoustic emission approach used for structural defects detection [22]. Health monitoring systems have the ability of bio-signals indication at any position. Modern healthcare devices are facilitated more with technology as per the requirements of the users [23]. Health monitoring devices containing conductive fibers/yarns/fabrics process the signals from one end to another end/portion of the structure as per the requirements [24]. Health monitoring devices have the potential for physiological tip-off and such waves provide an efficient way for disease diagnosis and health assessment [25,26]. Figure 3 represents the electrocardiogram electrode attachment on different regions.

Health monitoring systems continuously collect data from the body of humans by changing their health status with time. Moreover, the sensors used in health monitoring systems are highly flexible and comfortable to maintain a natural interaction with the human body [27]. Smartphone-based medical devices are more famous and widely used all over the globe for fitness purposes. Heath monitoring devices can be reduced (miniaturized) in size to handle complex computation and sensing efficient information [28]. Metamaterials textiles with sensor lattice for cordless skeleton are capable of observing constantly the health conditions of people by reducing human errors, and also analyse the better understanding of diseases from their origin [29]. Body health monitoring systems by using wearable sensors, the device properties are bio-friendly, lightweight, and attenuated with a good span of sensitivity. Optical fiber-based sensors on attachment to human skin have the potentials to monitor carpus (wrist) vibration, breathing, and pounding of fingers [30]. The usability of the whole health monitoring system increases by using wireless technologies [31]. Health monitoring allows patients and medical staff better communication from one site to another like health information data [32].

Materials

Health Monitoring Based on Fibers

Wet spinning and melt spinning's are the processes/methods of fibers preparation which is electrically conductive [33]. The type of materials, fibers configuration, and fibers arrangement are the main factors for determining the performance of smart textiles [34]. Conductive fibers may also have electrical as well as delivering good antimicrobial, anti-static, and electromagnetic shielding properties [35]. Conducting polymers/fibers made from the thermosetting materials (non-thermoplastic) at low temperatures, such as fibers degrade and cannot be remelted or reuse [36]. A materials/fibers electrical conductivity would be superior to the less dense fibers and vice versa [37]. Polymer optical fiber sensors may detect the damages, their recovery is very well at the initial stage, consequently reducing the conservation prices [38]. Sensors made from various textiles fibers along with good conductivity for health monitoring purposes are the extension sensors, pressure sensors, moisture sensing, etc. [39]. Fiber optics against electromagnetic radiation, the sensors have been reported largely in previous years because fibers immunity/exoneration was of tremendous quality [40]. Carbon nanotubes, graphene nanoplates, carbon nanofibers, and carbon black have good electrical conductivity [41]. Conductive metal nanoparticles, metal films, and CNTs along with graphene are promising materials to make flexible sensors [42]. On the aramid fibers (twaron) surface the deposition of silver nanoparticles can be made through cross-stacking of PDMS (polydimethylsiloxane) emulate a capacitive sensor [43]. Health monitoring based on fibers with carbon materials having hierarchical structures, flexible pressure sensors, highly sensitive, fast response, and durable sensors has been made [44]. Fiber-based smart textiles are assumed to the underweight, comfortable, and resilient. Fibers like conductive polymers, carbon-based materials, metals, and metal-oxide nanoparticles are promising materials/fibers for wearable electronic devices [45]. Repeated stretching may decrease the conductivity of conductive fibers due to the inner layer damaging. However, in conductive fibers, as compared to thin films the resistance change or change in resistance due to stretching is very low showing high conductivity [46]. Conductive fibers are used in wearable electronics by directly woven into textiles. Moreover, stretchable conductive fibers are used in underwater wearable electronics which can work as wireless charging [47].

Health Monitoring Based on Yarns

Sensors are made from conductive yarns and such yarns can be unified into the structures. Many electrodes and sensors containing conductive and piezoresistive yarns have many applications in the field of e-textiles [48]. Electrically conductive yarns into electrodes are quite useful in a situation for long term monitoring and healthcare [49]. Wearable systems containing conductive yarns for individual finger movements and wrist pulse with stretchable strain sensor [50]. The skin temperature can be measured by imparting temperature sensors within the textiles. Skin temperature sensors maybe not useful in some places where the temperature difference is small as compared to the large temperature difference [51]. Silver yarns in smart textiles are mainly used in threads for connections that have the same damaging effect of both washed and unwashed samples [52]. Conductive textiles by using yarns as a wearable electrode for physiological monitoring of signals are used in ECG (electrocardiogram) [53].

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Research is made on strain sensors comprising conductive wool yarn along with the development of soft robotics and healthcare applications as well [54]. Variations in yarn TPI (twist/inch) may enhance the strength of conductive yarns and a large number of items can be made from these stainless staple fibers for final use [55]. Strain range for stretchable conductive yarns of composite with high elongation at break is used in sensors [56]. Smart textiles may be used for energy harvesting, health monitoring, and biomedical sensors [57]. Electrically conductive yarns (ECY) are made with the desired properties at the different ratios of fiber to obtain the need for a particular desired product [58].

Conductive yarns classification is shown in Figure 4 [2]. Health monitoring using conductive yarns is one of the most demanding areas of research, being consummate the textile-based smart technologies. Electronic elements and electrically conductive yarns (ECY) are consolidated into the textile substrate to work as sensors, actuators, and communication purposes [59]. Electrically conductive yarns (ECY) are used for smart wearable devices to make various products and yarns is linked in between embedded controller, gyroscope, and rest of the instrument portion [60]. Nylon/Ag conductive yarns with some high properties of sensitivity, flexibility, and stability and have tremendous applications for high strain monitoring in the field of medical [61]. Conductive yarns make the textile circuit board as the washing process damage the connection elements [62]. Carbon nanotubes yarn sensors have good deformation along with high sensitivity [63]. The core-sheath yarns are inserted into the products having the ability to identify the motion of a human. Human body motions may be walking, running, jumping, and later on, signals are generated for healthcare monitoring purposes [64]. PDMS-CB (polydimethylsiloxane carbon black) based on stretchable strain sensor are used for non-human body health monitoring (structural) [62]. Researchers are engaged to make flexible electronic devices and to embed them into the fabric structure for getting various features [63]. Bespoke testing chamber for conductive yarn testing was achieved in an acoustic environment [65]. Wearable sensor systems quantifying physical and chemical signals are the tools for health monitoring [66]. Smart textiles cover the section of observation for customizing treatment of individuals with high sensitivity [67]. Several polymers conductivity can be enhanced using a processing agent by several orders of magnitude [68]. Smart textiles having electronic devices are embedded into the structure for transmitting, receiving signals are suitable for products with smart features, and monitoring of health [69]. Smart sensors can be made from carbon nanotube as raw materials with desirable properties. Those desirable properties of carbon nanotube may be achieved individually or in a composition like electrical, heating, mechanical, and optical properties [70]. Silicone materials with insertion of polyester yarn having stainless-steel rod from which conductive yarn are prepared for the transmission of an electrical signals [71]. Sensors made from carbon-based materials in the form of yarns are most probably used for strain monitoring, concentration of ions, biomolecules concentration, and change in heat [72]. Contemporary, innovation in smart textiles products for health monitoring using conductive yarn for various purposes [73]. Properties related to strength, modulus of electrically conductive yarns made up of different fibers/materials having graphene coating are mainly applicable for mechanical characteristics [74]. Mostly, textile-based sensors are attached directly to the body and they are comfortably fit [75]. For wearable health-monitoring electronics, graphene has been analyzed as the most promising material [76]. Hybrid polyurethane yarns strength and modulus are low, therefore, corresponding yarns still in search of better mechanical properties [77]. Graphene oxide coating over polyamide yarn provides durable electrically conductive yarns (ECY) with excellent fastness to washing properties as well [78]. Wearable sensors are mostly used for sensing human body movement during walking, running, or jumping by transmitting signals, and safe the patient from any future danger [79]. Stretchable electronics need flexible materials for the development of conductive yarns [80]. For the monitoring of joint angles, the wearable sensors fabricated from conductive yarns of nylon and spandex materials/fibers have a good feel of materials, dry easily, and a hindrance to mildew [81]. Electrically conductive yarns have many applications in weave able, knittable, and wearable yarn supercapacitors [4]. Polymers with conduction characteristics in the form of yarn and nanofillers are added to the spinnable polymers to achieve the desired properties [82]. As far as flexibility of conductive yarn is concerned, polypropylene is suited well. These materials also require excellent coating over the yarn surface for maintaining insulation in the existence of water [83]. Applying load/stress on elastic conductive yarns cannot reduce the conduction properties [84]. Yarns with greater conduction are made/spun from the oxide of metals, CNTs, and polymers [85]. Polyaniline coated polyester electrically conductive yarns (ECY) are stable environmentally, tremendous strength as per the requirement, and pliability [86]. Conductive yarn properties depend on wire types, diameters, and roving count [87]. Mechanical damage for conductive yarn is detected at less strain, with no indication of an electrical signal [88]. Shorter the distance between the layers of conductive yarns would result in better protection from the electric field [89]. Coating textile yarns by conducting polymers an immense variety with low surface resistivity of the conductive structure has been made [90].

Health Monitoring Based on Fabrics

Power system with self-sustainability in which the devices/tools of wearable energy harvesting and energy-storing are inserted/integrated [91]. Among all the preparatory processes of producing fabrics, woven made fabrics are found the best conductivity [92]. Conductive yarns from which smart clothing are made with outstanding corrosion protection property, and phenomenal uses of electromagnetic shielding in the field of e-textiles [93]. Military and civilian getting benefit from the conductivity-based fabrics made from conductive yarns especially of woven made structure [94]. Researchers made advancement in

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e-textiles by adding some technology-based features into sensors applications or through wireless communication technology. To perform diversity measurement, the neonate wears a baby jacket having patches (sensors) at six different positions that sense bipotential signals [95]. The exploitation of information and communication technology for healthcare systems presents a challenge to science [96]. A rapid change of interest in new sensing and monitoring devices for healthcare has witnessed in the last decade [97]. Woven fabric made from the electrospinning of PVDF yarns are highly sensitive, better time of response, and durability [98]. Plain weave fabrics have higher sensitivity as compared to satin and twill weave fabrics [99].

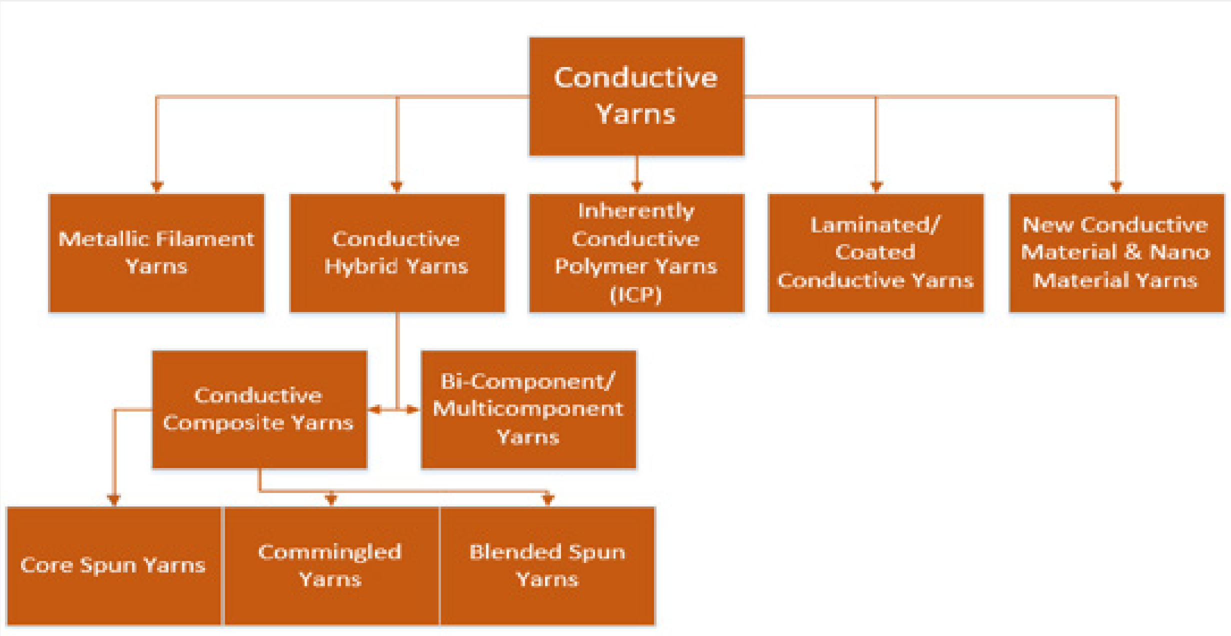

Figure 4: Classification of conductive yarns.

Conclusion

In this review paper, we have found that electrically conductive yarns (ECY) are highly sensitive and carry an electrical signal from one end to another. These signals are carried by the application of pressure/stress/load/force or by some mechanical means. Electrically conductive yarns with low resistivity can transmit high current with less or no obstruction. Electrically conductive yarns have many uses in the field of smart textiles or e-textiles such as smart socks, jackets, suits, etc. Smart socks comprise of conductive yarns in different positions such as heel, ball, and toe regions. The electrical signal is generated by applying pressure on the conductive yarns' regions and among these yarns' spandex provide soft-touch, quick-drying, and mildew resistance. The properties of conductive yarn depend on wire types, diameters, and materials characteristics. Electrically conductive yarns (ECY) of fibers like flax, glass, and polypropylene having graphene coating are tremendously known for better mechanical properties. In the medical field, nylon/Ag conductive yarns with high sensitivity, stability, and flexibility are used for health monitoring as well. The electrical conductivity of yarns decreases over time due to the washability factor. Researchers are still trying to make ECY having good electrical conductivity after washing several times. Moreover, Smart textiles may be used for energy harvesting, health monitoring, and biomedical sensors.

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