Wearable Flexible Sensors

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***Abstract*: In today's world, wearable sensors are used in many sectors like medical, security, communication, etc. But monitoring of physiological parameters is one of the most important applications of sensors. In today's life people are facing multiple physical, physiological, psychological problems. They have no time to visit doctors again and again. Sometimes there is a situation when a patient requires treatment on the spot. To solve these problems, we require a technique which collects all the data about people's disease in spaces ranging from personal to urban. Sensors fabricated with flexible materials have been attached to a person along with the embedded system to monitor a parameter and transfer the significant data to the monitoring unit for further analyses. The use of wearable sensors played an important role to monitor physiological parameters of a person to minimize any malfunctioning happening in the body.**

***Keywords*: Wearable flexible sensors, Physiological parameter, Wireless sensor network, Artificial skins, Strain sensors.**

1. Introduction

The advent of sensors in the application world has revolutionized the quality of human life. Earlier what it took hours to study or monitor an event can be addressed in minutes or seconds with the help of sensing systems. The dynamic use of sensors has led to the ever-growing modification of the existing sensors. They have been used for different sectors like gas sensing, environmental monitoring, monitoring constituents in food products like meat, beverages, etc. But monitoring of physiological parameters is one of the most important applications of sensors as it helps to develop a model regarding human behaviour. Sensors can be broadly classified into two categories, flexible and non-flexible. The former one is fabricated of materials which are malleable to a certain extent without changing its properties, whereas the later one is rigid and made of brittle materials. The non-flexible sensors have been developed earlier among which the sensors with silicon substrates are the most common ones. Even though these sensors find a vast field of applications, there are certain disadvantages like stiffness, intransigency, etc.

2. Material for wearable flexible sensors

The material used for fabrication of sensors is decided from some factors like the application of the sensor, its availability, total cost of manufacturing, etc. Organic electronics is one sector in the material side which has been substantially cultivated for the manufacture of flexible wearable devices. These types of sensors have been used in the manufacturing of thin film transistors, ionic pumps, polymer electrodes, etc. Organic and large area electronics (OLAE) is a process to develop electronic devices printed in thin layers using functional inks. The substrates used for these operations are main PET and PEN due to their transparency and lower cost compared to other organic polymers. OLAE process is currently used to develop wearable health and medical devices. Use of PDMS, PEN, PI and Polypyrene have been commonly done to develop flexible sensors for different applications. The electrode part of the sensor has been developed from different conducting materials like carbon-based nanomaterials and metallic nanoparticles. The carbon compounds include graphene, carbon nanotubes (CNTs), carbon fibers, etc. Among the metallic nanoparticles, silver, gold and nickel are some of the most commonly used ones in flexible wearable sensors.

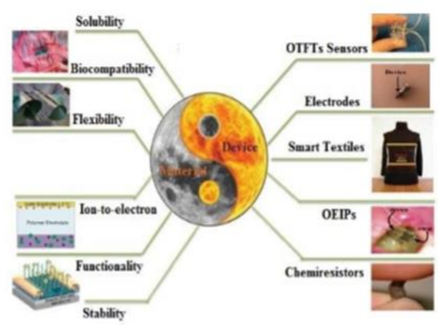

Fig. 1. Different prospects of wearable flexible devices using organic electronics

There are different kinds of techniques with which the flexible sensors are developed. The dimensions of the final products dictate the procedure used to make the sensor prototype. Photolithography, screen-printing, inkjet printing, laser cutting are some of the common ones. The raw materials used in developing these sensors depend on the applications for which the properties of the material vary. Polydimethylsiloxane (PDMS), Polyethylene terephthalate (PET), Polyethylene naphthalate (PEN), Polyimide (PI) are some of the insulating substrates commonly used to develop flexible sensors. The difference in these polymeric materials lies in their Young's modulus, refractive index, etc. There are some conductive polymers like poly(3,4ethylenedioxythiophene) polystyrene sulfonate (PEDOT: PSS), Polyacetylene, polyaniline are some of the examples of conducting polymers which conduct electricity due to their lower band gap compared to their insulating counterparts. These polymers are mainly used in developing solar cells, batteries; liquid crystal displays (LCDs), etc. Carbon nanotubes, silver, gold and copper nanoparticles, are some of the materials used for fabricating the electrodes in flexible sensors. Among CNTs, different sensing devices were developed with Single Walled Carbon Nanotubes (SWCNTs) and Multi- Walled Carbon Nanotubes (MWCNTs). These two types have been used accordingly in different based on their respective applications.

3. Type of sensing using wearable flexible sensors

The wearable flexible sensors have been employed to various kinds of sensing in everyday life. These implementations vary with the structure and properties of the sensors. Electrochemical sensing is one of the most common types of flexible sensing that has been performed over the years. The flexible sensors, with their unique chemical and electronic properties have been an excellent choice to carry out different types of biochemical sensing. Some of the common types of electrochemical sensing include monitoring of glucose, pH, cholesterol, etc. The glucose and pH sensors have been developed from CNTs due to their curvature sidewalls and hydrophobic nature which provides a strong interaction through π-bonding. Some of the sensors have used a layer-by-layer (LBL) structure to give it a sturdier structure. Two kinds of polymers, PDDA and PET, were used to develop the substrate. The SWCNTs, being used as electrodes, were functionalized with –COOH group to increase the oxidative nature of the electrodes. Along with glucose sensing, these sensors provided high sensitivity towards monitoring of pH between the pH values of 5 to 9. Other type of electrochemical sensing represents the monitoring of cholesterol, which is a lipid formed in the cell membranes of animals. These types of sensors have been manufactured with both SWCNTs and MWCNTs integrated with sol-gels. LBL method has also been employed with the structuring of these sensors to integrate assemble different materials in a compact way. So, these types of sensors have been developed with techniques like screen printing, spin-coating, where a separate membrane of enzymes like cholesterol esterase, cholesterol oxidase had been immobilized on the sensing surface.

Pressure and strain sensors are one of the most standardized applications of flexible sensors. Different kinds of piezoresistive and piezoelectric sensors have been developed till date to monitor various physiological parameters by using them as bandages, gloves, etc. These types of sensors vary regarding gauge factor (GF) and % of the tensile and compressive strain they can sustain without reaching the breaking point. Some of the pressure sensors had been manufactured as electronic bandages where the electrodes were developed by an agglomeration of two nanoparticles. The usage of more than of conductive material allowed the sensor to be used in different mediums.

Biomedical signal monitoring is another sector which has been worked up with wearable flexible electronic devices. Monitoring of metabolites on the skin was done by sensors with ion-electron potentiometric transducers developed from SWCNTs. Oppositely charged multi-layered films of MWCNTs were used to establish chemo resistive sensors. The detection of sodium (Na+) and potassium (K+) ions was detected using a sensor designed with Cu/PI flexible electronic layer attached to an antenna for wireless transmission of data to an Android smartphone. Monitoring of saliva for bacterial infection on tooth enamel had been done using graphene nano sensors. These sensors were connected to inductive coil antenna patterned with interdigital electrodes. Flexible Organic electrochemical transistors (OECTs) are another type of sensors used for testing of saliva by converting biochemical signals to electrical signals. They are developed with a PANI/Nafion – graphene bilayer film. These transistors were also developed by the lamination of polypropylene films and amorphous silicon thin-film transistors on plasma enhanced PI substrates. These sensors were used as pressure sensors and in large area sensor skins.

4. Sensor network for wearable flexible sensors

Real-time applications of the monitoring of different physiological parameters are significantly dependent on the sensor network used to monitor and transfer the recorded data. After processing the received data in the analog and digital division of the signal conditioning circuit, the data is transferred from the sensor node to the monitoring unit via router for further analysis. The selection of a particular communication network depends on the cost of set-up, power consumption, the number of sensor nodes, the range of trans-reception, etc. Bluetooth has been the most reasonable one due to its cheaper installation cost, less hardware, and high compatibility.

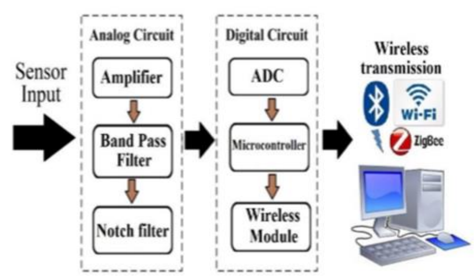

Fig. 2. Schematic diagram of the transmission of data from the sensor to the monitoring unit

Radio frequency (RF) is another network protocol which is used by different flexible acoustic resonators for data transmission. Wireless physiological management system (WPMS) was introduced which defines carrying the real-time physiological measurement data wirelessly from the medical sensors to the processing unit. The probable applications for this technique are in drug delivery systems like chemotherapy, diabetic insulin therapy, AIDS therapy. Another network protocol called Wearable Based Sensor Networks (WBSNs), based on IEEE 802.15.4 was introduced that had different probable applications like the ECG-based system, a wearable platform for light, audio, motion and temperature sensing. Research projects with antennas and RF systems integrated into clothes have also been progressed working on Body Area Network (BAN) where the low powered devices would be surface mounted on the clothing in a fixed position. BAN is categorized into three categories: off-body, on body, and in-body. Battery operated systems was another option that was considered where the developed system would be powered by a battery integrated into the system. The advantage of using self-powered systems is that the battery or the power unit of the wireless system does not have to be replaced every time the charging-discharging cycle gets over.

5. Applications of wearable flexible sensors

Different types of flexible wearable sensors are used in the application world based on the parameter being monitored. These parameters, as a result, would decide the fabrication technique of the sensor prototypes. For example, monitoring of physiological parameters of a person like limb movement, motions like walking, running, etc, gait analysis would require the sensor patches to be bigger are more flexible. But parameters like respiration, heart rate, cardiorespiratory signals would require the sensors to be subtle and sensitive. Another application of WFS is as glucose sensors via different mediums like tear, immobilization of glucose oxidase, etc. Electronic skins or e-skins are another category which was developed to mimic the functions like that of a natural skin and determine the changes in temperature, pressure or even your health conditions. These sensors are integrated with thermal actuators and organic displays.

Flexible sensors with high mechanical sensitivity, flexibility and durability were designed for speech recognition and physiological signals in the geometry of a spider sensory system. Biomedical signal monitoring was done involving monitoring of hydration state and electrophysiological activity monitoring using Optical, electrical and radiofrequency sensor. Spin-coated thin layers of PDMS and PI as substrates and bi-layers of sputtered Chromium (Cr) and Gold (Au) as electrodes. Monitoring of skin hydration through thermal conductivity, blood oxygenation, electrocardiogram (ECG), electromyogram (EMG), electrooculogram (EOG) are some of the suggested parameters that could be covered with these sensors. Another prominent aspect of the application of WFS is the monitoring of biological fluids like sweat and saliva via skin tattooed Nano sensors connected on the wrist and within the mouth respectively.

6. Future opportunities and Conclusion

Printed electronics is another sector which can be realized for developing future wearable flexible devices. It has always been a challenge to manufacture compatible printed devices with a high throughput. The reduction in the production cost of the sensor, being one of the main motives, the idea of using abundant cheap materials to develop intelligent, smart sensors by simple printing processes is always intriguing. Some of the other factors that are considered while developing printed electronics include scalable, environmentally friendly and mechanically enhanced devices. The mass production of low-cost materials like plastics and organic substrates would also lead to a wider range of applications. For example, the concept of quantum dots, where the semiconducting nanocrystals were tuned for the emission of light based on their resonating wavelength, had been exploited to develop three-dimensional (3D) printed light emitting diodes (LEDs). The use of printed electronics as wearable sensors has been conceptualized for a while now. Because of their high malleability, these printed devices can be easily attached to skins or textiles for monitoring purposes. It depicts the use of smart sensors in also every application in day to day living.

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