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Review Article

Sensors for Health Monitoring

Smart Health Monitoring Using Wearable Device Sensors: A Brief Review

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Abstract: Wearable technology is an emerging and indispensable area for health parameter monitoring that is expanding all year round for appraising, investigating, and treating critically ill patients significantly. As wearable technology develops and the demand for real-time analytic monitoring increases, researchers are urged to create more wearable monitoring devices. The newest generation of personal portable electronics is being lauded as comprising wearable monitoring systems. As material science, integrated circuit fabrication, industrial innovation, fabrication of integrated circuits, and structural design develop, wearable healthcare devices will usher in a new era for illness detection, treatment, and prevention. Numerous industries employ wearables, including agriculture, sports, and hospital navigation systems. In this study, the conceptual evolution of wearable gadgets and their usefulness in the field of personalised healthcare are examined. This study aims to present a futuristic examination of wearable health sensors and systems for smart, reliable health monitoring and rehabilitation.

Keywords: Biomarkers, Bio-media, Healthcare monitoring, Physiological states, Wearable biosensor

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1. INTRODUCTION

Health is a principal factor of every individual's need for an improved life, and it is expressed by the overall condition of physical, psychological, and social well-being and not simply a dearth of illness[1]. But it is critical that the well-being problems in the universe are in a predicament due to several factors like poor health services in urban areas, the existence of wide gaps between rural and urban health, non-availability of doctors and nurses during the critical situation as well as the ongoing global outbreak of Covid-19[2,3]. In addition, the world population is elevating progressively, and the surge in numbers of chronic diseases[4,5]. So, it is very challenging to monitor the health condition of many people at a time. Various physiological parameters of human health, such as arterial blood pressure, skin temperature, respiration rate, heart rate, SpO_2, blood glucose level, and other electrophysiological signals, speak for the health status of each individual and are very useful as reference values for human health monitoring[6]. Various measuring methods and tools, such as amplifiers, transducers, stimulators, monitoring and recording equipment, electrodes, transit time flow probes, data acquisition systems, software, etc., are currently available to collect, examine, monitor, and interpret physiological endpoints.Due to the advancement of medical sciences and computer technology, healthcare professionals have changed their approach to detecting illness through Internet of Things (IoT) based smart devices and offer innovative ways for treatment[7,8]. Healthcare systems amalgamated with IoT technology aid in improving quality of life and extending life expectancy. These approaches can be effectively implemented by acquiring the subject's or patient's behavioral and physiological messages from various distributed smart sensors[9]. Smart sensor-based real-time monitoring can successfully treat and support many lives during medical crises. Nowadays, considerable attention has been paid to wearable biosensors as they promise devices to monitor important physiological signs of an individual such as body temperature, heart rate, pulse rate, electrocardiogram (ECG), EEG, and other vital indications & symptoms[10,11]. The aspect of wearable devices has changed remarkably in the last few years from recording physical exercise activity to overcoming the extensive challenges in healthcare applications, such as managing blood sugar or remote monitoring of the elderly subjects[12,13]. The development of wearable biosensors, defined as wearable sensing devices that incorporate a biological recognition element into the sensor operation (e.g., enzyme, antibody, cell receptor, or organelle), has received significant attention from researchers to achieve these goals. The steadily rising rate of newly disclosed proof-of-concept studies shows the potential utility of wearable biosensors[14-16]. For example, smartwatches, where smart sensors are ingrained within a small watch that regularly monitors the subject's vital signs, and recorded data is transmitted to smartphones in real-time. If any physiological signals deviate from the standard value, an alert message will be delivered to the hospital so that prompt precautionary measures can be taken. The overall architecture of the smart health monitoring system is shown in the flow diagram depicted in Figure 1. This study highlights the wearable biosensors commonly used in various physiological parameter monitoring.

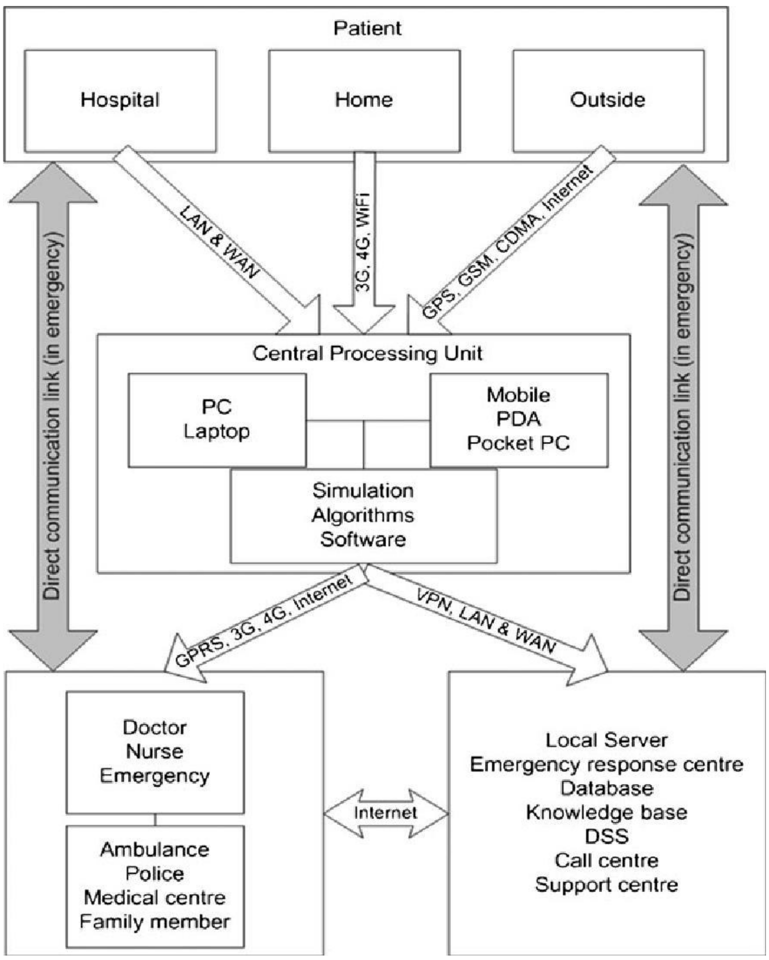

Fig-1: Architectural overview of smart health monitoring systems[17]

2. BIOSIGNALS AND BIOSENSORS

Biosignals are temporal depictions of variations in the energy that the body produces. These adjustments line up with differences in energy originating from various sources, including electrical, chemical, mechanical, and thermal. There has been a rapid increase in the quantity and variety of bio-sensing technologies outside the clinical and research lab contexts. Technology has continued to advance, enabling smaller size, weight, power, and cost. The development of an ever-growing number of sports and health monitoring apps for our smartphones that interact with bio-signals obtained via smartphones, smartwatches, or other sensor devices is a direct result of this rapid proliferation. The availability of bio-signals in various circumstances has been made possible through wearable technology. Additionally, the usage of bio-sensing platforms outside of the clinical setting aids in the transformation of conventional research methods into fresh goods and services. An overview of various physiological signals and the sensors used for their measurement and quantification has been enumerated in Table 1.

Table 1: Biological Signals and their Sensors[18]

Biosignals	Sensor Type	Sensor Location	Minimum sampling frequency (Hz)	Optimal sampling frequency (Hz)
EEG signals	Sintered Ag/AgCl electrodes	Scalp (in 10/20 electrode format)	256	256
Pulse (Heart rate)	Photoelectric Sensor	Lobes of Ear, Fingertip	64	256
ECG (Heart rate)	Disposable electrodes	Einthoven I/II, Goldberger, Wilson recording	256	1024
Electrodermal activity	Finger Electrode	Palm, Sole, Forehead	32	32
Respiration	Belt/Nose Flow sensor (Piezo sensor)	Thoracic or abdominal area	32	32
EMG	Disposable electrode	Face, Hand, Leg	256	2048
EOG	Sintered Ag/AgCl electrodes	On the ocular axis (vertical/diagonal/horizontal)	128	256

3. WEARABLE BIOSENSOR

Due to the expeditious advancement in the design and development of wearable biosensors, it is considered a potential candidate for individual health monitoring and personalized, cost-effective treatment by providing instantaneous information to physicians and interaction among doctors and patients[19-21]. Wearable biosensors (WBSs) are portable electronic devices that are attached to wearable systems (Figure- 2) embedded with biosensors to the human limb in the forms of smartwatches, thin bandages or tattoos, gloves, smart clothing, etc., for the realization of *in vivo* presumption, recording and calculation of data utilizing mobile or portable devices for uninterrupted non-invasive tracking and transmitting of physiological information[22,23]. These devices can also instantaneously evaluate biochemical markers in bodily fluids such as saliva, sweat, skin, and tears. This leads to tracking vital physiological signs by the patients themselves to keep a close check on blood glucose level, Blood Pressure, and Rhythmic condition of the heart, body temperature, to name a few, which plays a pivotal role in the sustainability of the physiological being[24,25]. Cutting-edge, novel biosensors have been designed to monitor and quantify targeted bio-markers leading to understanding the prognosis and diagnosis of the disease in a precise manner.

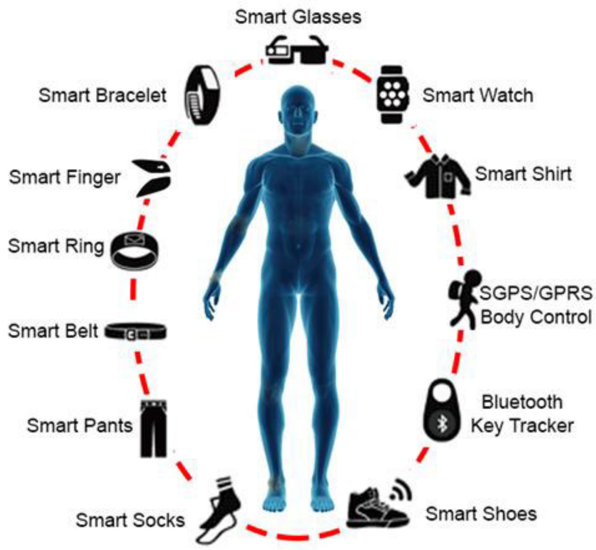

Fig-2: Wearable Biosensors[26]

In recent times, it has been observed that numerous wearable sensors hint at progress in their technological stack and art for a futuristic hassle-free world. Many applications of such devices keep the patient or subject updated about their daily continuous health parameters, igniting the sense of healthy living among them[27]. This real-time data convenience will enable better healthcare decisions, improve fitness outcomes, and increase the efficiency with which health systems are used[28]. Wearable sensors help a subject fully realize health activities and reduce the likelihood of hospitalization. Reduced hospitalizations and readmissions are the main benefits of such sensors, which will undoubtedly increase awareness in the coming days[29]. Additionally, several literature articles addressed that these sensors would unquestionably contribute to the globe as affordable wearable health equipment.

3.1. Various Wearable Biosensors for Smart Health Monitoring

During pandemic situations, COVID-19 and its variants have kept us slightly more stationary than in the past couple of years[30]. But because of that, we are more eager to track our fitness activity and get a better handle on what's happening inside our body in the post-pandemic era[31]. Wearable health devices (WHDs) have gained popularity in recent years as a promising technology that enables continuous ambulatory monitoring of a person's vital health status, both at the level of activity and fitness for self-health tracking and at the medical level, offering more information to healthcare professionals with the benefit of significantly reducing discomfort and interfering with daily activities as well as providing tools for early diagnosis and treatment guidance[32]. The technological upheaval in the MEMs architecture of electronic devices drives us to invent a design for a wearable that is more dependable and adaptable and contributes to a better world since it uses a contemporary approach to health monitoring[33].

3.1.1. Smart Watch

Smartwatches have evolved from fashion accessories to comprehensive health and fitness monitoring systems in the last few years[34]. And with the rising insistence on everybody's physical health, the market is full of devices that track our daily activity, exercise, sleep, and general health with a wide range of sensors. This device can even alert the wearers indicating alarming signs of potential heart problems, and call for help if we cannot get up from a heavy fall[35]. A Smartwatch (Figure- 3) is a portable wearable computer system in the form of a wristwatch device through which people can monitor their heart rate, blood pressure, O_2 level in the blood, and step count during gait movement[36]. It is also known as personal digital assistant (PDA) devices, generally powered with rechargeable lithium-ion batteries. Like miniaturized computers, a smartwatch may support wireless technologies like Bluetooth, Wi-Fi, and GPS. It collects information from *in vivo* or *in vitro* sensors and regulates or recovers input from other devices[37].

Fig-3: Smart Wrist Watch[36]

3.1.2. Smart Socks

Smart socks are regarded as WHDs in which a pressure transducer is penetrated inside comfortable fibre shocks that may limit gait patterns through which stepping cycles in diverse activities and numerous scenarios such as walking, jogging, standing, or sitting posture (Figure-4)[38]**.** It is a superb assistance for older people who have difficulty walking and a teaching tool for kids trying to walk, eliminating potential mishaps during stepping, etc.[39]. Athletes can also use them to change their training schedule. Information gathered and stored by pressure sensors is wirelessly delivered to the user's computer or mobile device for acceptable examination via a customized application. If necessary, an alarm is triggered for subject[40]. When our heels touch the ground, they alert us in real-time.

Fig- 4: Smart Socks[38]

3.1.3. *Ring Sensors*

The Ring Sensor is an oxygen saturation detector that enables real-time SpO_2 and heart rate monitoring. A ring-shaped device with an integrated light-emitting diode (Red and Infra-red) and photodiode can be worn continuously for continuous monitoring (Figure-5a)[41]. Blood discharges from the heart's ventricles each time the muscles contract, carrying a pressure pulse that travels through the vascular system. The photoelectric approach can identify pulse or changes in blood volume when a pressure pulse is transmitted through blood vessels, causing vascular wall movement that can be detected at various places (Figure 5b)[42].

(a) (b)

Fig- 5: a) Smart Ring Sensor & b) It's Working Mechanism [41,42]

Optical conductors are normally applied to enhance the signals, but photo resistors are occasionally employed. A unique processor is responsible for designing and managing the entire system. A home computer analyses the received waves after they have been received through a digitized wireless communication system.

3.2. *Smart Shirt*

The smart shirt is a specially created and developed by Georgia Tech product that has special sensors and optic trackers to detect wounds and is attached to a display to examine our body's vitals (Figure-6)[43]. This technologically advanced shirt provides a platform for surveillance, computation, and shock sensing. The sensors may be positioned on the shirt in the proper locations for all users, allowing it to be laundered with no damage. The basic advantages of a smart shirt as a wearable with detectors include monitoring various physiological parameters like heart rate, respiration rate, body temperature, etc. An integrated sensor and conducting fibre network are embedded in a smart shirt with band connectors that monitors vital signs and send signals to a personal controller's wireless server system to undertake future medical care research[44].

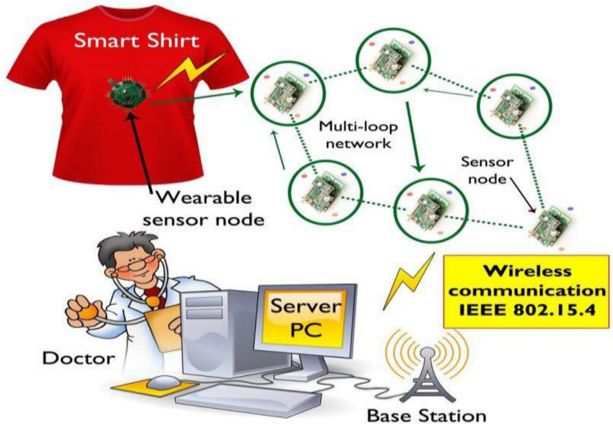

Fig- 6: Smart Shirt as Wearble Biosensor[43]

3.3. Smart Clothing for Premature Babies

Every year, more than 15 million preterm babies are born worldwide, and due to the loss of body fluid, over one million such infants expire or endure medical and psychological difficulties[45,46]. Polish researchers have developed successful smart attire for preterm babies to stop unintended fluid loss. This clothing is constructed of two layers, the first of which is made of regular fabric and the second of which is essentially a membrane that prevents the baby from perspiring excessively (Figure- 7).

Fig- 7: Wearable Jacket for Premature Baby[47]

Inserting monitoring sensors within the wearable cloth eliminates the longer period of electrode attachment to infants' immensely thin skin surface. This jacket will dispose of the painful process and stressful systems of changing the adhesive sensors. As the jacket utilizes wireless communication, parents and babies have greater privilege of movement in intensive care than that has been possible until now[48]. This smart cloth dwindles the baby's stress level and encourages bonding between parents and baby.

3.4. Digital Clothing for Examining Mental Status

Digital clothing with embedded tiny sensors (Figure 8) can measure vital physiological aspects like skin conductance, body temperature, and heart rate that are crucial for assessing a person's mental state[49]. Following that, information is entered into a database using a cell device, where a suitable response is given, taking into account the current circumstances and general characteristics of the persons[50]. When people feel guilty or anxious, the exhibited curtain can display cheery symptoms with its LED lighting.

Fig- 8: Smart Cloth for Mental Health Check up[49]

3.5. Tear-based Ocular biosensors for Glucose Level Monitoring

Tears are a physiological fluid that can be investigated for monitoring a person's physiological status, similar to blood and urine because biomarker molecules directly diffuse into tears from blood and show a tight association between the concentrations of the two[51,52]. Additionally, tear analysis offers excellent chances for eye illness identification[53]. Wearable solutions based on contact lenses offer an intriguing option for tear collection issues. They may be worn for extended periods without causing eye discomfort and are in close touch with basal tears[54]. All necessary parts, including the Central Processing Unit, power sources, and sensing system, are accommodated in these devices on the contact lens platform. These sensors were first introduced utilizing optical measurements of tear glucose based on how glucose reacted with concanavalin A or derivatives of phenyl boronic acid[55]. For instance, Google Smart Contact Lens continuously monitored the glucose levels in tears to help persons with diabetes[56]. A microscopic glucose sensor and a wireless chip are embedded between two delicate layers of the lens material (Figure- 9). Tears can drip into the sensor that determines the glucose level via a tiny pinhole in the lens. The system electronics component is placed outside the iris and pupil to protect the eye from harm. The contact lens contains an inbuilt wireless antenna that is as small as human hair and is an organizer for data delivery to the wireless device[57]. The organizer will gather, read, and evaluate the data delivered to the external device via the transmitter.

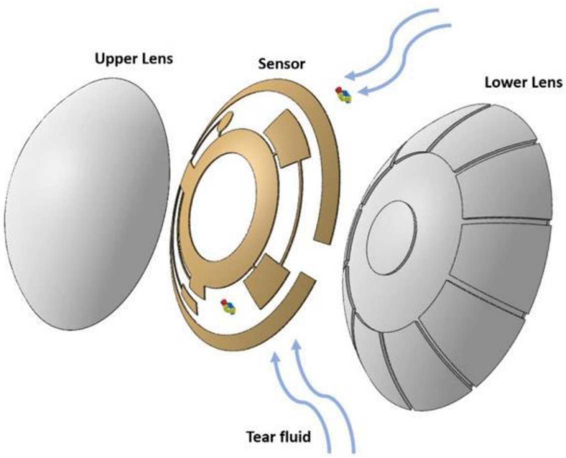

Fig- 9: Tear-based Ocular biosensors[57]

3.6. Oral-cavity wearable biosensors

In recent years, saliva has been considered one of the most promising biological fluids for diagnosis because many biomarkers are passed directly to saliva from the bloodstream through transcellular or paracellular pathways[58,59]. As a result, saliva is recognized as the 'mirror of the human body,' which reflects the body's physiological status and is acknowledged as a potential non-invasive alternative to blood examination[60]. The high protein content of saliva makes it a promising fluid for discriminating disease and stress biomarkers in biomedical and fitness monitoring approaches. Due to its easy collection, saliva has frequently been utilized on the *in vitro* diagnostic biosensors strip. Oral wearable sensor technology utilizes gingival crevicular fluid (GCF) and saliva as bio media to monitor dental diseases, biochemical saliva information, and food intake[61,62]. Dental wearable sensors are typically based on oral cavities and help diagnose and treat dental illnesses by monitoring dental decay, orthodontic treatment, and dental implants (Figure-10)[63-65].

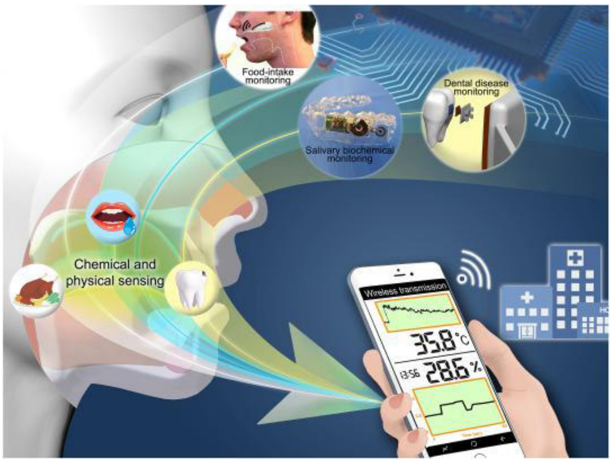

Fig-10: Working Principle of Wearable Oral Cavity Sensor[63]

4. MERITS OF WEARABLE BIOSENSORS

Wearable biosensor technology addresses the most crucial aspect of maintaining well-being by sending useful data about activities and human physiological states[66]. Wearable medical sensors are revolutionizing various application fields, including cardiovascular monitoring, troop tracking on the battlefield, and sports biomechanics[67]. An explosive rise in demand for wearable smart sensors has benefited from recent advancements in such small devices. The use of wearable biosensors encourages the relentless study of physiological information necessary for improving illness diagnosis and therapy[68]. Additionally, this practical tool will help limit the prolonged usage of expensive technologies for patient monitoring.

5. FLEXIBLE BIOSENSORS

The flexible healthcare sensor is the most important component of the wearable, modular health-monitoring system that has recently received much attention. The introduction to the flexible healthcare sensor covers basic flexible materials, manufacturing processes, and their applications in health monitoring. Various flexible sensing technology gadgets, notably smart, flexible, and artificial bionic sensors, have been created for healthcare purposes and may be employed to monitor physiological signals. Materials, manufacturing methods, and device configurations pertain to multidisciplinary research fusing materials science, device physics, chemistry, electronics, and computer science are the main elements of flexible sensing electronics. These devices are soft, elastic, and flexible, making them feasible to adhere to the skin, making it possible to wear them on anybody region for medical purposes. Flexible electronics make health-monitoring applications more cosy, biocompatible, energy-saving, and portable than traditional rigid and fragile sensors[69]. The fundamental components of flexible medical devices are flexible materials. Due to their unique molecular architectures, the polymers and rubbers that make up these devices can be identified by their inherent mechanical flexibility and stretchability. Many polymers, including polyimide (PI), polyethylene (PET), polyethylene (PEN), and polydimethylsiloxane (PDMS), have shown promise as substrates for flexible electronic[70-75]. Conducting polymers can be used as channel materials and electrodes for flexible transistors and flexible sensors, such as polyaniline (PANI) and poly(3-hexylthiophene) (P3HT)[76-78].

6. PHYSIOLOGICAL MOTION DETECTION SENSORS

Mechanical stimulations produced by human movements fall into two primary categories: tensile forces and pressure forces. To monitor these forces, many pressure and strain sensors have been created. The majority of daily human actions are created by hand and limb motion. A wearable sensor on the finger or gloves with sensors can be used to track finger movements. Sensing strips' state of stretching or bending is altered by finger movement. Parkinson's disease diagnosis and prognosis can be determined using the information acquired from a sensor affixed to the finger[79]. Over the years, numerous studies have been conducted to create wearable sensors for monitoring hands and fingers. Mechanoelectrical sensors generally have similar structures that contain two electrodes and active material. These sensors have used different techniques to convert the forces into electrical signals. Piezoresistive, capacitive, piezoelectric, and triboelectric sensors have been created to track human motions. These sensors provided varying levels of durability and gauged parameters for tracking various human actions, including breathing, complex knee motions, hand gestures, and finger bending[80]. Recently, a flexible strain sensor was made using PDMS and carbon nanotubes for human motion detection. In more detail, Pickering emulsion was used to prepare elastic multi-walled carbon nanotubes (MWCNTs) and PDMS microspheres, and copper electrodes were then glued to both sides of the microsphere array. The manufactured sensor demonstrated excellent conductivity and stability. The sensor's performance was assessed, and it was shown to be successful in detecting changes in various gestures[80]. Over the past two years, various sensors for human motion detection have been created (Figure 11).

Materials	Stretchability (%)	Durability (cycle)	Applications
Acrylic adhesive	200	10,000	Finger bending
Polyvinylidene fluoride	–	–	Respiration monitoring
Polyvinylidene fluoride	–	1750	Throat, elbow
Epoxy resin	–	3000	Arm movement
Graphene nanoplates	200	1100	Finger, wrist, knee
Reduced graphene oxide	100	2000	Wrist, elbow, knee
Ecoflex-carbon black	500	10,100	Finger motions
Carbon fibers/ecoflex	300	700	Elbow, wrist, finger
Carbon nanotubes	–	7200	Wrist, finger
Chitosan-glycerol	–	–	Hand movement
Polyvinylidene fluoride	–	–	Wrist bending
Gold nanoparticles	–	–	Finger, wrist
PDMS/carbon nanotubes	–	10,000	Foot motion
Polyethylene terephthalate	–	–	Arm movement
PDMS	400	1000	Wrist motion
Polyethylene terephthalate	–	10,000	Sleep monitoring
Polyvinylidene fluoride	–	1000	Elbow bending
Silver-printed PDMS	70	1000	Mouth movements
Thermoplastic polyurethane	500	1000	Finger, neck, knee
Polyaniline/phytic acid	1500	70	Knee motions
Ionic covalent hydrogel	1700	200	Finger, neck, knee
Functionalized fabrics	–	200,000	Elbow movement
Polyethylene dioxythiophene	–	–	Foot motion
Polyvinylidene fluoride	–	–	Arm, knee, jaw

Fig-11: Various Human Motion Detection Sensors[80]

7. WEARABLE SENSORS TO MONITOR REAL-TIME ENVIRONMENTAL PARAMETERS

Due to advancements in microelectronics, wearable technology can now gather important data that will help raise the standard of healthcare. Various sensors have been created in this context to track environmental factors in real time, including breathing gases, humidity, and ambient gases. This family of sensors can enhance interactions between people and their surroundings by protecting individuals from harmful environments. It should be noted that while old sensors typically produce correct data, their limitations such as size, weight, and bio-functional considerations prevent their integration with the human body. This causes their use to have many limitations. However, newly created biosensors with excellent human tissue adaptation offer real-time environmental threat identification[80]. After gathering data from the wearable sensors, a system is needed to monitor the user's health in real-time monitoring. This system shouldn't hamper the daily actions of the users. A technological solution for real-time data analysis appropriate for wearable sensors must be offered as the development and production of wearable sensors have expanded. Several investigations were conducted to satisfy the requirements and fully develop healthcare monitoring systems[81-83]. Using an e-health sensor platform, for instance, was advised in[81] to monitor ECG data and save the data as a text file for later processing. A system to track heart rate based on wireless sensor networks was created at the same time[84]. The created method might use a smartphone to alert family members or carers remotely. Notably, a healthcare system that uses a smartphone as a real-time monitoring system can help medical personnel by providing remote care and accurate diagnoses. Major steps in a real-time health monitoring system based on the Internet of Things (IoT) and wearable sensors are shown in Fig. 12.

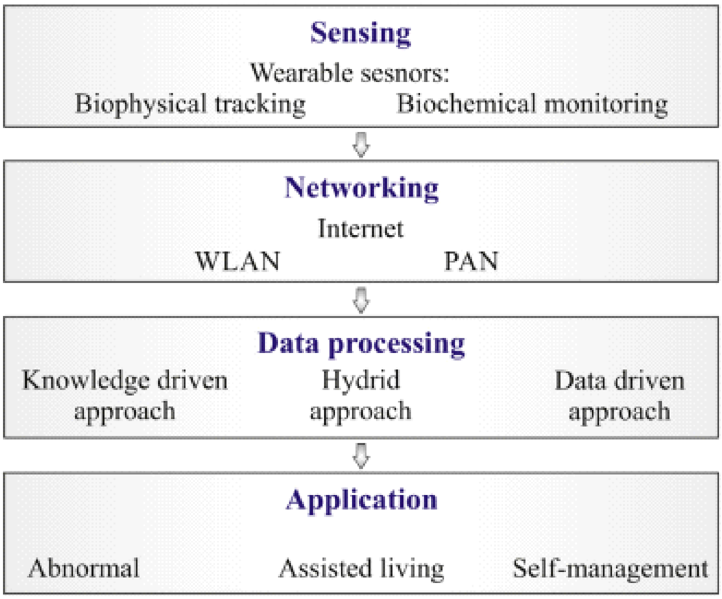

Fig-12: Steps in real-time tracking using wearable sensors[80]

8. ENGINEERING COMPLICATIONS RELATED TO WEARABLE DEVICES

Wearable sensor technology depends on various engineering factors, including material science, engineering aspects, fabrication processes, and assembly technologies.

8.1. Material Selection

The material choice greatly impacts the performance of wearable health sensors because of the uses of such sensors. A literature review reveals that many materials have been suggested to manufacture prototypes appropriate for various uses. Due to the variety of sensor technology, more than one type of sensor can occasionally satisfy demand. This problem may have an impact on wearable sensor material research and planning. However, besides meeting scientific and metrological specifications, this material selection should meet economic standards. Figure 13 depicts the various criteria based on which material selections are made for fabricating Wearable sensing devices[80].

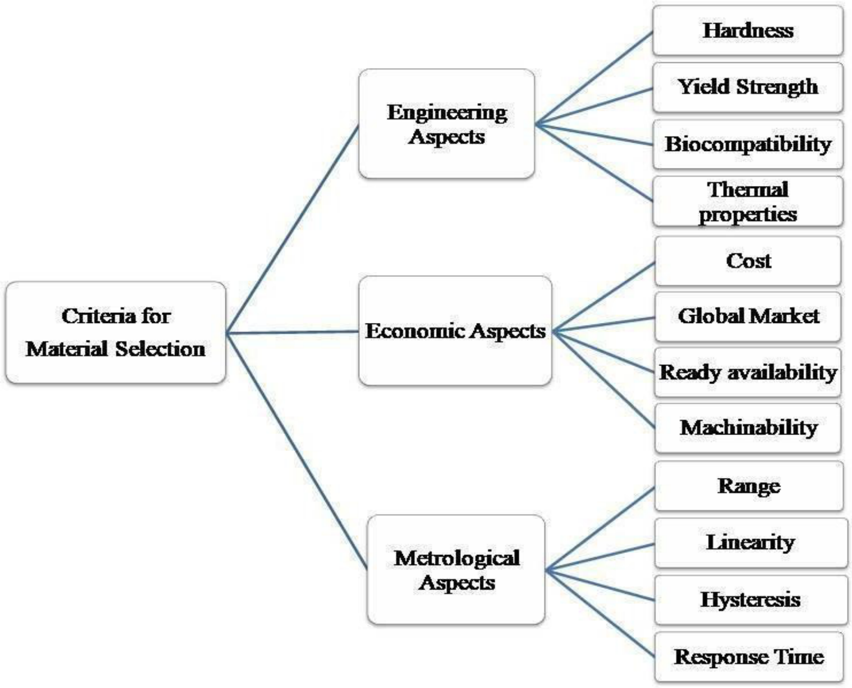

Fig-13: Criteria for choosing Materials for fabrication of Wearable Sensors

Wearable temperature sensors are now being made using a wide range of nanomaterials. More specifically, CNTs, nickel and copper metal nanoparticles, graphene, conductive polymers, and nickel have all been used as temperature-sensing elements[85-87]. To give the active material in flexible wearable sensors stability, a flexible sub-strate must be used. In this regard, the most often utilized flexible substrates in wearable sensors for health monitoring include polyurethane, PDMS, polyethylene tereph-thalate, Ecoflex, and polyethylene naphthalate[88,89]. The composition of rubber material with flexible rubber is a common technique for manufacturing piezoresistive sensors. In the studies cited in this text, graphene, CNTs, and silver nanowires were employed[90-92]. Using biocompatible materials is crucial because most wearable health sensors come into touch with human skin. In this context, biocompatible piezoelectric materials include poly-l-lactic acid, polyvinylidene fluoride, and poly-d-lactic acid, as well as inorganic ones such as zinc oxide, lead zirconate titanate, and lithium niobate. It is relevant since piezoelectric polymers have drawn much interest due to their affordability and use. Polyvinylidene fluoride is the most often utilized flexible piezoelectric material in wearable electromechanical sensors. Due to its tightly packed linear molecular structure, this substance displays distinctive physical characteristics, including semi-crystallinity. Silk is a flexible, natural material that makes a fantastic option for use in textile-based wearable sensors in addition to the listed inorganic and organic piezoelectric materials. A variety of wearable sensors can employ silk because of its piezoelectric properties[80].

8.2. Fabrication Techniques

With wearable technology, we are seeing the dawn of a medical revolution. Wearables with integrated transmission sensors can convey data to an electronic device for storage, processing, and visualization while continually and non-intrusively monitoring important physiological indicators[93]. This has been made possible by integrating numerous technologies, including data analysis, software development, sensor techniques, and micro-electromechanical technologies. Some design considerations include sensor accuracy, determining user needs and economic models for market usage, data privacy, and security. The most well-known subjects, privacy concerns, moral dilemmas, and a lack of trust, have emerged as the main design challenges when considering sensors in wearable devices into consideration[94]. Due to the increasing prevalence of chronic diseases, the aging population, and the global pandemic, people have been compelled to embrace a healthy lifestyle. This has prompted the creation of advanced personal healthcare devices and patient-centered software to recognize basic symptoms, monitor bodily processes, assist patients throughout therapy, and provide regular prescriptions. However, as these devices have shrunk, their development complexity has increased because of various sensor integration methodologies, connectivity possibilities, and low power consumption requirements[94]. Various cutting-edge fabrication techniques are utilized nowadays for the precision development of devices. These methods are mentioned as follows:

- Screen printing
- Roll-to-roll gravure painting
- Inkjet printing
- 3D printing
- Stamp Transfer
- Lithography

Since the advent of wearable sensors, the fabrication process for this class of sensors has undoubtedly advanced, but more work is still needed to get beyond the constraints. For example, most of today's wireless circuits are built on rigid plastic circuit boards. This field needs major advancements because it has yet to catch up to the development of flexible, stretchable wearable health sensors. The parts must be put together on a stretchy substrate to maximize the integrity of wearable sensors. Stretchable material-friendly fabrication procedures must be created in this situation[80].

9. WIRELESS COMMUNICATION STANDARDS FOR WIRELESS HEALTH MONITORING SYSTEMS (WHMS)

Social, defense, and medical service applications largely rely on wireless networks. Different wireless network interfaces, including Personal Area Networks (PAN), Body Area Networks (BAN), Wi-Fi 802.11, WiMAX, and cellular, have quickly supported these applications[95]. There are no differences between "wearable," "wearable devices," "wireless BAN (Body Area Network)," or "wearable technology." Similarly, the terms wireless wearable body area networks and wearable wireless body area networks are interchangeable in the literature. These words relate to microchips, other computing equipment, small electrical or mobile devices, or both capable of wireless data communication. Additionally, these components are made into tools, apparel, or accessories that can be worn, patched onto the body, or tools implanted, injected, or consumed within the body[96]. From the ones described here, Figure 14 references the key elements of the most widely used wireless technologies for WHMS. It is clear from the previous discussion that current standards need to meet BAN requirements owing to interference issues, security concerns, hardware module form factors, or power consumption[18].

	Range (typical)	Data Rate (max)	Power Cons.*	Cost per chip	Frequen-cy
Zigbee	10-75m	20kbps/ 40kbps/ 250kbps	30mW	$2	868MHz/ 915MHz/ 2.4GHz
Bluetooth	10-100m	1-3Mbps	2.5-100mW	$3	2.4GHz
IrDA	1m	16Mbps	-	$2	Infrared
MICS	2m	500kbps	25μW	-	402-405 MHz
802.11g	200m	54Mbps	1W	$9	2.4GHz

*Power consumption refers to maximum consumed power when the chip is on and it is sending/receiving.

Fig-14: Standards of Wireless Communication Systems[18]

10. RESEARCH DIRECTIONS IN WIRELESS WHMS

The use of wireless wearable body area networks requires a variety of open research contributions. Below are some of the main research challenges.

a. **Global RF Design:** It has been noted that some wireless channels are used in one region but not another or that some channels are permitted in the USA but not in other regions. As a result, the radio frequency of the Wireless Wearable BAN must be such that the devices can operate in any region of the world. As a result, wearable BAN devices must be able to work with a variety of RF designs[97].
b. **Performance:** Other nearby high-power ISM wireless devices may impair the functionality of low-power wearable and WBAN devices, making them less desirable for high-quality medical and healthcare applications. For instance, the Wireless Medical Telemetry Service (WMTS) frequency bands are widely used, but regrettably, they are only used for medical purposes in the USA. UWB is also a promising candidate technology for wireless wearables. However, it suffers greatly from interference from the coexistence of high data rate applications like wireless multi-media[98].
c. **2360-2400MHz:** The 2360–2400 MHz band has been approved for use by the Federal Communication Commission (FCC) for medical WBAN. It is anticipated that the band will be utilized to design an artificial nervous system that will allow paralyzed limbs and organs to regain functionality by restoring sensation and mobility. But to test and validate against the FCC's health-related norms and regulations[99], devices based on this medical WBAN frequency band are obliged to do so. Therefore, one of the biggest obstacles is creating devices that precisely comply with FCC standards.
d. **Channel Model Design:** The development of the RF channel model presents another research problem because it is crucial to the design of PHY (Physical Layer) technologies. The Physical Layer of the OSI Model or TCP/IP is called PHY. PHY is implemented to connect the MAC layer to the physical media, which in this case is a wireless Radio Frequency (RF). RF, a transceiver, a digital signal processor, a communication protocol, and channel codes make up the PHY. When using SOC (System on a Chip) technology, PHY and MAC are merged. The wireless PHY standards 3G, 4G, LTE, WiMAX, and UWB are a few examples.
e. **Design of Radio Antenna:** Due to limitations on size, shape, and material selection, designing an antenna for wireless wearable BAN devices is extremely crucial. The size of these antennae must be reduced because the devices are worn, patched on the body, or implanted within the body. The organ limits the shape, giving designers only a few options when designing antennae. Antennae should be made of materials safe for the human body, like titanium or platinum. However, compared to

antennae constructed of copper, those formed of such material function inadequately[98].

f. **Protocols of Physical Layer:** Wearable and BAN device physical layer protocols must guarantee low power consumption without sacrificing dependability, connection, throughput, and turnaround time. The power consumption of wearable/WBAN devices can be considerably reduced by quick wake-up from sleep mode and quick turnaround times. Currently, duty cycling is used to achieve energy efficiency, but researchers are working to find other ways to save energy, like low-power listening harvesting [97, 98].

g. **Designing of MAC:** A wearable BAN MAC (Medium Access Control) layer is always necessary, and it needs to be resistant to interference brought on by the coexistence of numerous WBANs in congested spaces like hospitals. Protocols at the MAC layer should be able to modify with frequent topology changes. Additionally, the WBAN's MAC protocol should be able to switch to a silent channel in the event of intense interference brought on by the presence of nearby, similar networks using the same frequency band[97].

11. CONCLUSIONS

According to a material science perspective, novel materials and improved fabrication techniques must be developed to fulfill the requirements of complex wearable sensors, such as ultra-sensitivity, high recognition correctness, comprehensive integration, and mass manufacturing. Creating a novel multi-functional material that combines two or more functional features may give designers of medical wearable devices more possibilities. The near future bears immense potential for wearable technologies to levelling the healthcare pricing trend. Shortly, computing in healthcare research could drive clinical development in healthcare delivery. New artificial intelligence models appropriate for wearable technology will be developed due to the employment of computers in the healthcare industry. These artificial intelligence models will be crucial in managing and forecasting fluctuations in patient health. Lastly, as healthcare changes, an increasing number of academics from many disciplines will come together to build an interdisciplinary community devoted to finding solutions for wearable devices for health coaching.

12. AUTHORS' CONTRIBUTION STATEMENT

Sandip Bag conceptualized the idea and drafted the manuscript. In contrast, Dibyendu Mandal reviewed the manuscript and performed the literature survey, which helped analyze the draft manuscript. Both authors taught the idea of designing the review flow in a systematic format.

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14. CONFLICT OF INTEREST

Conflict of interest declared none.

15. LIST OF ABBREVIATIONS

GCF: Gingival Crevicular Fluid
WHD: Wearable Health Device
WBS: Wearable Bio Sensors
ECG: Electrocardiogram
EEG: Electroencephalogram
MWCNT: Multi-walled Carbon nanotubes
PDMS: Porous polydimethylsiloxane
UWB: Ultra Wideband positioning

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