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REVIEW ARTICLE

Recent developments in textile based polymeric smart sensor for human health monitoring: A review

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Abstract In the modern age, the most important and prevailing issue is the monitoring of human health. To address this, several devices have been developed and a need new materials investigated. The idea of textile-based smart sensors is emerging rapidly. In this regard, ICPs and ECPs have attracted the attention of researchers due to their mechanical adaptability to suit the characteristics of textile fabric. The lighter weight, stretchability and wearability, etc. are considered an advantage while selecting the material for developing sensors not only in health monitoring but also in biomedical, sports, and military fields. The idea behind wearable sensing devices is to enable easy integration of the sensor device into daily life routines. Such wearable sensors also have the potential for real time and online monitoring of human health and integrate with smart monitoring devices. The purpose of this review is to discuss the recent developments in smart monitoring sensors.

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Contents

1. Introduction

With the progress in technology, there is also a need to develop new materials and resources for the betterment of human life. Nowadays, the development of smart sensors based on flexible material has explored new avenues for research by cutting down the structural barriers of traditional sensors (Tognetti et al., 2006). The traditional sensors and related gadgets were not ideal because their mechanical properties, conflicted with textile-woven structures. Therefore, flexible polymeric materials opened opportunities to develop a new class of smart sensors. Indeed, textiles are materials that can easily deform in all directions because of their flexible nature. Due to the inherent flexible properties of the polymeric material, such sensors would easily become part of the woven textile fabric and bear the bending, compression deformation, shear stress, and would not hamper the tensile strength of the fabric. Such sensors can be intimately incorporated in the textile structure and would have the ability to follow all these mechanical deformations without hindering the novel characteristics of textile such as feel, softness, etc. (Mahmoud, 2004).

Incessantly, human beings have aimed to detect and resolve health issues imparting morbidity and mortality. The prevalence of diseases often causes great pain and anxiety to people. To address sudden infirmity, work is succeeding gradually to evaluate the conditions by using a systematic pathway, including personal experience to simple auxiliary tools, and then examining all the collected evidence. It is now possible for medical professionals and organizations to accurately obtain real-time health status data, which is very helpful in diagnosing the disease and selecting appropriate medical measures to treat the disease (Kosack et al., 2017). To clinically diagnose disease(s) with a comfortable, wearable, non-invasive and efficient health monitoring system, a new concept based on stretchable/flexible sensors is proposed. These sensors work as an antenna to collect physiological data in many wearable health monitoring devices. For the last few years, various wearable sensor-based devices or gadgets have been developed and their properties also are changed to monitor the body conditions of a human being (X. Wang et al., 2017), such as wrist pulse (Nassar et al., 2017), vocalization (Tao et al., 2017), facial expression (Su et al., 2016), metabolism (Imani et al., 2016), breath and heart rate (Güder et al., 2016), etc. These wearable textiles-based sensors not only open the avenues towards innovations in telemedicine, biomonitoring, and rehabilitation, but also cause an evolution in several emerging fields of technology, such as people tele control, ergonomics, virtual augmented reality, wireless communication systems, and tele assistance (Carpi and De Rossi, 2005).

For the last 20 years, global research and development (R&D) is conventionally showing more interest in the field of sensors, in terms of published literature, financial contribution, and researches. It is well known that the purpose of a sensor is to provide data about our biological and physiochemical environment. Thus, new researches and invention of wearable sensor devicesis giving birth to numerous sensing gadgets for environmental and medical technologies (Sempionatto et al., 2019). The basic component of such devices are polymers, also known as electroactive conjugated polymers or intrinsically conductive polymers (ICP), and extrinsically conductive polymers. These materials exhibit properties of interest, formerly found only in inorganic materials, such as optical and electrical properties, to enhance smart monitoring. Actuators and sensors, which are embedded in textile, may be electrically powered and controlled by electronic devices integrated into the fabric (Takei et al., 2019).

These types of polymers are obtained by several methods such as electrochemical polymerization or chemical oxidation and electrochemical oxidation (Huynh and Haick, 2018). A polymer is an insulating material because it has no charge carrier within its structure, responsible for the conductance of charges. In majority of organic conjugated polymers, intrinsic charge carrier does not prevail. Therefore, external charge carriers are introduced in them to formulate these conductive polymers. However, conductive polymers can either reduce partially by accepting electrons or oxidize partially by donating their electrons (Dai, 2004). Hence, to generate conducting polymers, external charge carriers are to be integrated into them, this method is called doping (H. Wu et al., 2018).

2. Conducting polymers

Unlike ceramic and metals, polymers can be molded into a variety of complex structures. Before the discovery of conducting polymers, these are mostly used in non-electronic applications. After that, researchers from multiple disciplines contributed to research in this field and improved the conducting polymers. The conducting polymers can conduct electricity in a broad range like metals whereas at the same time they can also retain their polymeric mechanical properties (Burr et al., 2008; Fomo et al., 2019).

Conducting polymers are an essential component in the development of smart textiles, exhibiting a conductive or a semiconductive behavior, and are capable of conducting electricity and therefore, they are also referred to as organic polymers (Mattana, 2011). Till now, more than 25 conducting polymers have been discovered like polyacetylene, polyurethane, polyaniline, etc. (Benhamou and Hamouni, 2014). These materials exhibit both electrical and mechanical characteristics in plastics (S. Wang et al., 2019). These polymers have become prevailing conductive materials because they show comparatively high regulating electrical conductivity, can be customized to have sense, ease of preparation, biocompatibility, lightweight, flexibility, and relatively low cost. Conductive polymers combined the essential properties of conventional polymers and metals (Iqra Abdul Rashid et al., 2020).

Conducting polymers are divided into two subgroups (Kosack et al., 2017):

- Intrinsically conductive polymers
- Extrinsically conductive polymers

2.1. Intrinsically conductive polymers (ICP)

ICPs have grabbed attention as promising polymer materials having long conjugated double bonds in their backbone chain, these chains then combine to form intrinsically conductive polymers. The presence of these double bonds is a sign of enhanced conductivity of polymers. They can be synthesized simply by two methods *i.e.* chemical oxidative and electrochemical methods (Braeken et al., 2019). The most promising materials in these polymer groups are polyaniline, polyacetylene, polypyrrole, and poly (3,4-ethylene dioxythiophene), a derivative of polythiophene. They can be easily prepared and also illustrate good environmental stability and high electrical conductivity, but they show poor electrical characteristics (Heinze et al., 2010). From the last decade, to improve the low solubility of ICP, innovation in solution processing has occurred substantially. For example, in the case of polyaniline and polythiophene, solubility has to be improved by the chemical alteration of monomers with dopants (Majumder et al., 2017). A polymer needs to follow two conditions to become conductive, the first condition is that conductive polymers comprise alternating double and single bonds, known as conjugated double bonds. The second condition is that polymer configuration has to be intermittent by introducing electrons into it (reduction), or by removing electrons from it (oxidation) (Benhamou and Hamouni, 2014).

2.2. Extrinsically conductive polymers (ECP)

Another class of polymers is also synthesized by the blending (melt mixing or solvent mixing) of thermosetting plastic, thermoplastic or insulating polymer materials with conductive fillers. This class of polymers is referred to as conductive polymer composites (CPCs), or extrinsically conductive polymers (ECPs). Filler family include: ICP, Metal (Silver, stainless steel), Carbon (CB, CNT), oxide /non-organic (ITO, CuS). "However, they have much lower conductivity values then the ICPs (Grancarić et al., 2018)" but equal mechanical property (flexibility elongation). If we use CPC with 97% silver and 3% PU, conductivity will be close to conductivity of silver bulk but the CPC will be brittle.

3. Most commonly used ICPs in smart sensors

Various types of ICPs are used in the fabrication of smart sensors but the commonly used polymers are as follows:

3.1. Polyacetylene (PA)

Polyacetylene is a conducting polymer due to the simplest structure among all the other polymers. Its structure consists of a long chain of alternate double bonds arranging themselves in several ways to give different forms of structures like *trans*-Cisoid polyacetylene or *cis*-Transoid polyacetylene. It can be prepared with high conductivities as 10^3 S cm^{-1}. The degree

Fig. 1 Structure of polyacetylene.

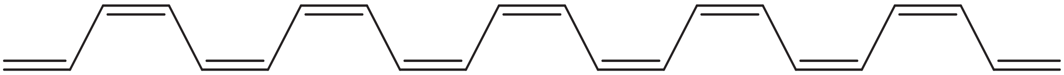

Fig. 2 Structure of *trans*-Cisoid polyacetylene.

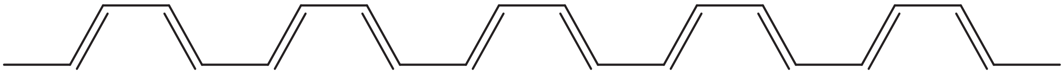

Fig. 3 Structure of *cis*-Transoid polyacetylene.

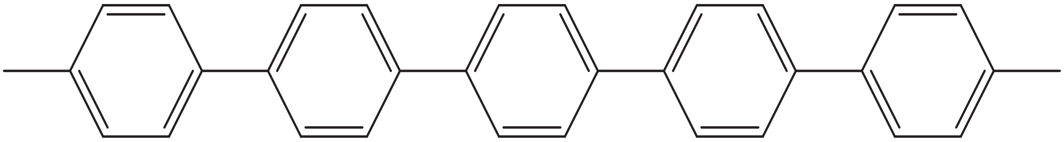

Fig. 4 Structure of polyparaphenylene.

of oxidation is a key parameter for the conductivity of polyacetylene and can extend between the range of 10^{-9} to 10^{3} S cm^{-1} comprising the semi-conductive and metallic systems (Mark, 2007). In the beginning, it was expected that organic chemists can tailor a pervasive family of conducting polymers just by substituting the hydrogens of polyacetylene with various functional groups and the properties could be varied systematically. Some derivatives of polyacetylene have also been prepared by replacing the hydrogens with phenyl or methyl groups. However, their conductivity cannot be elevated to a higher level due to less delocalization of electrons either by reducing or oxidizing agents. Thus, the significance of solid-state effects is increased by this failure and helps to define the electronic properties. Karasz and co-workers have revealed that to raise the conductivities of copolymer films of methyl acetylene and acetylene at the range of 50 S cm^{-1}, these polymers can be oxidized chemically with AsF_5 (Ishii et al., 2019) (See Figs. 1-3).

3.2. Polyparaphenylene (PPP)

Poly(p-phenylene) is another member of the family of conducting polymers. In 1979, for the first time, Ivory *et al.* synthesized PPP. Simply, benzene rings join through a single bond to each other to form long chains, giving rise to poly(p-phenylene). Ivory *et al.* were able to oxidize PPP using AsF_5 to raise its conductivity from 10^{-14} S cm^{-1} to 500 S cm^{-1} (Chow and Someya, 2020). N-type poly(p-phenylene) can also be prepared using alkali metals as reducing agents. Biphenyl, terphenyl, and tetraphenyl are the oligomers of poly(p-phenylene), react with AsF6 in an instantaneous oxidative polymerization, which leads to the formation of conducting poly(p-phenylene). When AsF_5 reacts with single crystal plate of terphenyl to develop PPP, this polymer exhibits strong electrical and optical anisotropy (Dias et al., 2019) (See Fig. 4).

3.3. Polypyrrole (PPy)

Polypyrrole (PPy) gained importance because of its stability in oxidized states and highly conductive nature. It also has some significant characteristics such as simple oxidation reaction and low-cost method, making it more advantageous over other conducting polymers. However, in comparison with PANI, pyrrole monomers have higher costs than aniline monomers, therefore they become less attractive for some potential purposes (Shi et al., 2021). At room temperature oxidized PPy is chemically stable relative to polyacetylene. Degradation of PPy only takes place when the temperature exceeds 150–300 °C (Fernandez et al., 2021). The electrical conductance of PPy ranges from 10 to 1000 S/cm depending on the presence of counter ions (Lekpittaya et al., 2004). Electrochemical polymerization of PPy can be carried out both in aqueous media or non-aqueous media as dichloromethane (Tamburri et al., 2009), acetonitrile (D. Wang et al., 2021), and propylene carbonate (She et al., 2021) (See Fig. 5).

3.4. Polythiophene (PT)

Both polythiophene and pyrrole have similar structures, but in polythiophene, the amine group of pyrrole is substituted by Sulphur. It has been stated that polythiophene particles synthesized by chemical polymerization, possess poor electrical conductivity (2×10^{-2} S/cm) (Ahmadian-Alam et al., 2021). However, the electrical conductivity of electrochemically poly-

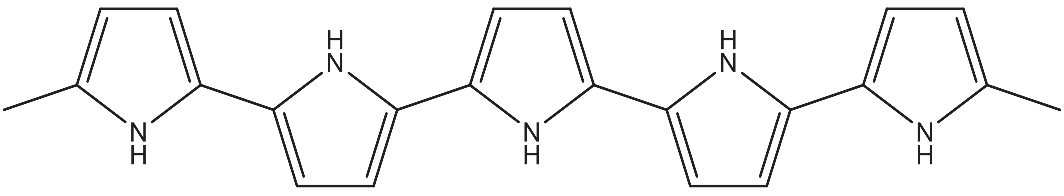

Fig. 5 Structure of polypyrrole.

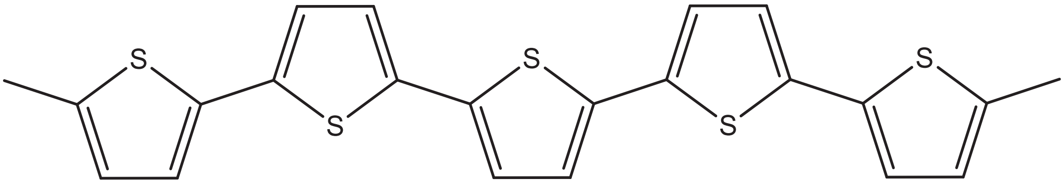

Fig. 6 Structure of polythiophene.

merized polythiophene (PT) is comparable with PPy (Iqra Abdul Rashid et al., 2020). Facchetti (Facchetti, 2011) have demonstrated the mechanism of electrochemical synthesis of polythiophene. As thiophene has a similar structure to the pyrrole therefore method to prepare it, is also comparable to PPy. For electrochemical polymerization of polythiophene, a non-aqueous media is used. The most commonly used electrolytes for polymerization are benzonitrile (Sapurina and Shishov, 2012), Acetonitrile (Balint et al., 2014; Tamburri et al., 2009), and propylene carbonate (Ramanathan et al., 2007). One of the most widely studied polymers of today is Poly (3,4-ethylene dioxythiophene) (PEDOT) because of its stability and tunable electrical conductivity. In the doped state, it shows higher conductivity than that of the PPy, which can further be improved by post-treatment or blending methods (Xu et al., 2021). Moreover, the highly stable oxidized state facilitates it to keep up with conductivity for a considerable length of time even at high temperatures and thus making it an excellent material for the electrode of an actuator. Besides these, the synthesis of PEDOT by easy and simple methods like electrochemical or chemical reaction, makes it more useful (Yang et al., 2020) (See Fig. 6).

3.5. Polyaniline (PANI)

The most commonly conductive polymer is polyaniline (PANI). PANI has considerable properties like high chemical stability, cheap monomers, high value of capacitance, tunable properties, and ease of synthesis. Due to these properties, this polymer has high significance over other conducting polymers. PANI doped with counter ions always degrades thermally at a temperature higher than 200 ^{0}C (Koncar et al., 2009). PANI exhibits good electrical conductivity ranging from 10 to 100 S/cm (Lekpittaya et al., 2004). The degree of doping, oxidation level, molecular weight, and fraction of crystallinity is considered to be the tuning tools to control electrical conductivity. PANI can be transformed into two forms, either in protonated form by reduction or deprotonated form by oxidation (A. Liu et al., 2021). During the electrochemical polymerization process of PANI, if the value of pH of the solution is too high then sides are generated. Therefore, PANI is always polymerized in the presence of an acidic environment. If polyaniline is prepared in neutral, basic, or weak acidic media then the conductivity of the final product decreases (Bashir, 2013; M. F. Shakir et al., 2020) (See Fig. 7).

4. Methods of preparing intrinsically conducting polymers

4.1. Electrochemical polymerization

For the preparation of conducting polymers, different procedures are available. However, the general method to prepare electrically conducting polymers is electrochemical synthesis which is the most preferred method because of its reproducibility and simplicity (Hsiao et al., 2018). By this method, a thin layer of polymer can be produced, and also by altering the parameters of electrochemical polymerization such as time of electro-polymerization and current density, the viscosity of film can be precisely controlled (Wustoni et al., 2020). The polymerization can undergo oxidative (Gerard et al., 2002) as well as reductive reaction(s) (Malinauskas, 2001). During this method, few factors should be considered, for example, applied voltage versus applied current and the selection of electrolytes. Because, physical and electrical properties of electrically conducting polymer are significantly affected by these factors (Gerard et al., 2002).

Usually, an electrochemical cell is used for the electrochemical coating. This cell is comprised of three electrodes; one is designated as a working electrode on which substrate is to be coated and the other is a counter electrode and reference electrode made up of inert materials usually platinum and Ag/AgCl or Saturated Calomel Electrode (SCE) respectively. The polymerization solution consists of supporting electrolyte, solvent, and monomer. This method is further classified into potentiostatic, potentiodynamic, and galvanostatic electropolymerization (Advincula, 2015). This method is beneficial as it is simple and appropriate for practical application, and by specifying the time during polymerization, the thickness of the polymer film can be controlled (Zhou et al., 2021) (See Fig. 8).

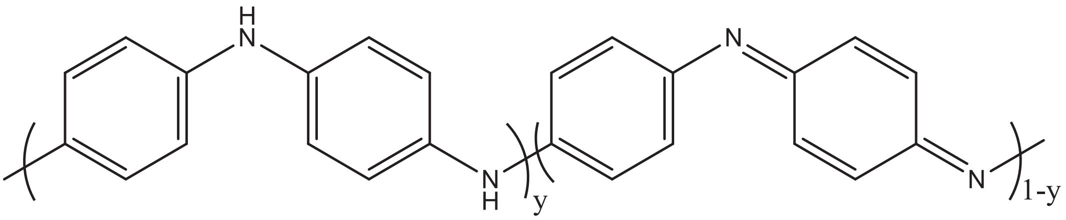

Fig. 7 Structure of polyaniline.

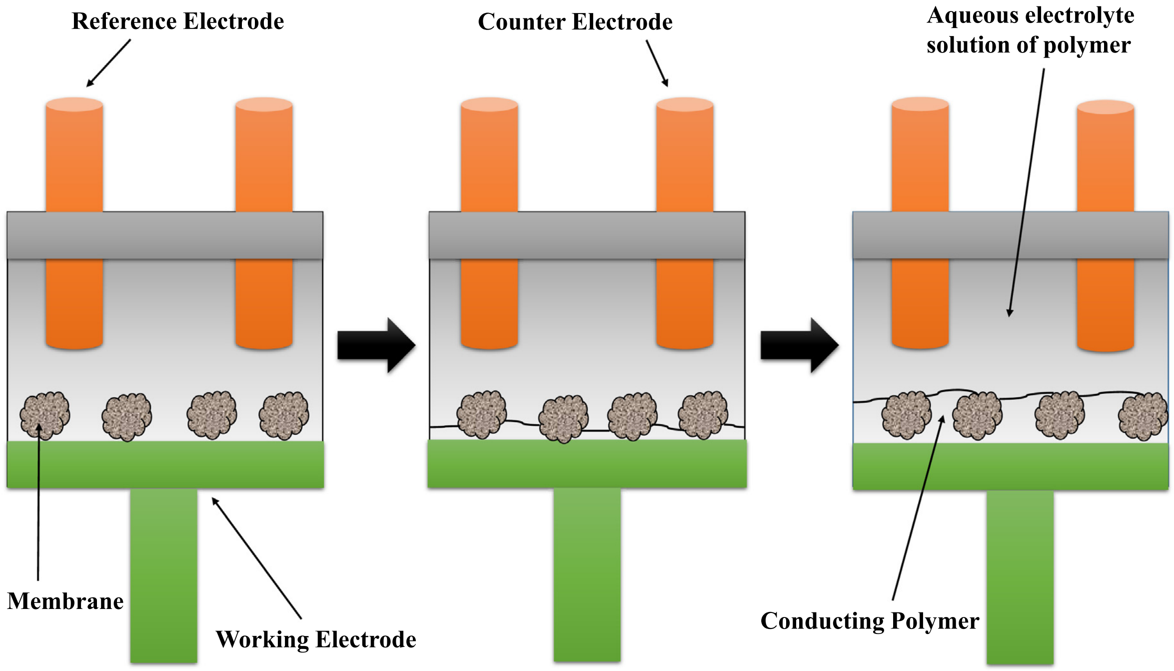

Fig. 8 Electrochemical polymerization.

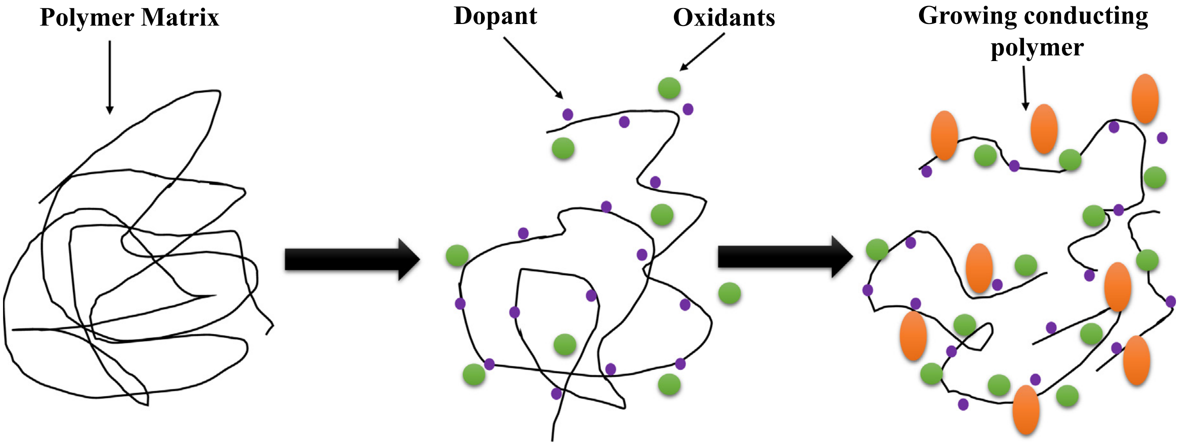

Fig. 9 Method of polymer's doping.

4.2. Doping

Inorganic conjugated polymers, the doping reaction is a reaction to transfer the charge, resulting in reduction or oxidation of the polymer instead of the formation of holes. It is possible to attain high electrical conductivity if the conducting polymers are to be doped with a suitable dopant. For example, if the polymer is polymerized in the presence of a sulphonate dopant then it can result in better conductivity. Conducting polymers have an enormous molecular difference in their types *i.e.* polyvinyl chloride**,** polystyrene, etc. this property helps in the preparation of conducting polymer-coated textiles under definite polymerization conditions or by simple modifications of monomers (Hebeish et al., 2016) (See Fig. 9).

The physio-mechanical properties of conductive textile are affected by oxidants, monomers, dopant anions, and fabrication parameters like pH, temperature, time and the flow of liquor in the coating vessel. To reduce the formation of side products, polymerization has to be done at low temperature which restrains the completion and continuation of the polymerization reaction (Gioello, 1982). Elasticity and potential flexibility are the foremost advantages of conductive polymer-based sensors having compatibility with textile structures. Moreover, all the parameters of these materials such as temperature variation, electrical conductivity, UV radiations and moisture are observable and therefore can be measured (Krupa et al., 2004). The technique is beneficial because by controlling the mobility and size of dopant counter ions, the

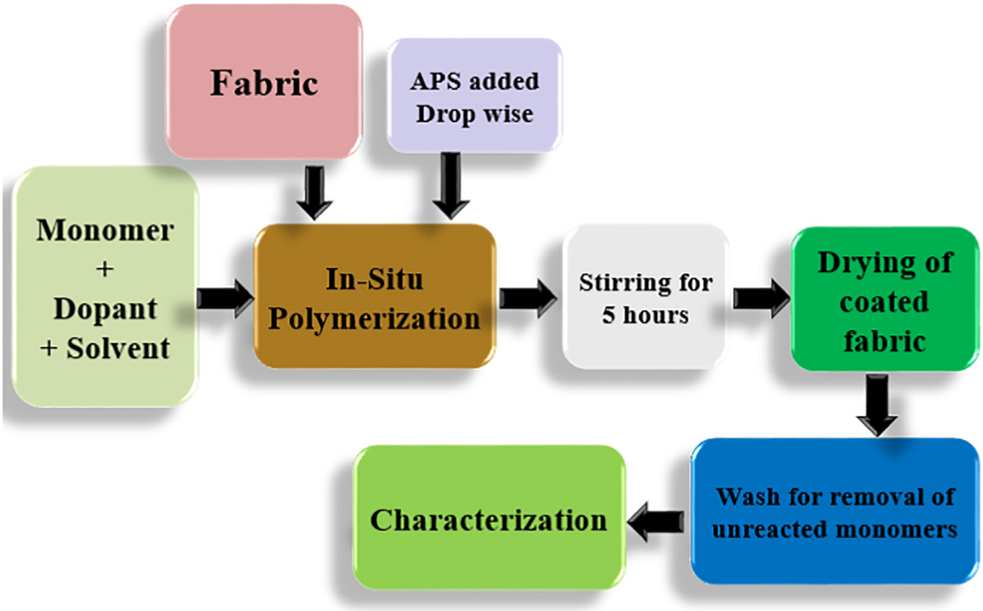

Fig. 10 Flow diagram of preparing conducting textiles.

properties like mechanical, optical, and electrochemical of the doped conjugated polymers can be tailored (Scholes et al., 2017) (See Fig. 10).

5. Applications of conducting polymers

Conducting polymer exhibits unique characteristics due to the presence of multi-components and their synergetic/combined effect. Therefore, these conducting polymers are likely to find applications in several disciplines, such as sensors, catalysis or electrocatalysis, energy, biomedicine, nano-electronic devices, electrorheological (ER) fluids, chemical or biological sensors, EMI shielding, and microwave absorption (Das and Prusty, 2012; Iqra A Rashid et al., 2021) (See Fig. 11).

6. Textile or clothing

Currently, textiles have numerous applications almost in all human activities. As compared to other materials, they also have various advantages *i.e.* strength, flexibility, and ductility. Due to these reasons, the recent integration of multifunctional properties in such an ordinary material has become an innovative step towards the upcoming generation of textiles (Gorgutsa et al., 2014). Advances both in nanotechnology and materials science have provided novel strategies for system's design in applications like healthcare industries (Paradiso et al., 2005), sports training (Tang and Stylios, 2006), working wear and military (Libertino et al., 2018). Textile innovation about 27,000 years ago can be considered as the first of humanity's inventions of material (Y. Ma et al., 2021). Humanity's need for textiles has been consolidated in the passing millennia either for protection against the environment or his desire to convey a message about them themselves; whether it would be wealth-related, stylistic, or artistic. The textile creation has been therefore closely coupled with key innovations that shaped the society *i.e.* the knitting frame by William Lee in 1859 (L. Wang et al., 2021), Spinning jenny by James Hargreaves around 1765, and the flying shuttle by John Kay in 1733 (Zhang et al., 2021), which laid the foundation for the first industrial revolution.

Textile is a porous and flexible material, prepared by knitting, braiding, nonwoven or weaving synthetic, natural fibers, or artificial fibers *i.e.* polyester or cotton (Shim et al., 2008). Fabrics are fibrous materials with a hierarchical structure. The first integration level or smaller units are known as fibers and can be characterized by a high ratio of thickness to length; these units are intertwined to form a thread (Castano and Flatau, 2014). The second integration level is the twisting of thread to form yarn. The yarn then gets turned into fabric in the third integration level utilizing different techniques like knitting and weaving (Lomov et al., 2001). Fabrics being new wafers of silicon have generated much interest owing to the advent of soft computing and portable devices. Structurally, woven and knitted fabrics were used for electronic clothing that can be worn for observation. Flexibility is the main advantage of textiles relating to a few extents of wearing comfort.

Knitted fabrics possess the advantage of being deformable and stretchable to some extent have been employed where the need of fabrics to be in fitting or close to the body, for example, for sportswear or leotards. Woven fabrics are comparatively best suited where large body movements are not a significant factor and provide more dimension stability. Exploring the functions of duality, weft and warps interlacing within woven fabrics have been discovered as electrical circuit's network along with supporting material for the integrated electron (Dhawan et al., 2004). The fabric's nature makes them an ideal tool for designing sensors that have direct contact with humans. An important role is played by the origin or nature of fiber units such that natural, regenerated, or synthetic which decides the final fabric characteristics. Synthetic fibers have less absorption of water thus they are more hydrophobic in nature compared to natural ones which are

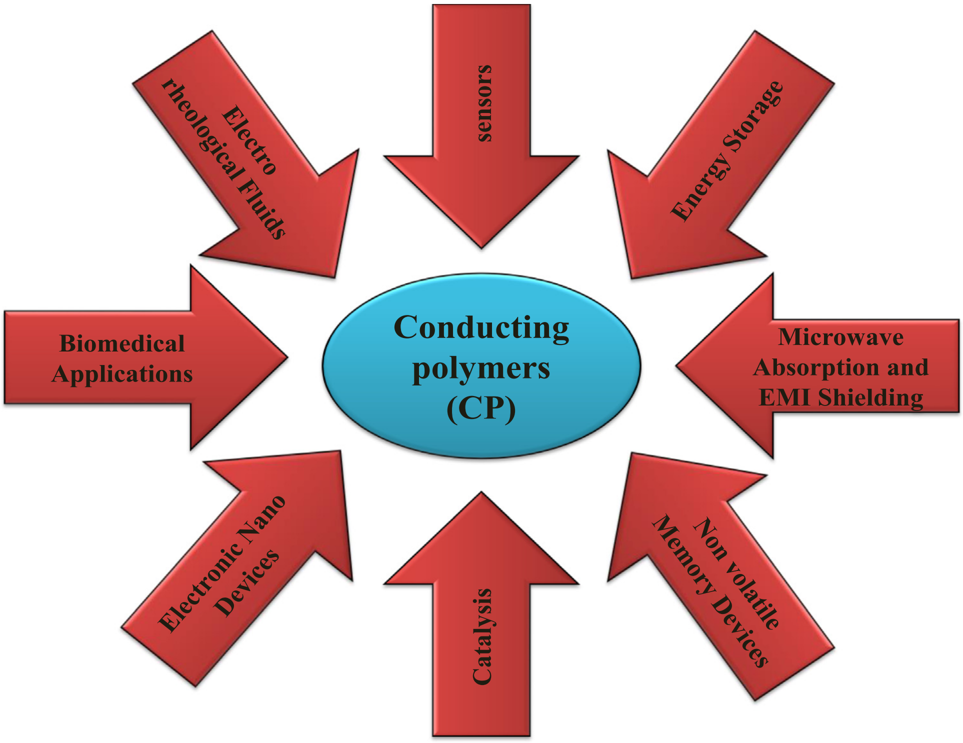

Fig. 11 Applications of conducting polymers.

hydrophilic and also exhibit better mechanical agreement (Koe, 2017). Various fiber types like acrylic, polyester, nylon and natural fibers have been reported in the manufacturing of fabrics by several methods (Lam Po Tang, 2007). Among the methods, we list knitting, sewing, non-woven textile (Castano and Flatau, 2014), embroidering (Tognetti et al., 2006), braiding (Castano and Flatau, 2014), spinning, weaving (Langereis et al., 2013), printing, laminating/coating, and chemical treatments (Gu, 2021), and providing significant features like controlled hydrophobic behavior.

7. Methods of coating textile

The coating is a method of applying a formulated compound or viscous fluid (liquid) on a textile substrate. It can be applied to fabrics, yarns, or surface of fibers to develop electrically conductive textiles. Such a method is appropriate for applying on many types of fiber capable of generating good conductivity considerably without alteration of existing properties of the substrate like handling, flexibility, and density (Meoli, 2002). The coating of polymer is usually carried out with a conductive coating paste. (CPC).

Coating methods for conductive textiles can be attained via

7.1. In situ polymerization

While employing *in situ* polymerization, all the reagents and fiber materials are added at a time. Chemical polymerization takes place within the bulk solution and polymers so produced, either precipitate out as insoluble entities or deposit impulsively on immersed fiber's surface as shown in figure 12 (Sasso et al., 2011). Bulk polymerization has to be carried on the surface of the fabric as much as possible for a better result of coating. Usually, this can be attained by selecting an opti-

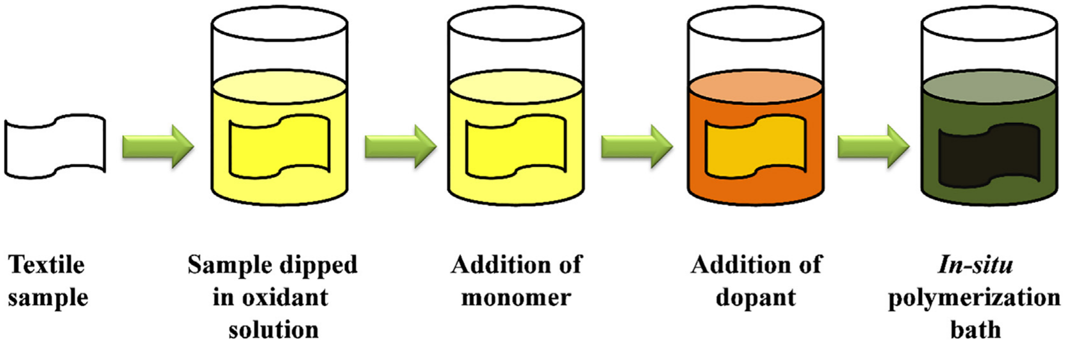

Fig. 12 In situ polymerization method.

Fig. 13 Conductive coated textile fabrics.

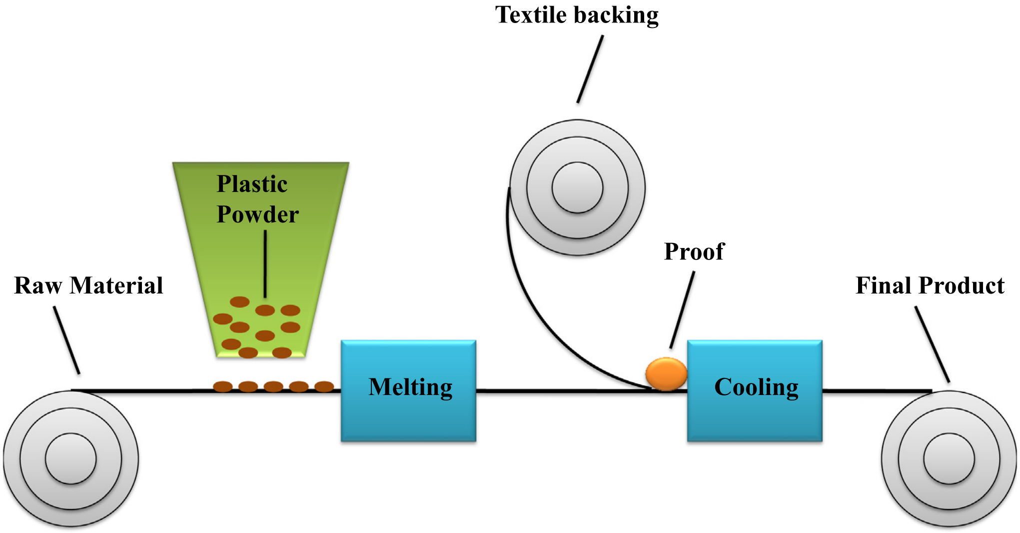

Fig. 14 Two-step polymerization method.

mal condition for reaction *i.e.* ratio and concentration of reactants, the temperature of the reaction, and suitable treatment of the surface of the material for coating (Qu and Skorobogatiy, 2015). Besides these, *in situ* polymerization also has various advantages such as ease to mechanize, use of cost-effective materials, and the capability to assimilate with several other curing and heating methods. Such polymer composites, which cannot be processed by melt and solution processing due to their insolubility and thermal instability, can easily be prepared by this method. This method also gives very good miscibility with almost any types of polymer (Iqra Abdul Rashid et al., 2020) (See Figs. 12 and 13).

7.2. Two-step polymerization

In this method, fiber materials firstly adsorb certain reagents and then initialize polymerization reaction by adding the rest of the reagents. In the first step, textiles are subjected normally to agitation, heating, padding, or ultrasonic vibration treatment for promoting the reagent's penetration into their structure. The surface undercoating process should be enriched with oxidizing agents or with monomers; the main distinctive purpose of such processes is the polymerization exclusively takes place at the surface and possibly within the structure of the fiber. This process however is not suited for a few textile materials that are not enriched sufficiently with either oxidants or monomers layer in a separate step preceding the polymerization of the surface (Malinauskas, 2001). Due to several kinds of conducting polymers along with their innumerable molecular differences, specific conditions of polymerization of simple monomers modification allows the textiles coated with conductive polymer to suit various application (See Figs. 14).

7.3. Chemical vapor deposition (CVD)

CVD is another process for coating conducting polymers. This process comprises of two stages for coating polymers to develop electro-conductive materials. The CVD process, being

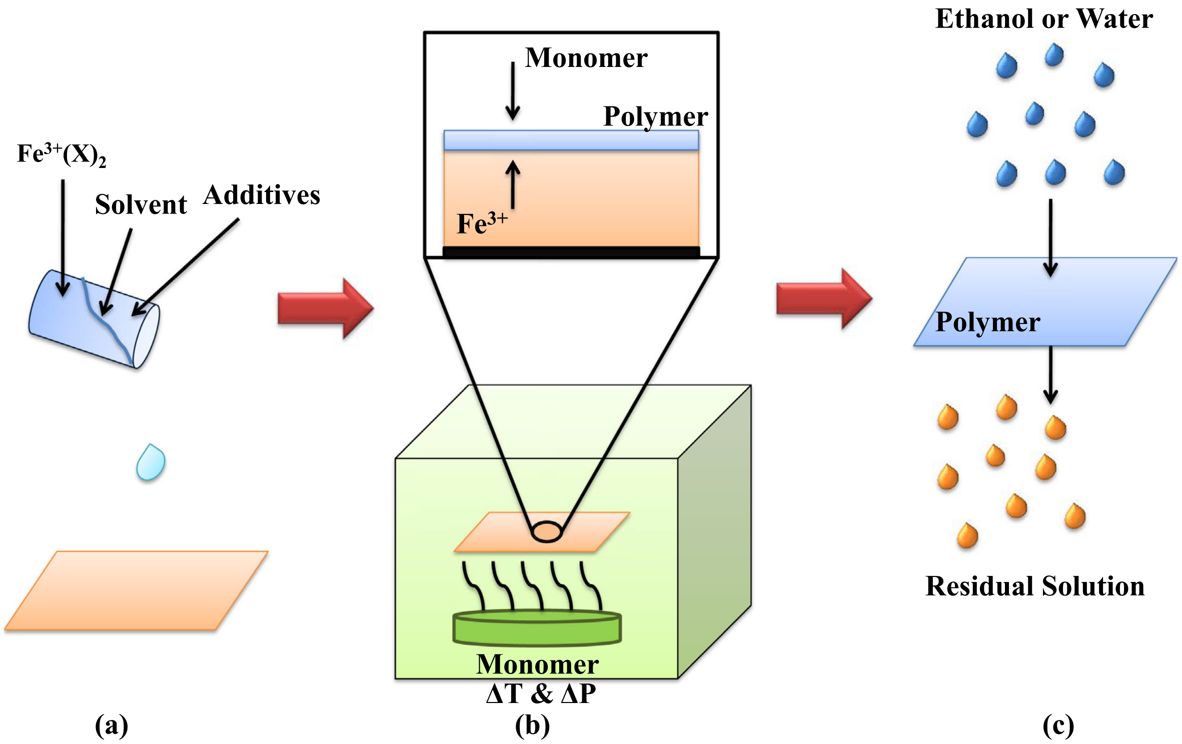

Fig. 15 Chemical Vapor Deposition.

economical, allows the unreacted monomers as well as oxidant and dopant solutions to be easily recovered. Fabrics coated with the vapor phase deposition method exhibit a uniform coating on the fiber's surface as the oxidant and dopant have been evenly applied on the surface of fiber in polymerization. This method produces nanoparticles having low aggregation, increasing the coverage of the surface area, and also causes better connection among polymeric chains. Hence results in increased conductivity of conducting polymers as compared to aqueous coating (Cucchi et al., 2009). The bonding among conducting fibers and polymers determines the actual coating tendency of the polymer on the substrate. Fibers of animals, such as wool, can also be a good option as substrate material for conductive polymers to get attached on its surface, owing to functional group abundance, to which dopant anion and polymer molecules can attach by bonds like ionic or hydrogen bonds. Also, the wool fibers' surface morphology provides adsorption sites for conductive polymers (Huynh and Haick, 2018). This method also has various advantages like a wide variety of substances can be deposited with high purity, has a high deposition rate, and enables uniform coating. Other than these, CVD does not require high vacuum process and is therefore economical in production, since many parts can be coated at the same time (Achard et al., 2020) (See Figs. 15).

8. Smart sensors and their applications

Sensors are the key component for monitoring applications in wearable electronic systems, that collect information from the wearer and transmit it to a processer. Innovations in monitoring have developed garments and vests, incorporated with various sensors which provide physiological data like heart rate, skin conductivity, body temperature, etc., and location information, by satellite services (Goulev et al., 2004). Various traditional sensors have been made depending on their requirements and size. Conducting materials like carbons or metals can be integrated into smart textile sensors. However, recent study inclinations are making use of the new array of polymers to build up flexible sensors from textile materials, due to their varying properties with the environmental conditions, *i.e.* change in temperature, pressure, and moisture, etc. Thus, for use in textile and smart clothing, new flexible sensors have especially been prepared (Lam Po Tang, 2007).

In smart clothing, sensors work as sensory nervous system that detects the signals and transmits the data to the processor. Conductive polymers are proficient in responding electrically to changes in their molecular structure that are caused by ambient radiations, changes in temperatures, or disclosure to volatile substances (Zubair et al., 2021). Baby pajamas to support in averting cot death, an electronic bra to detect breast cancer, and the LifeShirt system (monitoring physiological measurements) are modern examples of textile integrated sensors. The implication of such types of accessories or garments covers several fields such as the military, sports, rescue, clinical, or healthcare, where the detection of crucial signs is indispensable. In the medical sector, for continuous long-term observation of patients' conditions, smart monitoring garments can be used. They also provide latent assistance to fight against cot death in babies (Hibbert, 2004; H. F. Shakir et al., 2019). Various smart sensors and their applications are briefly described in Table 1.

Real-time information about the physiological actions and conditions of a person can be monitored and recorded via these wearable sensory devices. Sensor-based wearable health monitoring devices may consist of various sorts of flexible

Table 1 Various sensors and their applications.

Sensor type	Polymer used	Fields of applications	Special features	Ref.
Capacitive Sensors	Poly(3,4 ethylene dioxythiophene): poly (styrene sulfonate) (PEDOT: PSS) perfluoro polymer (Cytop)	Sensitive to pressure in the range of human touch	The weaving technique and die-coating system are used	(Takamatsu et al., 2012)
Piezoelectric Sensors	Polyvinylidene fluoride (PVDF)	Sensor for monitoring cardiopulmonary activity	Equipped with an advanced electronic control unit and wireless communication support	(Lanata et al., 2009)
Piezoelectric Sensors	Poly (vinylidene fluoride-co-trifluoroethylene)	Sensitive to strain and stress actions	Melt spinning process is used to obtain filaments	(Kechiche et al., 2013)
Piezoelectric Sensors	Poly(vinylidene fluoride) (PVDF), high density polyethylene (HDPE)	Used to detect the heartbeat of a human.	Carbon black (CB) is added to make conductive composites	(Nilsson et al., 2013)
Piezoelectric Sensors	Polypyrrole/polyurethane (PPy/PU) elastomer	A waistband-like detector to monitor human's breath	A dopant anthraquinone-2-sulfonic acid sodium was added to enhance the conductivity of the sensor	(Balint et al., 2014)
Piezoresistive Sensors	Thermoplastic elastomer (PPyTPE)	Can detect 27 postures of upper body	Silicone film was used to realize the attachment of sensor thread to textiles	(Mattmann et al., 2008)
Piezoresistive Sensors	Polypyrrole	Intelligent knee sleeve to monitor strain	Ferric chloride (FeCl3) as oxidant and 1,5 naphthalene sulfonic acid tetrahydrate (NDSA) as dopant was used	(Munro et al., 2008)
Piezoresistive Sensors	Polyaniline (PANI)	Strain sensor	Ammonium persulphate was used for polymerization	(Muthukumar and Thilagavathi, 2012)
Piezoresistive Sensors	PU/PEDOT: PSS	PU/PEDOT: PSS fibers were co-knitted with a commercial Spandex yarn.	Polymer-coated fibers and commercial Spandex yarn were co-knitted by wet spinning process	(Seyedin et al., 2015)
Piezoresistive Sensors	Elastomer	Strain sensor for rapid prototyping human interfaces	CNT is sandwiched between two polymer sheets and work as an electrode	(Yamaji et al., 2017)

Table 2 Some Pressure sensing devices.

Shape of device	Material used	Types of fabric	Fabrication methods	References
Small patches of fabric	PANI and Hydrochloric acid (PANI/HCl) solutions	Nonwoven cotton fabric	Immersion and printing	(Liu et al., 2019)
Socks	Polycarbonate (PC) and polymethylmethacrylate (PMMA)	Knitted fabric	Immersion	(Guignier et al., 2019)
Fabric pads	Polypyrrole(PPy)	Cellulose fiber of cotton	*The in-situ* vapor growth method	(Lin et al., 2020)
Bands	Polyaniline (PANI) and PANI/nano-silver	Cotton-woven twill fabric	Stirring	(Z. Ma et al., 2020)
Vest	[3-(methacryloyloxy) propyl] trimethoxysilane and copper	linen woven fabrics	Immersion	(Z. Liu et al., 2021)
Socks	Graphene oxide (GO), Polystyrene (PS), polymethyl methacrylate (PMMA), polydimethylsiloxane (PDMS), poly(dimethylsiloxane)-graft-polyacrylates (PDMSg-PAA)	Cotton fabric	Breath figure method	(Zhang et al., 2021)

sensors that can either be incorporated into clothes, elastic bands, and textile fibers or directly attached to the human body. The sensors are proficient in computing physiological signals such as blood pressure (BP), body temperature, respiration rate (RR), heart rate (HR), arterial oxygen saturation (SpO2), electromyogram (EMG), electro-dermal activity (EDA) and electrocardiogram (ECG) (Nemati et al., 2012; Pantelopoulos and Bourbakis, 2009). Several diseases such as neurological, cardiovascular, and pulmonary diseases at their early stage can be detected and diagnosed with continuous monitoring of physiological signs. Also, these sensory devices are very feasible in real-time monitoring of an individual's activities, proving very helpful in posture analysis, gait pattern, sleep assessment, and fall detection. The sensory gadgets connected in a wireless Body Sensor Network (BSN) (Al Ameen et al., 2012; Dementyev et al., 2013), firstly collect data and con-

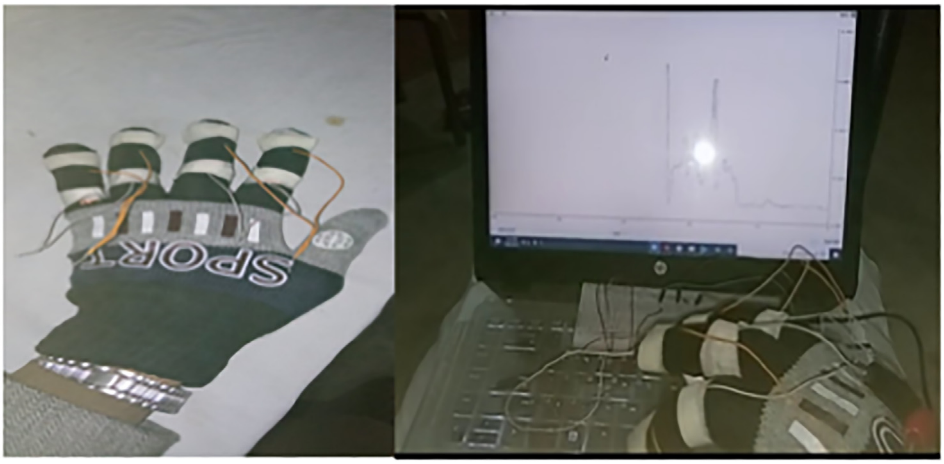

Fig. 16 Fingers movement monitoring.

vey it to the processing unit using an appropriate communication protocol, preferably a short-range and low-power wireless media, such as ANT+ (Coskun et al., 2013; Mehmood and Culmone, 2015), Bluetooth (Chintala et al., 2020; Suzuki et al., 2013), Near Field Communications (NFC) (Lam Po Tang, 2007; Pang et al., 2015) and ZigBee (Valchinov et al., 2014). Various pressure sensors and their fabrication methods are briefly described Table 2.

8.1. Movement and postures monitoring

For monitoring the movement and postures, various archetypes have been developed that assist in rehabilitation and help to improve body postures as well as reduce sports and other injuries. Previously, these devices did not get recognition because of some disadvantages such as being heavyweight, bulky to wear as well as not easy to remove, because they had to be directly attached to the body for data acquisition . Recently, the concept of integrated or firmly attached sensors within textile has changed the perception about sensors being uncomfortable. Most flexible sensors are based on the principle that stretching causes variation in the electrical resistance of these devices. In 1986, Neilly made good efforts to develop stress and strain sensors for fabrics and became the first researcher to explore these flexible sensors that can be prepared from piezo-electric polyvinylidene fluoride (PVDF) polymer films. Though, the developed films have some limitations for example tensile stiffness, electromagnetic interference, sensitivity to temperature, and transitory output signals, which limited their usage in wearable textiles. A simple, latest but successful innovation, is a knee sleeve based on a fabric strain sensor, which acts as a biofeedback gadget and sends information in the form of beeping sound after monitoring the movements of the wearer's knee during physical activity. However, these sensors have been developed as disposable devices because of having a limited lifetime (King et al., 2014).

Prototypes with durable and complex accessories, and garments *i.e.* leotards, gloves, and jackets having sensors attached to their surfaces, exhibit the ability to monitor or sense the physical activities and positions of different parts of the human body. In coated fabrics, polypyrrole has particularly been investigated for coating applications (Farringdon et al., 1999). Such materials have been found to have transducing properties *i.e.* strain gauges, topology change, and exhibit a decrease in the value of electrical resistance as physical deformation occurs. In 2005, De Rossi *et al.,* described gauge factors of sensors comparable to gauge factor of nickel. Although, they have also described that with time sensor also shows a strong variation in resistance, and the response time of material alters (Anwary et al., 2021; Tao et al., 2017).

Flexible wearable sensors are gaining more attention with the advancement of wearable sensing tools. In this search, one more textile-based polymer-coated sensor was prepared. Firstly, polyaniline (PANI) was obtained by the *in-situ* polymerization of aniline. Then PANI was coated on cotton knitted fabric by the method of deposition to fabricate conductive fabric. This conductive knitted fabric gives satisfactory sensing performance with maximum gauge factor and high linearity. So this device can be used for the monitoring of human physical signs and movement by studying the change in resistance of the fabric sensor during the movement of different parts of the human body, like knees, throat, fingers, and elbows (Zhou et al., 2021) (See Figs. 16).

8.2. Strain and stretch sensing

For the measurement of movement at different strain ranges, wearable strain gauges can be applied instead of conventional strain gauges. These strain gauges are made up of conducting polymer-coated textile materials. De Rossi and co-workers investigated flexible strain gauges using conducting polymer-coated textiles for the first time in 2009. He stated that piezoresistive properties of these coated materials are due to the presence of conductive elements that facilitate in detecting local strain on textile fabric Özdemir and Kilinç (2015). Another investigation is focusing on the fabrication of wearable strain gauges prepared from conducting polypyrrole coated nylon Lycra fabric, to be able to do biomechanical monitoring; for example intelligent knee sleeve. This knee sleeve sends a response to the player by producing an audio tone and is manufactured using conducting polypyrrole coated Lycra strip. When the coated textile/fabric material is stretched out, the resistance of the fabric varies resulting in a variation in the output of an electronic circuit. Therefore, according to strain produced by coated fabric, different audio tones are emitted providing a real time feedback to its user (Munro et al., 2008).

In several fields of applications, the main area of focus is analyzing gesture and posture and also the monitoring of body kinematics. In 2000, the University of Pisa, Italy, developed a leotard based on elastic fabric (Lycra) coated with a conductive polymer. Using a wet process, more than 20 sensors were applied onto the fabric comprising of direct deposition of polypyrrole layers on fibers in an epitaxial position via a mask-based process for proper patterning of the sensorized areas. The coated fabrics possess significant strain sensing qualities: 0–30 Hz bandwidth, TCGF = 0.02 gauge factor's temperature coefficient, and GF = -12 gauge factor. This sensor has been used to monitor movements and postures of the trunk and several parts of the body such as elbow joints of the spine, vertebral column, glenohumeral, and scapular segment (De Rossi et al., 2000).

In 2005, the Institute of Textiles and Clothing, Hong Kong Polytechnic University developed polypyrrole-coated fabrics based on flexible strain sensors by both chemical vapor deposition and *in situ* polymerization. Flexible strain sensors prepared by these materials exhibit good stability and high sensitivity. Different techniques that have been used to enhance the stability and sensitivity of the sensors, include: (a) polymerization of pyrrole at low temperature, (b) strengthening of fabrics coated with conductive polypyrrole (c) use of chemical vapor deposition (CVD) method for the deposition of thin coatings of polypyrrole on the fabric surface, and (d) introduction of large anion *i.e.*, dodecyl benzene sulfonate in polypyrrole film.

In the CVD method, plain knitted Lycra fabric was used. Firstly, the fabric was immersed in sodium dodecylbenzene sulfonate aqueous solution and then ethanol solution of $FeCl_3$ in sequence, and by a padding machine wet take-up was controlled at ~100% after each immersion to prepare flexible strain sensors. The conductivity strain tests reveal that the prepared sensor shows a high strain sensitivity of ~80 for a deformation that is as large as 50%, while by small variations in conductivity and sensitivity its stability can be maintained for more than 9 months.

While in solution polymerization or *in-situ* polymerization, PPy-coated fabric is prepared by soaking the fabric in an aqueous solution of $FeCl_3$ and then adding the pyrrole and sodium dodecylbenzene sulfonate aqueous solution in a flask slowly with continuous stirring. The whole process is to take place at room temperature and at the end of the procedure the obtained fabric is to be washed with water and ethanol, , and then dried in vacuum. The polypyrrole-coated fabric finds its applications in rehabilitation, wearable hardwareand sensing garment, etc. (Li et al., 2005).

In 2005, Intelligent Polymer Research Institute, University of Wollongong, Australia, also developed a conducting polypyrrole-coated textile based on nylon Lycra. This sensing fabric was prepared using an *in situ* chemical polymerization method. White nylon Lycra fabric, ferric chloride as an oxidizing agent, and 1,5-naphthalene sulfonic acid tetra-hydrate as a dopant were used in the preparation of the sensor. A piece of fabric was immersed in an aqueous solution having both dopant and pyrrole monomer, and then to initialize the polymerization on the surface of the fabric, $FeCl_3$ solution was added into the flask. The obtained fabric could acquire the shape of different parts of the human body and function ideally as biomechanical wearable sensor, so it could be used in various applications to measure the movement of different human body parts. Generally, conductive PPy-coated nylon Lycra fabric was less stable in the air because it reacts immediately with many atmospheric chemicals, particularly oxygen. This novel method can be widely used for medical treatment, rehabilitation, injury prevention, and for the improvement in sporting techniques (J. Wu et al., 2005).

In India PSG College of Technology reported that polyaniline coated conductive fabric was also prepared by using *in situ* chemical polymerization method. Plain woven polyester fabric GSM 86 was used as a coating substrate and all other chemicals were obtained from S.D. Fine Chemicals Ltd., India. In this process, aniline was dissolved in HCl solutions for diffusion. The dry pre-weight fabric sample was placed in the solution and allowed to soak well and dopant ammonium persulfate was separately dissolved in HCl solution for polymerization. After that, the polyaniline-coated fabric was taken out and washed in distilled water containing HCl and was dried. These coated textiles are used as smart sensors to sense a stretch in the body (Muthukumar and Thilagavathi, 2012).

8.3. Pressure monitoring

Pressure sensors are used commonly as interfaces and switches within electronic devices for monitoring vital user signs. Various technologies have been developed to prepare pressure sensors (Ashruf, 2002; Rothmaier et al., 2008). The principle of its operation is the variation in resonance frequency of piezoelectric charge is created through overlaid elastic foam within the matrix of conductive threads under applied pressure or change in capacitance. In capacitive sensors, the variation in parasitic resistance and capacitance can be reimbursed via electronics thus wiring has a marginal influence on sensed signals.

Matrix with a variety of pressure capacitive sensors has been developed by the Computing Wearable Lab of Zurich ETH for integration in textiles. With such a method, they are capable to calculate the pressure on the body of humans thus detecting muscle activity of the upper arm. Application of this matrix on different areas of the body can give more details about the tracking of motion or the physical state of muscles (Meyer et al., 2006). The British Eleksen Limited Company (formerly known as Electro-textiles) commercialized soft and sensory fabrics based on flexible textile using a mixture of conductive nylon and fibers under Tradename Elektex® (Smart Fabric Interfaces).. Such combinations result in 3D structures that are reasonable in price, durable, wearable, and washable.

A soft-touch keyboard "KeyCaseTM" had been manufactured by an American-based company known as Logitech Inc. (Le Lieu; Switzerland) having the ability to wrap PDA (Personal Digital Assistant) for protection and storage. This keyboard is made up of textile and is light in weight. The company of U.S "Pressure Profile Systems" Inc. (Los Angeles, CA, USA) develops, designs, and manufactures multi-element tactile and pressure sensing systems with high performance known as ConTacts and Tactarray. Similarly, the Centre of Design at Brunel University in the UK has prepared the sensory fabric for handicapped children to make themselves understood. These fabrics are composed of two layers of electric conductive textiles separated by a non-conductive mesh layer. Conductive layer comes in contact with each other when the textile is pressurized causing the flow of electric stream (Stoppa and Chiolerio, 2014). The Center team of Istituto Italiano di Tecnologia for Micro-Bio Robotics in Pisa, Italy has prepared three axial composite capacitive sensors completely based upon conductive fabrics (commercial) having high stability and compliance under manipulation (Viry et al., 2014).

8.4. For electrocardiogram monitoring

In all forms of medical treatments, monitoring of physiological parameters like blood pressure, heart rate variability, an electrocardiograph (ECG) is of vital importance. Implication of a range of signal recording devices is that it confines a patient to bed during observation. But recent inventions in smart sensors for electrocardiograms make life more comfortable and easier. These sensors were designed in various forms such as jackets, vests, sleeves, wrist bands, etc. to be worn near to the body (Khairuddin et al., 2018).

Cetiner and his co-workers had developed a fabric-based smart sensor for monitoring of electrocardiogram or to observe the electrical activity of a human heart. The sensor was fabricated by *in-situ* polymerization of 3,4-ethylene dioxythiophene (EDOT). Iron(III) chloride ($FeCl_3$), acetonitrile, and p-toluene sulfonic acid monohydrate (p-TSA) were also used as polymerizing reagents. While woven polyethylene terephthalate (PET) fabrics were used as substrate. Development of these fabric-based sensors could be an alternate for commercial sensors used in monitoring electrocardiogram and they could be implied for the monitoring of a long time physical signal without using hydrogel. These types of sensors are washable, lightweight, and appropriate to integrate into clothing and have flexibility in terms of integrating materials, sensor size, and sensor design (ÇETİNER et al., 2017).

Recently, Ankhili and his co-workers fabricated a smart sensor using polyamide as conducting material in detecting the signals of the electrocardiogram. Polyamide threads were embroidered in the form of bands between two electrodes on plain cotton fabric. Thermoplastic polyurethane films were applied as a protective cover on these bands. The embroidered bands can record the electrical signals during long-term ECG monitoring (Ankhili et al., 2019).

Biomedical conducting gadgets are very useful in the detection of bio-signals. For medical diagnosis, these high-performance sensing devices play a vital role in obtaining biosignals. In this scenario, Polyvinyl chloride (PVC) and Polypyrrole (PPy) were used to fabricate these devices. The PPy/PVC sensors showed better performance in comparison to the commercially available sensors and fabricating such type of polymer-based devices can bea very helpful tool to get any type of biosignal (Suaste-Gómez et al., 2019).

Using a biocompatible polymer (poly (ethylene dioxythiophene): poly (styrene sulfonate), (PEDOT: PSS)), highly conductive and flexible dry electrodes were prepared by mechanically loading laser-induced graphene (LIG). The LIG was coated by spraying PEDOT: PSS to enhance the toughness and the electrical conductivity of the electrode. Thereby, this fabricated electrode proved to be very efficient in obtaining the electrocardiogram (ECG) signals. Since the electrodes were flexible and thin so it was evenly and efficiently attached to the skin. Finally, the mobile application was made for long-term monitoring and real-time monitoring of ECG signals (Zahed et al., 2020).

Zhang *et al.,* also stated a high-performance bio-potential electrode prepared by the blends (PWS) of WPU, PEDOT: PSS, and *D*-sorbitol. PWS exhibit high mechanical stretchability, high conductivity, and self-adhesion to skin conditions, and all the substances are biocompatible. These films of PWS are adhesive to the skin and easily adaptable to the furrows of the wrinkles. They also do not cause any irritation to the skin. By using PWS dry electrodes, long-term (maybe for a month or even longer) ECG monitoring can be obtained. The PWS electrodes always create a conformal contact to the skin because of their self-adhesion ability. To prompt movement of the muscles, an electrical vibrator is used. Hence, these PWS electrodes can produce signals of high quality even under vital vibration (Ouyang, 2021).

8.5. Detection of ballistic penetration

The key investors in developing the smart monitoring textiles are the safety and military sectors because the functionalities of sensors always prove helpful in supporting the frontline personnel in a combat zone. In recent years, many investigations have also been carried out in the quest for smart clothing for fighters, rescue workers, policemen, fire soldiers, and other special forces. To serve the military, one smart garment prototype had been developed, in which a backbone based on a conductive circuit of optical fibers was arranged in a network of columns and rows. As the bullet penetrates through the jacket, the conductive path of the fibers breaks down and is detected via a processor, which then helps to detect the exact location of the penetration. The info can then be immediately transferred to medical teams. The same concept of fabric damage can be used to develop protective garments for other types of fields such as biological and chemical fields, whereby a warning signal can be emanated when a tear or hole occurs in the fabric (Koe, 2017).

Another example of this tactic includes the blending of the polyaniline with poly (ethylene oxide) (PEO). The method of electrospinning is used to prepare a volatile organic solution based on emeraldine salt (a form of polyaniline) and PEO. Then this solution is used in the preparation of conductive nanofibers. These fibers are then characterized electronically to show the response against explosive reducing agents such as hydrazine as well as liquid and gaseous samples of bases and acids. Rapid response is an interesting feature of these high-surface-area materials (Guo et al., 2020).

Conductive optical fibers can also be prepared by a coating of conducting polymers such as polypyrrole and polyaniline. *The in-situ* polymerization method is used for the deposition of a thick film of conductive polymer on fiber-optics. This process allowed the control of the level of doping and alsothickness of the film. These films show chemical responses against reductive, oxidative, acidic, and basic vapors. These strategies are used to increase the level of protection of firefighters, medical, law enforcement, and military personnel while dealing with biological and chemical threats in various environments ranging from warfare to industrial, urban, and agricultural (Nurazzi et al., 2021).

9. Future perspectives

In the second half of the twentieth century, to improve our lifestyle, significant technological advances in several disciplines led to the emergence of a variety of tools and technologies. The 1990 s and early 2000 s combine the technologies and expertise of researchers from different fields *i.e.* textile and fashion designing, textile technology, electronics, material science, information technology, etc., to develop multifunctional products resulting in an integrative revolution in the world. A typical example of collaborative work of researchers and experts from various disciplines is interactive and smart clothing. The range of smart fabric and intellectual textile was estimated at US$ 300 million in 2003 and exceededUS$ 720 million by 2010 (Schwarz et al., 2010). The two main consumer markets; the markets of the United States and Japan, both have invested (and continue to invest) significant amounts in this field of research.

Although, revolutionary developments have also been reported in Europe, particularly in Italy, Finland, Belgium, United Kingdom, and France, in upcoming years, the industrial community is also expecting a significant contribution from China in this field of textile-based smart sensors. It is evident because significant developments have already been made in the fabrication and design of smart interactive textiles for monitoring applications. Now industries are inclining towards the research and development of single component manufacturing required for applications *i.e.* microprocessors, actuators, sensors, etc. This dynamic interest of industry serves as a fuel for the innovation in this field. Interactive clothing design research is also useful for applications like general and clinical health surveillance, during military and sports activities, including monitoring for signs of life and injuries, location and position, and as communication systems. Several prototypes have already been prepared and their field trials in extreme environments and clinical trials in the medical sector have also been started. The massive commercialization of few systems has not gone too far, and there is still a lot of work to be done to solve all the technical problems, especially about:

- the durability of the system, including resistance to washing and long-term accuracy of performance
- power management efficiency, easy handling, including the ability to wear/use clothes without any assistance
- movement, including weight loss
- cost versus durability or long life of the product
- comfort and appearance, including handling, breathability, absorption, draping, etc.

The last point emphasizes the importance of aesthetic product design, which is mainly related to the functional and technical textiles field. The idea of product development covers all elements of design, logistics, workability, and technology. Although technology has been introduced in numerous fields, end-user functionality is still the subject of extensive and advanced research. The design module of research for such applications, by contrast, is still in its infancy, but with the introduction of new interdisciplinary researchers, it is growing rapidly. The sociological and logistical characteristics of such smart sensor textile have not been fully studied, mainly because the marketing of these products has not yet taken place on a large scale.

The research community must solve the problem of confidentiality and security of data transmission and in modern short-range communication systems, it is necessary to strengthen encryption and decryption systems to avert the "accidental" transfer of personal information among people with intelligent communicating tools. Privacy rights and data protection are the main problems that are felt strongly by consumers and several human rights organizations. In this context, the integration of radio frequency identification (RFID) technology into outdoor clothing has triggered a response for reasons of confidentiality and customers would have reservations on using such devices.

10. Conclusion

As a growing field, interactive smart textiles continue to grab the attention of industry and academia alike and are continuously being investigated for new applications and opportunities. The technical and functional sides of wearable sensing systems have also been investigated extensively for monitoring applications and continue to develop. As wearable systems are becoming more and more advanced and complex, therefore many issues like outfit deformation during use and launderabilitycan hinder the application of such smart systems. At the beginning of invention, research is just specified to the fields of textile and clothing, but with time the advances have been made according to the demands of consumers and industries, and also urge scientists from different disciplines to collaborate to develop new textile-based sensors, intercommunication devices, textile circuitry, actuators, and processors. Still, there are several technical, non-technical as well as practical tasks that have to be addressed. With the awareness of clients in lifestyle products, it is anticipated that the applications for wearable monitoring outfits will expand for the individual consumer. As the aged population is a significant factor, these clothing systems could play a vital role to facilitate the liberty of the disabled and aged persons, by permitting them to go on with their routine activities, which can be monitored by online monitoring systems. These systems would also cause a sign of relief for working mothers and can monitor the position of their baby in the cot and prevent cot death. However, to reach this commercialization level, accuracy, convenience, reliability have to be upgraded, cost-effectiveness and associated organization for the assistance and monitoring, need to be improved.

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