UNIT I INTRODUCTION TO WEARABLE SYSTEMS AND SENSORS

Wearable Systems- Introduction, Need for Wearable Systems, Drawbacks of Conventional Systems for Wearable Monitoring, Applications of Wearable Systems, Types of Wearable Systems, Components of wearable Systems. Sensors for wearable systems-Inertia movement sensors, Respiration activity sensor, Inductive plethysmography, Impedance plethysmography, pneumography, Wearable ground reaction force sensor.

Chapter 1

Wearable Systems- Introduction

Wearable technology is any kind of electronic device designed to be worn on the user's body. Such devices can take many different forms, including jewelry, accessories, medical devices, and clothing or elements of clothing. The term wearable computing implies processing or communications capabilities, but in reality, the sophistication among wearables can vary.

The most sophisticated examples of wearable technology include artificial intelligence (AI) hearing aids, Google Glass and Microsoft's HoloLens, and a holographic computer in the form of a virtual reality (VR) headset. An example of a less complex form of wearable technology is a disposable skin patch with sensors that transmit patient data wirelessly to a control device in a healthcare facility.

Need for wearables

Fundamentally, wearables can perform the following basic functions or unit operations

• Sense

• Process (Analyze)

• Store

• Transmit

• Apply (Utilize)

Of course, the specifics of each function will depend on the application domain and the

wearer, and all the processing may occur actually on the individual or at a remote location

(e.g., command and control center for first responders, fans watching the race, or viewers

enjoying the mountaineer's view from the Mount Everest base camp).

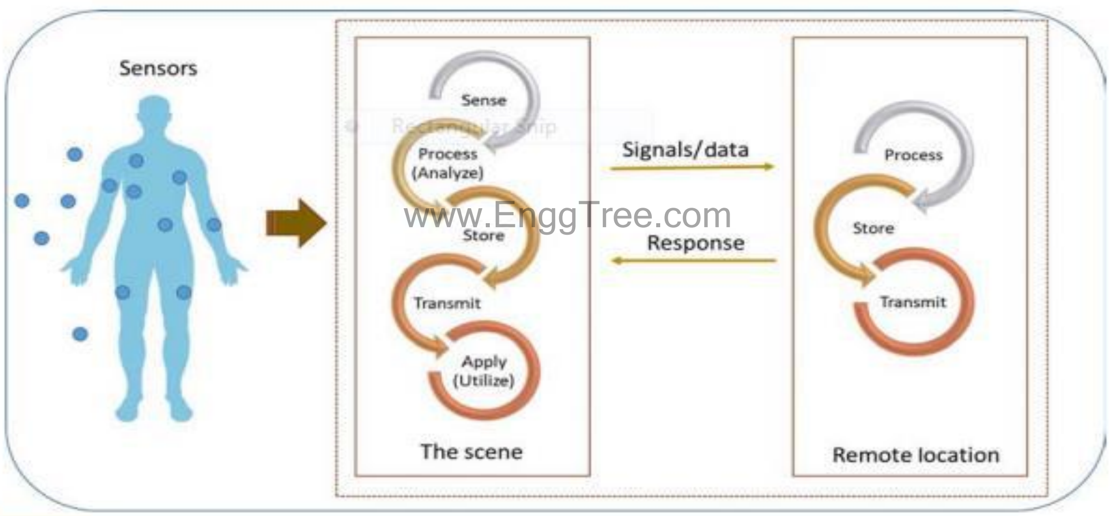


FIGURE 2 Unit operations in obtaining situational awareness: the role of wearables.

Figure 2 is a schematic representation of the unit operations associated with obtaining and

processing situational data using wearables. For example, if dangerous gases are detected by a wearable on a first responder, the data can be processed in the wearable and an alert issued. Simultaneously, it may be transmitted to a remote location for confirmatory testing and the results – along with any appropriate response (i.e., put on a gas mask) – can be communicated to the user in real-time to potentially save a life . This same philosophy can also be used by an avid gamer who might change his strategy depending on what "weapons" are available to him and how his opponents are performing. Each of these scenarios requires personalized mobile information processing, which can transform the sensory data into information and then to knowledge that will be of value to the individual responding to the situation. While wearables are being used in many fields, as discussed, this chapter will focus primarily on wearables in the healthcare domain. Wearables provide an unobtrusive way to longitudinally monitor an individual – not just during the day but, over the individual's life-time. Such an expansive view of the individual will be valuable in detecting changes over time and help in early detection of problems and diseases leading to preemptive care and hence, a better quality of life. Inferring the potential of wearables in other application domains should be straightforward and can be accomplished by instantiating the fundamental principles and concepts presented here.

Attributes of wearables

A sensor is defined as "a device used to detect, locate, or quantify energy or matter, giving a signal for the detection of a physical or chemical property to which the device responds". Not all sensors are necessarily wearable, but all wearables, as discussed earlier and shown in Figure 2, must have sensing capabilities. The key attributes required of an ideal wearable are shown in Figure 4. From a physical standpoint, the wearable must be lightweight and the form factor should be variable to suit the wearer. For instance, if the form factor of the wearable to monitor the vital signs of an infant prone to sudden infant death syndrome prevents the infant from (physically) lying down properly, it could have significant negative implications. The same would apply to an avid gamer – if the form factor interferes with her ability to play "naturally," the less likely that she would be to adopt or use the technology. Esthetics also plays a key role in the acceptance and use of any device or technology. This is especially important when the device is also seen by others i.e., the essence of fashion. Therefore, if the wearable on a user is likely to be visible to others, it should be esthetically pleasing and, optionally, even make a fashion statement while meeting its functionality. In fact, with wearables increasingly becoming an integral part of everyday lives, the sociological facets of the acceptance of wearables open up exciting avenues for research. Ideally, a wearable should become such an integral part of the wearer's clothing or accessories that it becomes a "natural" extension of the individual and "disappears" for all intents and purposes. It must have the flexibility to be shape-conformable to suit the desired end-use; in short, it should behave like the human skin. The wearable must also have the multifunctional capability and be easily configurable for the desired end-use application. Wearables with single functionality (e.g., measuring just the heart rate) are useful, but in practical applications, more than one parameter is typically monitored; and, having multiple wearables – one for each function or data stream – would make the individual look like a cyborg and deter their use even if the multiple data streams could be effectively managed. The wearable's responsiveness is critical, especially when used for real-time data acquisition and control (e.g., monitoring a first responder in a smoke-filled scene). Therefore, it must be "always on." Finally, it must have sufficient data bandwidth to enable the degree of interactivity, which is key to its successful use. Finally, wearables can be classified based on their field of application, which can range from health and wellness monitoring to position tracking. "Information processing" is listed as one of the application areas because many of these traditional functions such as processing e-mail can now be done on a wearable in the form of a wristwatch. It is important to note that not all the classes are mutually exclusive. For instance, a wearable can be multifunctional, active, noninvasive, and be reusable for health monitoring. The proposed taxonomy serves two key functions: First, it helps in classifying the currently available wearables so that the appropriate ones can be selected depending upon the operating constraints; second, it helps in identifying opportunities for the design and development of newer wearables with performance attributes for sp ecific areas that need to be addressed.

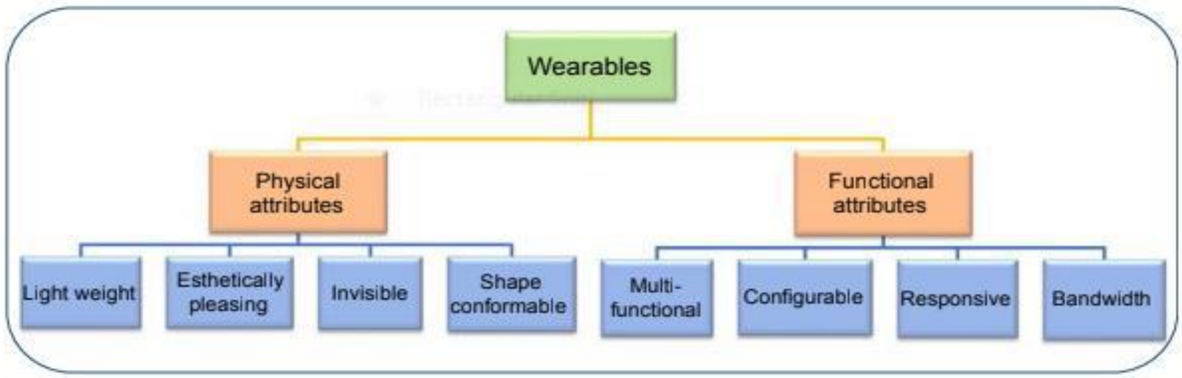


FIGURE 4 Key attributes of wearables.

Taxonomy for wearables

Figure 5 shows the proposed taxonomy for wearables. To begin with, they can be classified as a single function or multifunctional. They can also be classified as invasive or noninvasive. Invasive wearables (sensors) can be further classified as minimally invasive, those that penetrate the skin (subcutaneous) to obtain the signals, or as an implantable, such as a pacemaker. Implantable sensors require a hospital procedure to be put into place inside the body. Noninvasive wearables may or may not be in physical contact with the body; the ones not in contact could either be monitoring the individual or the ambient environment (e.g., a camera for capturing the scene around the wearer or a gas sensor for detecting harmful gases in the area). Noninvasive sensors are typically used in systems for continuous monitoring because their use does not require extensive intervention from a healthcare professional.

Wearables can also be classified as active or passive depending upon whether or not they need the power to operate; pulse oximetry sensors fall into the former, while a temperature probe is an example of a passive wearable that does not require its power to operate. Yet another view of wearables is the mode in which the signals are transmitted for processing wired or wireless. In the former, the signals are transmitted over a physical data bus to a processor; in the wireless class of wearables, the communications capability is built into it, which transmits the signals wirelessly to a monitoring unit.

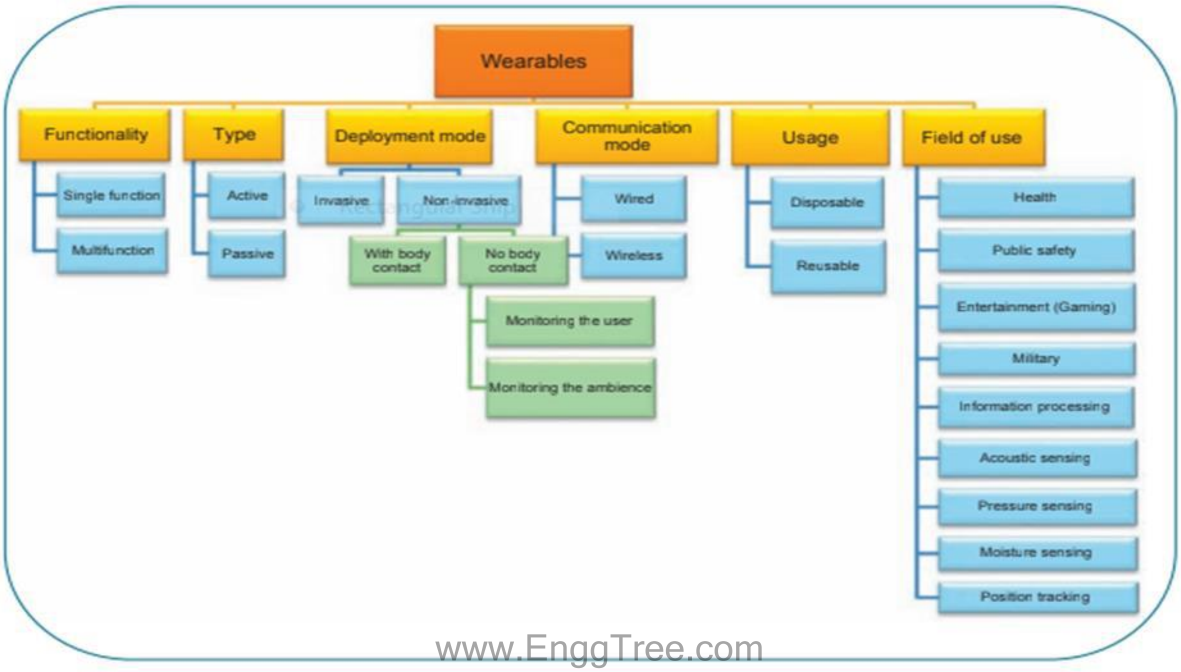


FIGURE 5 The taxonomy for wearables.

Components of wearable Systems.

The main components of wearable devices are as follows

1. Control

Wearable-specific microcontrollers are small, so as to be comfortable and discrete. On the other hand, the distinctive shapes and colors can function as a decorative element. Several of the boards available are hand-washable (minus the power source). Read the documentation carefully.

2. Input/Output

In place of pins, these boards have metal eyelets which you can loop conductive thread through to sew soft circuit connections. Some boards also have snaps — or eyelets large enough to solder on snaps — for easy removal.

3. Conductive Textiles

A material containing metals, such as silver or stainless steel, through which an electrical current can flow is said to be conductive. Wearable systems can make use of these materials in a variety of ways, such as:

- Thread for making circuits
- Fabric for capacitive touch sensors
- Hook-and-loop for switches

4. Sensors

Sensors gather information about the environment, the user, or both. Examples of the former include light, temperature, motion (ACC), and location (GPS). Examples of the latter include heart rate (ECG), brain waves (EEG), and muscle tension (EMG). A few wearable microcontrollers have basic sensors onboard. Other manufacturers offer a range of external sensor modules that connect to the main board.

5. Power

When scoping out a wearable design one of the first things to consider is the power requirement. Do you just want to illuminate a few LEDs, or do you want to run a servomotor? Boards with an integrated holder for a lithium coin battery are nice for low-power projects that need to be self-contained. However, boards with a standard JST connector (with or without a circuit to charge LiPo batteries) are more versatile.

6. Actuators

One generic way to describe a wearable system is: In response to X, where X is the input from a sensor, Y happens. Actuators such as LEDs, buzzers or speakers, and servomotors are what make things happen.

7. Networking

To communicate with smart devices, the internet, or other wearable systems, you need wireless connectivity. In addition to Wi-Fi and Bluetooth, wearable-friendly options include:

- BLE, which has lower power consumption than classic Bluetooth, a range of 50m, and a data transmission rate up to 1 Mbps
- NFC, a radio frequency field with a range of approximately 20cm and data transmission rate up to about 400 Kbps

Types of Wearable Systems

1.Smartwatches:

These days, the watches are tech-enabled. They double up as a fitness tracker, and sleep monitor in addition to being the classic time-keeping device. Smartwatches provide us with many other features including enabling us to make & attend phone calls and check messages. Some watches have the feature of playing FM radio or audio & video files with a Bluetooth headset. They generally connect to the smartphone via an app and act as a supporting device. They are often referred to as a ‘Wearable

Computer' on your wrist because of the bundle of features that can use through the touchscreen.

2.FitnessTrackers:

Fitness Trackers are among the wearable technology devices wearable on the wrist. Fitness trackers were primarily launched to perform the function of pedometer, i.e. counting the number of steps but they have evolved to become an overall health monitor since then. They perform various functions including tracking your heartbeat, monitoring your sleep, calories burned, and other metrics. They share the data to the app on the smartphone. In toto, they make a perfect health tracker. Some devices are enabled to regularly share the information on the metrics of the wearer to their physicians to keep them informed and help early detection of any issue.

3.SmartJewelry:

Jewelry no more acts like pieces of ornaments on your neck or hand, they have become smart. Smart Jewelry are those wearables like necklaces, wrist bands, bracelets, or rings that are tech-enabled to help you track your steps, track monitor your heartbeat & sleep, and some even notify you of incomingcalls.

4.GameSimulators:

The rise of VR in gaming has given rise to many wearable devices that simulate an environment and make the experience more realistic, engrossing, and adventurous. The devices include VR Headsets (also called Head-Mounted Displays or HMDs) that create a visual simulation and bands that come with built-in sensors to detect your movements. These bands enable you to control your movements through hand gestures.

5.SmartClothing:

The advancement of technology with IoT has fostered many inventions including Smart Clothes. Smart clothes are also popularly known as E-Textile as they come integrated with electronic devices that measure the health metrics of the wearer. Smart clothes help measure health-related aspects like heart rate, respiration rate, sleep, the body temperature, and provide you with that information. Smart clothing also includes smart shoes that examine your health, steps, fatigue, and collect other metrics to help you improve health and prevent injury.

6.SmartGlasses:

Ranging from simple smart glasses that are equipped with Bluetooth wireless music and hands-free calling to the glasses that can live stream videos to take photos, to advanced smart glasses that are AR-enabled to give you an immersive experience, these smart glasses are the of eyewear. Smart glasses can enable the user to read text messages and reply to them hands-free. Smart glasses by some companies are equipped with features like internet access and browsing through voice commands.

7.HeartbeatTrackers&BloodPressureMonitors:

There are fitness trackers for a specific use case like monitoring the heartbeat or regularly measuring the blood pressure. These devices help track the metrics among the people who suffer from related diseases. The fitness trackers record and provide the measurements to the wearer regularly. Some devices are enabled to share the data with the physician.

8.SmartEarbuds:

New to enter the wearable technology market are earbuds. Though Bluetooth earbuds are existing for a while now, they aren't considered among wearable technology because they do not collect and send data. But some companies are making earbuds smart. Smart earbuds have a built-in gyroscope, GPS, and compass. The sensors in the earbuds relay the information to the smartphone, which enables it to know your direction and movement. Hence, the smart earbuds are equipped to provide directions in real-time.

9.SmartContactLens:

Smart Contact Lens is among the recent inventions made possible with IoT. The smart contact lenses currently available in the market are helpful for medical reasons. It helps monitor eyes for various diseases like Diabetes, Glaucoma, and cataracts. It helps in the treatment of farsightedness. Apart from medical reasons, some companies are working on smart contact lenses that are AR-enabled, work on solar power, and capture and store images and videos. Smart lenses are among the implantable devices.

Applications of wearables

Currently other applications within healthcare are being explored, such as:

- Applications for monitoring of glucose, alcohol, and lactateor blood oxygen, breath monitoring, heartbeat, heart rate and its variability, electromyography (EMG), electrocardiogram (ECG) and electroencephalogram (EEG), body temperature, pressure (e.g. in shoes), sweat rate or sweat loss, levels of uric acid and ions – e.g. for preventing fatigue or injuries or for optimizing training patterns, including via "human-integrated electronics"
- Forecasting changes in mood, stress, and health
- Measuring blood alcohol content

- Measuring athletic performance
- Monitoring how sick the user is
- Detecting early signs of infection
- Long-term monitoring of patients with heart and circulatory problems that records an electrocardiogram and is self-moistening
- Health Risk Assessment applications, including measures of frailty and risks of age-dependent diseases
- Automatic documentation of care activities
- Days-long continuous imaging of diverse organs via a wearable bioadhesive stretchable high-resolution ultrasound imaging patch or e.g. a wearable continuous heart ultrasound imager (potential novel diagnostic and monitoring tools)
- Sleep tracking
- Cortisol monitoring for measuring stress
- Measuring relaxation or alertness e.g. to adjust their modulation or to measure efficacy of modulation techniques

- **Epidermal skin technology.** According to Science Daily, the Terasaki Institute for Biomedical Innovation invented wearable electronic skin for monitoring health. A next-generation of wearables, this ultra-thin e-skin patch can be attached to the wearer's chest area along with a small wireless transmitter by using water spray and can be worn for up to a week. It is sensitive enough to pick up and record electro signals, such as heartbeats and muscle movements, which can be sent to healthcare providers via the cloud so they can monitor the user's vitals remotely. This powerful wearable is a steppingstone for monitoring chronic illnesses such as heart failure and diabetes.

- **Health monitoring.** People use wearable technology to track and receive notifications for their heart rate and blood pressure, watch their calorie intake or manage their training regimens. The COVID-19 pandemic boosted the use of wearable technology, as consumers gained a broader awareness of personal hygiene and taking precautions to prevent the spread of infections. Apple, for instance, updated its Cardiogram app by introducing a new sleeping beats-per-minute feature that monitors heart rate fluctuations for COVID-19 patients.

- **Entertainment and gaming.** The gaming and entertainment industries were the first to adopt VR headsets, smart glasses and controllers. Popular VR head-mounted displays, such as Oculus Quest, Meta Quest and Sony PlayStation VR, are used for all types of entertainment purposes, including gaming, watching movies and virtual traveling.

- **Fashion and smart clothing.** Clothing known as smart clothing, or intelligent fashion, has been gaining wide popularity over the past few years. Smart jackets, such as Levi's jacket made with Google's Project Jacquard technology whose threads are composed of electrical fibers, enable the wearer to answer calls, play music or take photos right from their sleeves. Smartwatches, wristbands, smart shoes and smart jewelry are also popular examples of wearable technology.

- **Military.** These wearables include technology that tracks soldiers' vitals, VR-based simulation exercises and sustainability technology, such as boot inserts that estimate how well the soldiers are holding their equipment weight and how terrain factors can affect their performance.

- **Sports and fitness.** Sports use wearable athletic devices that are either built into the fabric of the sports apparel or are incorporated into sports equipment, such as bats and balls. The GPS and Bluetooth-linked devices relay real-time data to coaches for analysis through connected electronic devices such as laptops. Besides wearable athletic devices, familiar wearable technology such as Fitbit, Apple Watch, Garmin, Samsung Galaxy Watch and Polar are used extensively to track various areas of the player's health and performance metrics.

Advantages of Wearable Technology

- **Rapid data results can help drive improvements**. Having immediate data to make decisions and drive improvements may be helpful, rather than waiting for more formal or detailed assessments.
- **Detailed data can supplement loss analysis and loss trends.** Additional data can help identify specific trends in your claims history.
- **Can help build a business case for senior management.** It can be challenging to help senior management make decisions or determine if some of your funding should be spent on improvements. The data from wearable technology devices can help support your business case for that spend.

- **Data from wearable sensors offers promising job risk analysis and evaluation opportunities for safety and ergonomics practitioners.** Most ergonomic assessments or evaluations require additional time to observe and manually collect data. Having instant data can save time and expedite ergonomic assessments or evaluations.
- **Enhance employee wellness programs.** More organizations are starting to promote wellness programs for employees. Some wearable technology devices can assist with easily tracking wellness program data that could supplement or support your efforts.

Disadvantages of Wearable Technology

- **Requires a time commitment to review and analyze data.** A team or committee may need to review the large amount of data that is generated from the devices.
- **Requires financial commitments and planning**. You may need senior management or finance team approval prior to the full implementation stage. The cost of wearable technology depends on how many employees and locations are involved.
- **Devices could lead to distraction.** For many employees, wearing this device for an entire shift can be distracting, especially if the device has haptic feedback or vibration reminders.
- **Data security and privacy could be compromised with legal, financial, and personal consequences.** An information technology (IT) department will need to ensure the data generated from the devices is secured for authorized individuals and ensure proper consent is obtained from each individual whose data is being collected.

- **Devices could lead to over-trust or under-trust.** This could be challenging when reviewing all the data to determine realistic trends. Sometimes this results in trusting or not trusting all the reviewed data before making any decisions or improvements.

Sensors for Wearable Systems

Introduction

When designing wearable systems to be used for physiological and biomechanical parameters monitoring, it is important to integrate sensors easy to use, comfortable to wear, and minimally obtrusive. Wearable systems include sensors for detecting physiological signs placed on-body without discomfort, and possibly with capability of real-time and continuous recording. The system should also be equipped with wireless communication to transmit signals, although sometimes it is opportune to extract locally relevant variables, which are transmitted when needed. Most sensors embedded into wearable systems need to be placed at specific body locations, e.g. motion sensors used to track the movements of body segments, often in direct contact with the skin, e.g. physiological sensors such as pulse meters or oximeters. However, it is reasonable to embed sensors within pieces of clothing to make the wearable system as less obtrusive as possible. In general, such systems should also contain some elementary processing capabilities to perform signal pre-processing and reduce the amount of data to be transmitted. A key technology for wearable systems is the possibility of implementing robust, cheap microsystems enabling the combination of all the above functionalities in a single device. This technology combines so-called micro-electro-mechanical systems (MEMS) with advanced electronic packaging technologies. The former allows complex electronic systems and mechanical structures (including sensors and even simple motors) to be jointly manufactured in a single semiconductor chip. A generic wearable system can be structured as a stack of different layers. The lowest layer is represented by the body, where the skin is the first interface with the sensor layer. This latter is comprised of three sub-layers: garment and sensors, conditioning and filtering of the signals and local processing. The processing layer collects the different sensor signals, extracts specific features and classifies the signals to provide high-level outcomes for the application layer. The application layer can provide the feedback to the user and/or to the professional, according to the specific applications and to the user needs. Recent developments embed signal processing in their systems, e.g. extraction of heart rate, respiration rate and activity level. Activity classification and more advanced processing on e.g. heart signals can be achievable exploiting miniaturization and low-power consumption of the systems. Examples of data classification are[1, 2, 3]: classification of movement patterns such as sitting, walking or resting by using accelerometer data [4] or ECG parameters such as ST distance extracted from raw ECG data [5, 3]; another example is the estimation of the energy consumption of the body [6, 7]; in [8] the combined use of a triaxial accelerometer and a wearable heart rate sensor was exploited to accurately classify human physical activity; estimation of upper limb posture by means of textile embedded flexible piezo resistive sensors [9]. Examples of integrated systems for health monitoring are in [10, 11]. In the following paragraphs, two classes of sensors which can be easily integrated into wearable systems are reported and described. More specifically, inertial sensors to monitor biomechanical parameters of human body and sensors to capture physiological signs are addressed, describing the operating principles and indicating the possible fields of application.

Sensors for Wearable Systems

Biomechanical Sensors

Biomechanical sensors are thought to be used to record kinematic parameters of body segments. Knowledge of body movement and gesture can be a means to detect movement disturbances related to a specific pathology or helpful to contextualize physiological information within specific physical activities. An increasing of heart rate, for example, could be either due to an altered cardiac behavior or simply because the subject is running.

Inertial Movement Sensors

Monitoring of parameters related to human movement has a wide range of applications. In the medical field, motion analysis tools are widely used both in rehabilitation and in diagnostics. In the multimedia field, motion tracking is used for the implementation of life like videogame interfaces and for computer animation. Standard techniques enabling motion analysis are based on stereo-photogrammetric, magnetic and electromechanical systems. These devices are very accurate but they operate in a restricted area and/or they require the application of obtrusive parts on the subject body. On the other hand, the recent advances in technology have led to the design and development of new tools in the field of motion detection which are comfortable for the user, portable and easily usable in non-structured environments. Current prototypes realized by these emergent technologies utilize micro-transducers applied to the subject body (as described in the current paragraph) or textile-based strain sensors. The first category, instead, includes devices based on inertial sensors (mainly accelerometers and gyroscopes) that are directly applied on the body segment to be monitored. These sensors can be realized on a single chip (MEMS technology) with low cost and outstanding miniaturization. Accelerometers are widely used for the automatic discrimination of physical activity and the estimation of body segment inclination with respect to the absolute vertical. Accelerometers alone are not indicated for the estimation of the full orientation of body segments. The body segment orientation can be estimated by using the combination of different sensors through data fusion techniques (Inertial Measurement Units, IMU). Usually, tri-axial accelerometers (inclination), tri-axial gyroscopes (angular velocity), magnetometers (heading angle) and temperature sensors (thermal drift compensation) are used together. Main advantages of using accelerometers in motion analysis are the very low encumbrance and the low cost. Disadvantages are related to the possibility of obtaining only the inclination information in quasi-static situations (the effect of the system acceleration is a noise and the double integration of acceleration to estimate the segment absolute position is unreliable). Accelerometers are widely used in the field of wearable monitoring systems, generally used in the monitoring of daily life activities (ADL). Physical activity detection can be exploited for several fields of application, e.g. energy expenditure estimation, tremor or functional use of a body segment, assessment of motor control, load estimation using inverse dynamics techniques [26, 27] or artificial sensory feedback for control of electrical neuromuscular stimulation [28, 29, 30]. Usually, three-axial accelerometers are used. They can be assembled by mounting three single-axis accelerometers in a box with their sensitive axes in orthogonal directions or using a sensor based on one mass [31]. An accelerometer measures the acceleration and the local gravity that it experiences. Considering a calibrated tri-axial accelerometer (the accelerometer signal (y) contains two factors: one is due to the gravity vector (g) and the other depends on the system inertial acceleration (a), both of them expressed in the accelerometer reference frame :The inclination vector (z) is defined as the vertical unit vector, expressed in the accelerometer coordinate frame [4]. In static conditions, only the factor due to gravity is present and the inclination of the accelerometer with respect to the vertical is known. In dynamic conditions, the raw accelerometer signal does not provide a reliable estimation of the inclination, since the inertial acceleration is added to the gravity factor. This estimation error grows as the subject movements become faster (e.g. running, jumping). Many algorithms have been developed and tested to perform a reliable estimation of the subject body inclination: most of them use low pass filters with very low cut-off frequency in order to extract z[4] (i.e. introducing a considerable time delay), others implement more complex techniques which use a model-based approach mainly based on Kalman filter techniques. An example of integration of these sensors in a garment was developed in the frame of the Proetex project (FP6-2004-IST-4-026987), which aimed at using textile and fibre based integrated smart wearables for emergency disaster intervention personnel. The ProeTEX motion sensing platform is used to detect long periods of user immobility and user falls to the ground and it is realized by means of two tri-axial accelerometer modules. One accelerometer is placed in the higher part of the trunk (collar level) in order to detect inactivity and falls to the ground. The second sensor is placed in the wrist region and its aim is to achieve more accuracy in inactivity detection, since an operator can move his arms while his trunk is not moving. The core of the motion sensor is the processing algorithm described in, which allows to perform a reliable estimation of the body inclination even in the case of intense physical activity such as running or jumping. This algorithm allows a good estimation of subject activities and generated fall alarms with very high sensitivity and extremely low level of false positives.

Respiration Activity sensor

The most challenging vital sign to accurately record during continuous monitoring is the respiratory activity due to the fact that the signals are affected by movement artifacts and filtering or feature recognition algorithms are not very effective. Monitoring of respiratory activity involves the collection of data on the amount and the rate at which air passes into and out of the lungs over a given period of time. In literature, there are several methods to do this, both directly, by measuring the amount of air exchanged during the respiration activity, and indirectly, by measuring parameters physically correlated to breathing, such as changes in thorax circumference and/or cross section, or trans-thoracic impedance.

Direct methods are based on a spyrometer that measures directly the airflow in the lung exchanged during inspiration and expiration, but of course it cannot be integrated into a wearable system because it employs a mouthpiece, which could interfere with the freedom of movements, disrupting the normal breathing pattern during measurement, thus causing discomfort for the user. Indirect methods exploit displacements of the lung that are transmitted to the thorax wall and vice versa, and therefore measurements of chest-abdominal surface movements can be used to estimate lung volume variation. In literature, a number of devices have been used to measure rib cage and abdominal motion including mercury in rubber strain gauges, linear differential transducers, magnetometers, and optical techniques, but almost all cannot be comfortably integrated into a wearable system. For reference only, it is worthwhile citing a more sophisticated technique, called stereo photogrammetry, which makes it possible to estimate the three-dimensional coordinates of points of the thorax, estimating therefore volume variations. Nevertheless, this system presents a considerable drawback in that it is cumbersome, extremely expensive, and can only be used in research environments or in laboratory applications. Indirect techniques that can be implemented in wearable systems are respiratory inductive plethysmography, impedance plethysmography, piezo resistive and/or piezoelectric pneumography. These systems are minimally invasive and do not interfere with physical activity.

Inductive Plethysmography

The inductive plethysmography method for breathing monitoring consists of two elastic conductive wires placed around the thorax and the abdomen to detect the cross sectional area changes of the rib cage and the abdomen region during the respiratory cycles. The conductive wires are insulated and generally sewn in a zig-zag fashion onto each separate cloth band. They can be considered as a coil and are used to modulate the output frequency of a sinewave current produced by an electric oscillator circuit. As a matter of fact, the sinewave current generates a magnetic field, and the cross-sectional area changes due to the respiratory movements of the rib cage and of the abdomen determine a variation of the magnetic field flow through the coils. This change in flow causes a variation of the self-inductance of each coil that modulates the output frequency of the sinusoidal oscillator. This relationship allows for monitoring the respiratory activity by detecting the frequency change in the oscillator output signal. For accurate volumetric measurements using RIP, it is assumed that the cross-sectional area within the rib cage and the abdomen coil, respectively, reflects all of the changes occurring within the respective lung compartment, and further that the lung volume change is the sum of the volume changes of the two compartments. Under optimal situations, lung volume can be approximated with an error less than 10%.

Impedance Plethysmography

This technique consists of injecting a high frequency and low amplitude current through a pair of electrodes placed on the thorax and measuring the trans-thoracic electrical impedance changes [40]. As a matter of fact, there is a relationship between the flow of air through the lungs and the impedance change of the thorax. The measurements can be carried out by using either two or four electrode configurations. Electrodes can be made of fabric and integrated into a garment or,even, embedded into an undershirt. It is worthwhile noting that by measuring the trans-thoracic electrical impedance it is possible to non-invasively monitor, in addition to breathing rate also tidal volume, functional residual capacity, lung water and cardiac output.

Pneumography Based on Piezoresistive Sensor

Piezoresistive pneumography is carried out by means of piezoresistive sensors that monitor the cross-sectional variations of the rib cage. The piezoresistive sensor changes its electrical resistance if stretched or shortened and is sensitive to the thoracic circumference variations that occur during respiration. Piezoresistive sensors can be easily realized as simple elastic wires or by means of an innovative sensorized textile technology. It consists of a conductive mixture directly spread over the fabric. The lightness and the adherence of the fabric make the sensorized garments truly unobtrusive and uncumbersome, and hence comfortable for the subject wearing them. This mixture does not change the mechanical properties of the fabric and maintains the wearability of the garment. Figure 1.3 shows where the two conductive wires or bands could be applied.

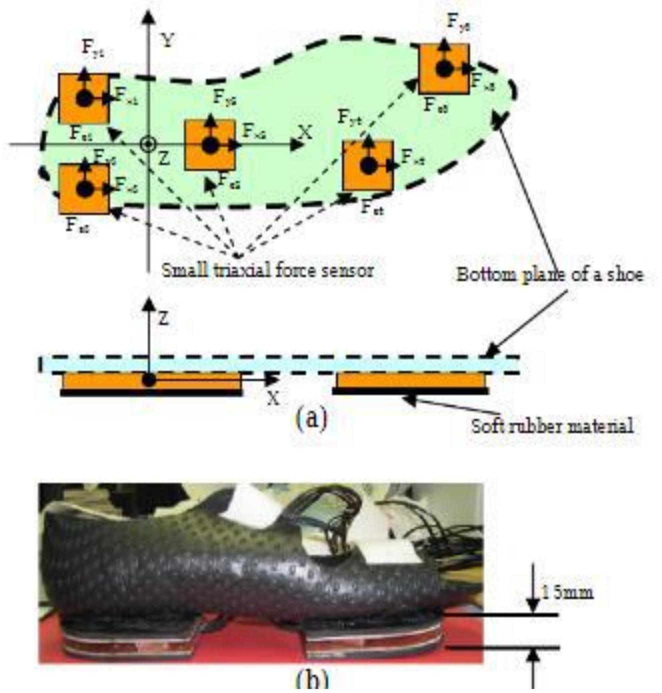
Plethysmography Based on Piezoelectric Sensor

This method is based on a piezoelectric cable or strip which can be simply fastened around the thorax, thus monitoring the thorax circumference variations during the respiratory activity. A possible implementation can be a coaxial cable whose dielectric is a piezoelectric polymer (p(VDF-TrFE)), which can be easily sewn in a textile belt and placed around the chest. The sensor is sensitive to the thorax movements and produces a signal directly proportional to the thorax expansion in terms of charge variation, which was converted in an output voltage proportional to the charge by means of a charge amplifier. A suitable local processor can enable implementation of the Fast FourierTransform in real time and extraction of the breathing rate.

Wearable GRF Sensor System

The quantitative analysis of gait variability using kinematics and kinetic characterizations can be helpful to medical doctors in monitoring patients' recovery status in clinical applications. Moreover, these quantitative results may help to strengthen their confidence in the rehabilitation. Walking speed, stride length, the centre of mass (CoM) and the centre of pressure (CoP) have been considered as factors in the evaluation of walking gait. According to one study on slip type falls, friction force was used to draw up important safety criteria for detecting safe gait, so the transverse components of ground reaction force (GRF) may provide important information for quantifying gait variability. Many kinds of stationary systems such as force plates and instrumented treadmill devices are available to measure CoP and triaxial GRF. Because a stationary force plate cannot measure more than one stride, in studies of continuous walking, a complex system consisting of many force plates and a data fusion method must be constructed . Therefore, the force plate technology probably imposes some constraints on our ability to measure human movement and is not feasible for measurements in everyday situations. An instrumented treadmill or dynamometric platform formed by laying two force plates under a treadmill can overcome some limitations of the system with distributed multiple force plates in successive measurements of the GRF for gait evaluation. However, a guide used to constrain the direction of the foot is necessary to ensure that subjects walk along a straight line, because if a human body segment motion analysis system is not available for a simultaneous measurement of the foot orientation, any technique based on force plates conventionally requires subjects to walk along a pre-defined specific path. Although gait variability can be assessed in straight walking , gait analysis concentrating solely on straight-line walking or running may not adequately interpret gait variability, because turning or walking direction changes probably have effects on extrinsic gait variability . To overcome such limitations of stationary devices in GRF measurement, many researchers are developing wearable sensors attached to shoes . Pressure sensors have been widely used to measure gaits and the distributed vertical component of GRF and to analyze the loading pattern on the plantar soft tissue during the stance phase of gait , but in these systems the transverse components of GRF (friction forces) which are one of the main factors leading to falling, have been neglected. By fixing two externally mounted sensors beneath the front and rear boards of a special shoe, researchers have developed an instrumented shoe for ambulatory measurements of CoP and triaxial GRF in successive walking trials, and the application of the instrumented shoe to estimate joint moments and powers of the ankle was introduced in. The mounted sensor itself, having a height of 15.7 mm, increases the height and weight of the shoe, and affects normal walking gait. Moreover, its application study was restricted to human kinetics analysis using the spatio temporal measurements of GRF and CoP.

A wearable GRF sensor system was constructed using five small triaxial force
sensors (USL06-H5-500N-C, weight: 15 g, size: 20 mm × 20 mm × 5 mm). The GRF and CoP measured using the wearable sensor system were expressed in a global coordinate system which was located on the interface between the instrumented shoe and the ground. The origin of the global coordinate system was fixed to a point around the anatomical centre of the ankle when the sensor system was worn on the foot. The x-axis was chosen to represent the anterior-posterior direction on the interface plane contacting with the floor, which was based on landmarks from the shoe. The z-axis was made vertical, and the y-axis was chosen such that the resulting global coordinate system would be right-handed. By mounting the five triaxial sensors on an aluminum plate beneath the shoe, we can accurately align all five local coordinate systems defined for each triaxial sensor with the global coordinates. Fxi, Fyiand Fzi (I = 1, 2, 3, 4 and 5) indicate triaxial forces measured by the distributed five triaxial sensors, and (xi, yi) is defined as the position of each triaxial sensor, for example, (x5, y5) indicates the position of the sensor placed on the forefoot. The total weight of the sensor shoe is about 300 g, and the shoe size is 250 mm.


Y
X
Z
Small triaxial force sensor
Bottom plane of a shoe
Soft rubber material
(a)
15mm
(b)

UNIT II SIGNAL PROCESSING AND ENERGY HARVESTING FOR WEARABLE DEVICES

Wearability issues -physical shape and placement of sensor, Technical challenges - sensor design, signal acquisition, sampling frequency for reduced energy consumption, Rejection of irrelevant information. Power Requirements- Solar cell, Vibration based, Thermal based, Human body as a heat source for power generation, Hybrid thermoelectric photovoltaic energy harvests, Thermopiles

Wearability issues

Wearable devices and electronics present a unique interface of technology and humanity, thus producing unique challenges that need to account both for technological and human aspects of the problem. Human behavior may affect the operation of wearable as much as the technology advance. The following aspects may be considered as some of the challenges facing the field of wearables:

(a) Break-through applications of wearable electronics. From the dawn of history, the evolution of wearables is driven by the practicality, utility, and convenience they provide. The challenge of modern wearable electronics in discovering ubiquitous applications, as its future growth is contingent on emerging applications in health, wellness, and other personal needs. Novel applications of wearables may need to be supported by extensions of sensing and data analytics capabilities, thus presenting a compelling use case

(b) Minimization of user burden and integration with everyday wear items. The illustrations of wearable devices frequently include pictures of individuals instrumented at every possible location on the body, such as arms, legs, torso, etc. Practically, such a scenario represents an unrealistically high user burden and is unfeasible. A related challenge is the seamless integration of wearable electronics in everyday wear items, such as textiles clothing, footwear and accessories.

(c) Efficient and informative interpretation of data generated by wearable devices. Wearable devices may generate an abundance of data, for e.g., health-related sensor signals.The challenge lies in the interpretation of such data streams and connection with health outcomes, using sensor data to guide behavioral interventions and health education. Emerging methods of artificial intelligence carry a promise of solution to the problem of data analysis and interpretation.

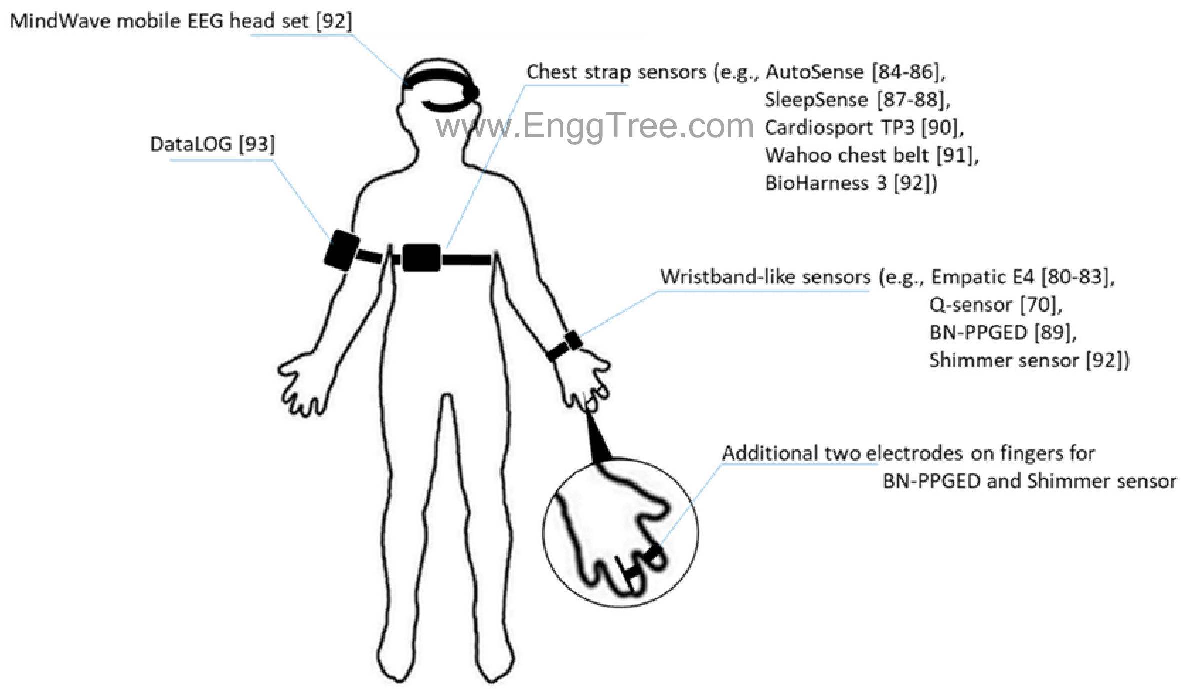
(d) Ultra-low power operation. A wearable device should ideally sustain a lifetime operation without or minimal user interference. In terms of power, this implies operation on a battery, energy harvested from the body, or a combination thereof. This requires low-power operation both for analog and digital electronics of a wearable. Wireless power delivery may be explored to seamlessly charge many devices without need to connect each individual device to a charging circuit (for e.g., charging all socks in a drawer), biofuel cells and supercapacitors may need to be utilized in the power subsystems.

(e) Flexible and stretchable electronics. Epidermal and body compliant electronic devices may be considered a subset of wearables with additional requirements of allowing shape changes in response to body movement, making such devices especially sensitive to motion artifacts, demanding high biocompatibility and adaptability to variation in human body shapes, sizes, and characteristics.

(f) Biocompatible communications. Communications from the body (to the outside world) and on the body (between multiple wearables) demand new solutions, as traditional radio methods experience challenges due to absorption by body tissue. The related challenges include development of efficient methods for communicating through or on the body, including the organization of wearables in body sensor networks and their integration into the Internet of Things Biodegradable Electronics. If wearable electronics are to become the true mainstream, the challenge of sustainable, ecologically viable manufacturing, and disposal needs to be addressed.

(h) Privacy and Security. By definition, a wearable is an electronic device that resides on or close to a person and is present in a variety of life situations. The challenges include protection of personal information, preventing the unauthorized use of wearables for biometric identification, and ownership of the data produced by wearables

physical shape and placement of sensor



The sensor such as 3-axis accelerometer can be used as body position sensor. This sensor provides information of patient's position i.e. standing, sitting, supine, inclined, left and right. Such accelerometer based sensor can easily be interfaced with any microcontroller boards such as arduino uno, arduino mega etc.

Design for wearable BSNs focuses on specific and important issues for developing wearable computing systems that take into account the physical shape of the sensors and their active relationship with the human form.
Design for wearability requires unobtrusive sensor node placement on the human body based on application-specific criteria.

Criteria for placement can vary with the needs of functionality and convenience. Functionality criteria constrains node placement to regions where relevant data can be sensed. The number of nodes required to capture all relevant data can vary based on the quality of information sensed at individual locations. Convenience criteria include:(1) physical interference with movement,(2) difficulty in removing and placing nodes,(3) social and fashion concerns,(4) frequency and difficulty of maintenance(charging and cleaning)
For example, in continuous healthcare monitoring, patients will be expected to charge the sensors or replace the batteries on a regular basis, as they do with cellphones and other electronics.However, the frequent need to charge and the bulk of the battery can frustrate the users, causing them to no longer wear the sensors. Furthermore, batteries are the heaviest component in the system. By decreasing power usage, the size and weight of each sensor node can decrease, thus increasing patient comfort and device wearability.

This makes energy usage a primary constraint in designing BSNs, limiting everything from data sensing rates and link bandwidth, to node size and weight. Thus, one of the important goals in designing BSNs is to minimize energy consumption while preserving an acceptable quality of service. Energy consumption can be decreased by lower sampling frequency, decreasing processing power, and simplifying signal processing.
Another effective technique is deactivating nodes thatare unnecessary for specific tasks.

Technical challenges - sensor design and signal aquisation

As engineers seek to develop new and innovative wearable diagnostics, many are focusing on smaller, more energy-efficient devices. In the process, respondents say they are fighting the kind of typical constraints that factor into many of today's product development efforts, citing top among them the areas of cost (38%), durability (37%) and power management (35%).

There are other unique challenges in designing diagnostic wearables to be used by a patient, caregiver, or consumer in a non-medical setting. High user expectations around ease of use, the need for intuitive user interfaces and complete documentation, as well as the need to account for the vagaries of uncontrolled home care settings top the list of challenges cited by engineers.

Data collection and connectivity represent another area for concern. Nearly one third (30%) of respondents pointed to connectivity as a challenge. Over two thirds (82%) agree that there isn't a lot of clarify about how to effectively capture and use the data or doing something medically effective with it once collected. Nearly all (94%) cited a need to for ownership of data security and privacy.

sampling frequency for reduced energy consumption

Sampling rate or sampling frequency defines the number of samples per second (or per other unit) taken from a continuous signal to make a discrete or digital signal. For example: if the sampling frequency is 44100 hertz, a recording with a duration of 60 seconds will contain 2,646,000 samples.

Long battery runtime is one of the most wanted properties of wearable sensor systems. The sampling rate has an high impact on the power consumption. However, defining a sufficient sampling rate, especially for cutting edge mobile sensors is difficult. Often, a high sampling rate, up to four times higher than necessary, is chosen as a precaution. Especially for biomedical sensor applications many contradictory recommendations exist, how to select the appropriate sample rate. They all are motivated from one point of view — the signal quality. In this paper we motivate to keep the sampling rate as low as possible. Therefore we reviewed common algorithms for biomedical signal processing. For each algorithm the number of operations depending on the data rate has been estimated. The Bachmann-Landau notation has been used to evaluate the computational complexity in dependency of the sampling rate.

Wearables, or wearable technology, are devices or gadgets that a person wears on their body. However, these wearable devices are more than the latest pair of headphones or a new digital watch. Wearables can be considered smart gadgets — smart meaning they're equipped with all types of sensors including accelerometers and gyroscopes, to mention a few, as well as using Bluetooth technology for making a wireless connection to your smartphone. Some wearables are designed to help you achieve goals such as staying fit, losing weight, or becoming more organized.

Power requirements of wearables:

Wearables, like the vast majority of other portable electrical technologies, require batteries, and the device's power requirements drive the battery form factor. Of course, we (consumers) all want products that are smaller, thinner, and have a longer-lasting battery life. There are scores of battery options for which battery technology can best fit wearables' requirements.

Some of the more common types of wearable batteries include:

- Alkaline
- Nickel-Metal-Hybrid (NiMH or Ni-MH)
- Lithium-Ion (Li-Ion) and Lithium-Ion Polymer (LiPo, LIP, Li-poly)

Alkaline batteries are tried-and-true — they've been around since the 1960s — and are both safe to use and are easily replaceable. A few examples of alkaline batteries are the AA and AAA.

Alkaline batteries are also available in the button cell (AKA: coin cell) form factor. These batteries have a standard voltage of 1.5 V and a size of 11.6 mm in diameter by 5.4 mm in height. However, when compared to lithium and silver oxide batteries, alkaline batteries offer both the least energy capacity and stable voltage — their voltage drops gradually with use rather than providing a steady and stable voltage before experiencing a sharp drop-off at the end of life.

A **Nickel-metal-hybrid** (NiMH or Ni-MH) battery is a type of rechargeable battery.

NiMH batteries can have two to three times the capacity of an equivalently sized nickel–cadmium battery (NiCd), and its energy density can approach that of a lithium-ion battery.

Lithium-ion (Li-ion) and **Lithium-ion polymer** (LiPo, Li-Po, LIP, Li-poly) batteries are the most popular batteries today for wearables. "For wearables today mostly small LiPolymer cells or LiCoin Rechargeable cells are used."

From lithium-ion batteries to coin cell batteries, and from battery life to size and fit, there are many options of which battery technology best fits your needs. Regardless of which battery is utilized, eventually it must either be replaced or recharged. In a perfect world the battery would last forever, but although the world is far from perfect, there is another option — energy harvesting. Of course solar cells (they get their energy from sunlight) and thermoelectric generators (they produce electricity from a temperature gradient) have both been around for a while, albeit neither technology would be practical for wearable devices because they cannot guarantee a continuous supply of energy — sunlight is intermit and body heat has a low thermoelectricity output. What is needed is an energy harvester that both works continuously and allows for high levels of electrical energy generation. Enter TENGs, or triboelectric nanogenerators. This energy-harvesting technology was invented to generate electricity from ambient mechanical motion such as rotary motion, vibrations, oscillating motion, and expanding/contracting motion.

Another approach of energy-harvesting technology is by generating small electric currents through the relative movement of layers, a process called triboelectric charging. "Materials can become electrically charged as they create friction by moving against a different material, like rubbing a comb on a sweater. By sandwiching layers of differently materials between two conducting electrodes, a few microwatts of power can be generated when we move."[4]

No matter how wearables get their energy, it is expected that wearables will become the "must-have" gadgets for both personal and professional use. According to Intersil, "…wearables are such a hot trend that ABI Research forecasts the category is growing at a CAGR of 56.1% and will reach 487 million units in 2018."[5] And given that we (consumers) all want products that are faster, better, and cheaper "…system designers are constantly challenged to create smaller, more efficient and cost effective solutions that will place wearables on the wrists of many more people."

Wearable Device Architectures

Intersil states, "A typical wearable device architecture includes a microprocessor, memory, display, sensors, communication IC and battery charger blocks, among others. It uses at least three DC-DC converters and 3-5 low dropout (LDO) regulators, depending on the system application."[5] Perhaps a nice compromise between wearables that are battery-free (i.e., utilize energy- harvesting technologies) and wearables that are equipped with rechargeable batteries, is using rechargeable batteries of which incorporate wireless charging.

Texas Instruments (TI) offers their wireless charging PMP11311 reference design for wearable devices. TI appreciates the fact that wearable technology devices "…require advanced power management to achieve long battery run times with always-on functionality. Additionally, the devices need to use small rechargeable batteries and enable small footprint designs."

TI's reference design provides a wireless charging input, a highly configurable battery management solution using a Li-Ion battery charger, and a low quiescent current DC/DC buck/boost converter. Figure 8 below illustrates TI's wireless power system.

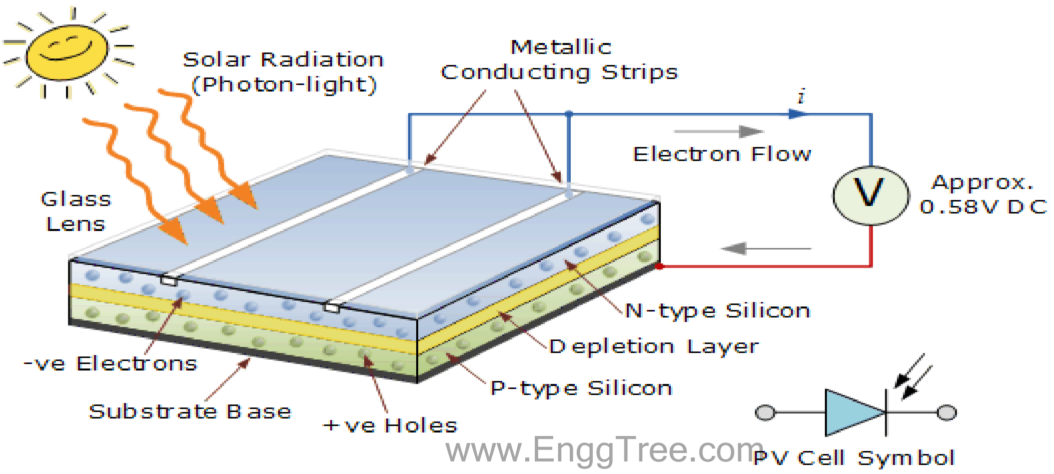
Another semiconductor company that realizes the coming growth explosion of the wearable market is Linear Technology. Linear Tech offers their LTC3331 which is a complete energy-harvesting solution that delivers up to 50mA of continuous output current when harvestable energy is available.

Solar Cells & Batteries Used in Wearable Devices

Wearable devices have been increasingly popular in the past few years. Everything from smartwatches as a fashionable, convenient extension of one's smartphone to thin bands for fitness tracking, wearable devices are rising in popularity. Such devices can add value to everyday life by providing a way to access information more readily. These electronic devices, however, are no help when they are dead. Minimizing charging frequency is important for all portable devices, but arguably even more so for wearable devices. If the goal is to always have a device readily available, extended battery life is essential. Therefore, some companies have created wearable devices that can be recharged using solar cells. This increases charge time potential while still being able to wear and operate the device as intended without inconveniencing the user

Basics of Solar Cells

The most common photovoltaic cells are silicon-based. Understanding semiconductor physics is critical to understanding the operation of solar cells. To create a solar cell, silicon layers will be doped to have more electrons, an n-type layer, in one (or some) layer(s) and others doped to have fewer, a p-type layer. P-type layers have an excess of holes–effectively locations where electrons are missing. These types of doped materials are configured so a p-type layer will be next to an n-type layer. The excess electrons and holes flow between the layers. This flow of charge carriers and creation of ions induce an internal electric field. Photovoltaic cells have this type of structure. When sunlight hits a photovoltaic cell, absorption of sunlight will excite electrons, creating holes in their place. The flow of the electrons creates electricity which can then be harnessed. Silicon solar cells generally have an efficiency hovering somewhere around 20 percent. The performance of solar cells is highly dependent upon the duration and intensity of the light they are exposed to.



Solar Cells in Wearable Devices

While large solar panels installed on building roofs might be the first thing that comes to mind when talking about photovoltaic cells, they can be produced for much smaller applications. Garmin currently advertises a limited offering of solar-powered watches. These smartwatches have impressive battery lives. They list their Instinct Solar watches operating for 54 days on a single charge. Going off solar power alone and assuming 3 days outside at 50,000 lux, they claim unlimited battery life for their watch in battery saver mode. Both the watch's screen and a photovoltaic ring around the screen can convert solar energy into electricity. Employing virtually the entire watch face for capturing solar power maximizes the charging power from the sun.

PowerWatch is a company that also uses solar power to recharge their watches. It is worth noting, however, that solar power is the secondary charging method. The primary charging method is not conventional either, but is achieved through a thermoelectric power sensor. Their MATRIX Prometheus sensor uses the thermal energy from the wearer's body and converts it to an electrical output that powers the watch. This is a prime example of companies finding alternative methods for charging wearable devices.

Dawn of Solar-Powered Textiles

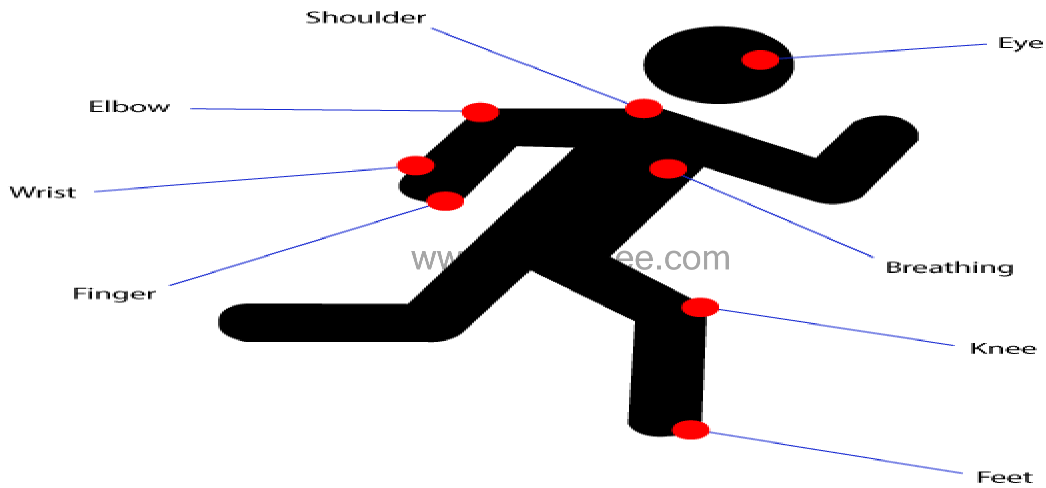
Not only are photovoltaic cells being developed for powering wearable electronic devices, but to be woven into everyday clothing. Nottingham Trent University's School of Art and Design has a group which is researching how to create solar cells small enough to be laced into textiles. The group is attempting to combine solar cells into clothing in a way that is unnoticeable to the wearer. The goal is to create clothing that appears the same as all other clothing, only while simultaneously producing electricity. The material comprises of numerous solar cells integrated into the material measuring 3mm by 1.5 mm. The cells would be coated in resin to protect it from the wear and tear of regular usage and laundering. The photovoltaic cells would produce electricity which could be used to charge a device via a USB connection integrated into the clothing.

The group out of Nottingham is not the sole party interested in creating solar cells conducive to being part of daily fashion. Researchers at Rice University have been exploring flexible photovoltaic cells to be sewn into clothing or other wearable items. They see the flexibility of the solar cells as a critical achievement as traditional solar cells are far too rigid and brittle to be practical for clothing. Flexible solar cells are able to bend with the movement of the fabric without damage to the solar cell itself while maintaining the integrity of the garment. While their flexible cells are less efficient than conventional solar cells (a difference of roughly 7%), the flexibility could be well worth the deficit. The flexibility of the solar cells is achieved through using a material that is made up of "sulfur-based thiol-ene reagents". The researchers have reported that cells with 20% thiol-ene content provide the prime combination of efficiency and flexibility.

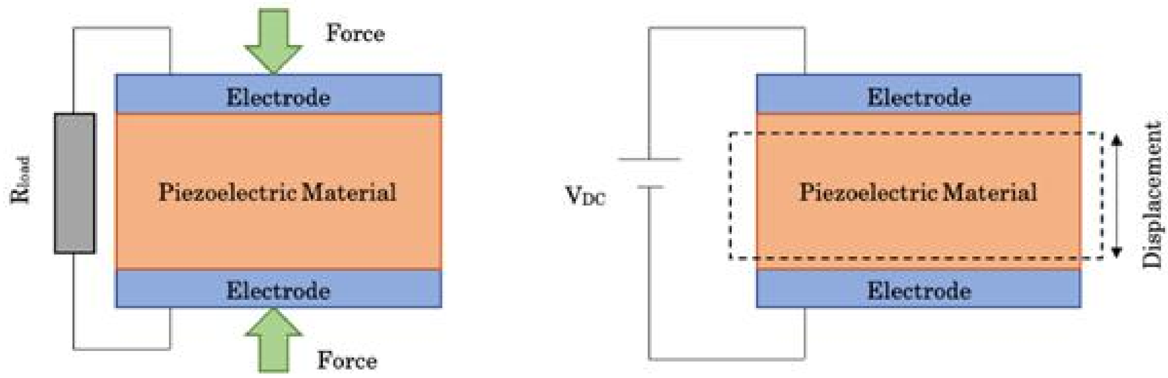
Still other researchers have been creating flexible solar cells. Organic, ultrathin photovoltaic cells have been developed at the RIKEN research center in Japan. These solar cells were created by using an annealing process to improve the thin cell's durability while retaining flexibility. Their solar cells have an energy conversion ratio of approximately 12%. Again, this is lower than the conventional silicon-based solar cell's energy conversion ratio by about 10%. However, their research does show promising results with regards to the environments in which these ultrathin cells can be operational. They say that the solar cells are remain stable even under high temperatures and humidifies. This type of functionality and durability would indeed be beneficial for use in wearable devices.

Vibration based power Requirements of wearable devices

With the vast amount of wearable technology available, the demand for compact devices with smaller batteries, or no batteries at all, and longer charge duration has presented a challenge. Consumers of wearable technology want the convenience of a portable device without the need for frequent charging or bulky and expensive batteries. Producers of wearable technology are then tasked with creating devices that meet this demand. The use of piezoelectric components in wearable technology is a solution for this issue.
The use of piezoelectricity stands to reduce, or even eliminate, the need for frequent charging of devices and batteries. Consumers will no longer be burdened with having to be near an electrical outlet, which will in turn conserve electricity. As a result, wearable devices and more efficient batteries will have longer usable lives. This will also reduce the environmental hazards presented by the frequent disposal of batteries and electrical components into landfills.
Harvesting energy using piezoelectric ceramic involves the conversion of energy from vibrations that occur during walking, breathing, and moving on many parts of the body.



When stressed, piezoelectric components create an electrical current that can be immediately used or stored. The amount of energy produced is still relatively small and required body movements aren't often regular and predictable. Also, a large surface area is often necessary to harvest a sufficient amount of energy. This presents a challenge when thinking of the small size needed in wearable devices.



Direct and inverse piezoelectric effects.

Two promising factors in surmounting these obstacles are the versatility of piezoelectric components and the fact that the efficiency of piezoelectric energy harvesting has increased, while the power requirements for current wearable devices have been reduced.
There are four different types of materials that can be used for piezoelectric energy harvesting: ceramics, single crystals, polymers, and composites. Of these, ceramic is the preferred material for this type of energy harvesting because of its low cost, effective piezoelectric properties and easy incorporation into energy harvesting devices.
Piezoelectric vibration energy harvesting is the preferred method for use with wearable devices since it is the most capable of producing the power level needed for small-scale devices.

There are two kinds of mechanical energy that can be scavenged from the human body. The first is related to continuous activity, such as breathing and heart beating; while the other is related to discontinuous movements, such as walking and joint movements. Of these, the process of walking produces the largest amount of power compared with other body motions. It has been recorded that a 68kg man is able to generate 67W when walking at a speed of two steps per second. The easiest way to harvest this energy is through piezoelectric shoe inserts.
Body joints are also attractive locations for harvesting energy due to their high motion amplitude, fast angular velocity, large impulse force, and high frequency of use in daily human activities. For example, the knee joint produces high biomechanical energy since it generates a larger torque in comparison to other human joints. Knee joint motions are often related to gait motion, where walking and running frequencies are normally in the range of 0.5-5 Hz.

Even for relatively minor activities such as eye blinking, piezoelectric transducers have effectively been used to convert motional energy into electricity. For example, a self-powered sensor was developed for both energy harvesting and health rehabilitation monitoring, which was based on polymeric piezoelectric nano/microfibers.
Furthermore, continuous energy can be harvested from the process of human breathing. There are two kinds of energy that can be collected in this case. The first relies on scavenging energy due to the intake and release of air, which can produce approximately 1 W of power. The other relies on chest expansion, which requires a tight band fixed around the chest of the user to generate around 0.83 W when breathing normally.

Wearable Piezoelectric Applications

Piezoelectric components can be used for wearable technologies and other new technologies. Their use presents vast possibilities across many industries. Human comfort, convenience, health and safety have the potential to be greatly improved with the availability and use of products containing piezoelectric components. Many of these capabilities and products are already emerging in today’s society.
These include:

- A piezoelectric pacemaker that is powered by the rhythm of a beating heart. This eliminates the need for invasive and dangerous surgery for battery replacement
- Footpath lighting powered by footsteps striking energy-absorbing tiles

- The ability to power monitoring and sensor devices in remote and dangerous places (bridges, pipelines, etc.). This eliminates the risk to humans that arises when batteries need charging or replacing
- A vehicle driver's seat that uses piezoelectric sensors to monitor and sense driver's heart rate and respiration. It uses vibration sensors to allow ventilation and massage features to be automatically activated in the seat when driver stress is detected
- Wearable devices that can be charged by walking, running or other physical activity

Some wearable sensors on the market today include fitness and activity wristbands and monitors that observe distance, respiration, heart rate, and even sleep patterns. Wireless blood pressure cuffs measure patient's blood pressure through a phone app. Quartz watches have been around for a long time and employ the natural piezoelectric property of quartz to keep precise time. Monitors that detect and measure fetal heartbeats use piezoelectric components to convert the vibration into a readable signal.

The use of "smart" fabrics is also gaining popularity. The flexible fabrics are infused with piezoelectric materials that act as sensors to measure, monitor, and harvest energy. A single pressure-sensitive layer is sandwiched between two conductive layers. These sensors are currently being developed for use as shoe insoles, clothing, and wearable devices that measure information such as pressure, steps, energy expended, etc. The amount of energy created by the fabrics differs with factors such as the type of piezo material used and the movement of the user.

Design Challenges in Wearables with Piezoelectric Technology

There are challenges facing the design and implementation of piezoelectric technology within wearable devices.

Material Choice

Textiles that have a greater elasticity perform at a greater efficiency when harvesting piezoelectric energy. The greater elasticity of the material increases the stresses occurring in the garment and, consequently, increases the elongation of piezoelectric elements. In addition, the garment must be form fitting in order to increase the clothing pressure and increase the piezoelectricity efficiency by increasing the strain exerted on the harvester on the garment. However, with this increased tightness of the garment on the user, this subsequently restricts the user's movements and their ability to harvest energy.

Durability

Energy harvesters are required to have high environmental durability and operational reliability. However, in the case of piezoelectric energy harvesters, the material properties may change during the manufacturing process, even if the piezoelectric effect is caused by intrinsic physical properties such as the crystal structure of the material. When a strain is repeatedly applied to a material, macroscopic cracks may occur resulting in a drop in the amount of power generated. Clarifying the mechanism behind the deterioration of materials that occurs during the conversion of kinetic energy into electric energy and taking countermeasures are challenges for piezoelectric technology.

Operating Frequency

It is a well-known issue with piezoelectric energy harvesters that they do not harvest energy efficiency at varying frequencies. These devices operate at a high frequency whereas humans have an ultra-low frequency of around 1Hz. As the operating bandwidth of piezoelectric energy harvesters is quite high, this significantly limits their utility within real world applications in wearable devices. In addition, the motion range of humans is usually much higher than the predetermined device size and so resonant devices cannot render the advantage of powerful magnification. The operating excitation frequency must fall in the resonant frequency range of harvester so as to obtain the best results. Most commonly, the frequency up conversion technique is used to overcome this hurdle. Mostly, mechanical plucking mechanism by using piezoelectric bimorph was used for frequency-up conversion to power low-powered electronics. However, these devices showed some drawbacks such as reduced longevity due to direct contact between bimorph and plectra and noise. To overcome such challenges, a prototype for piezoelectric knee-joint EH by replacing mechanical plucking by the non-contact magnetic plucking device to perform the frequency-up conversion and achieve a power output. In addition, piezoelectric vibrational EHs with a flexible 3D structure fabricated by a microfabrication process can cover low frequencies and achieve a large strain.

Future Considerations and Complications for Wearable Technology in General

Before portable and wearable self-powered system can move toward large-scale practical applications, there are still many problems that should be fully addressed soon. Most wearable and portable self-powered systems are based on flexible materials, which experience device performance degradation during long-term operation. Therefore, in the future, we should study additional material and structural designs to improve the stability of the system under long term work while ensuring the wearability of the device.

Currently, portable wearable self-powered electronic devices are mainly desktop laboratory devices, which only demonstrate a concept. Since there is no work to propose a standardized manufacturing process for portable and wearable self-powered electronic devices, it is impossible to achieve complete consistency with respect to the performance of two different devices. Therefore, in the future, we need to consider the issue of performance calibration between different devices, or we can develop standardized processes for portable wearable devices that can be mass produced.

Hybrid energy harvesting technology that integrates multiple transduction methods is most likely to act as a power source for future self-powered systems. However, the large differences in the frequency, amplitude, and waveform of electrical power converted through different transduction methods make it an unsolved problem to develop power management technologies suitable for different energy harvesting methods. Furthermore, an increasing number of functional modules are being integrated into self-powered systems. We need to rationally design power management circuits to improve the energy conversion efficiency and achieve energy distribution among various functional modules. In addition, a wireless module is needed to realize the transmission of information.

Human body as a heat source for power generation

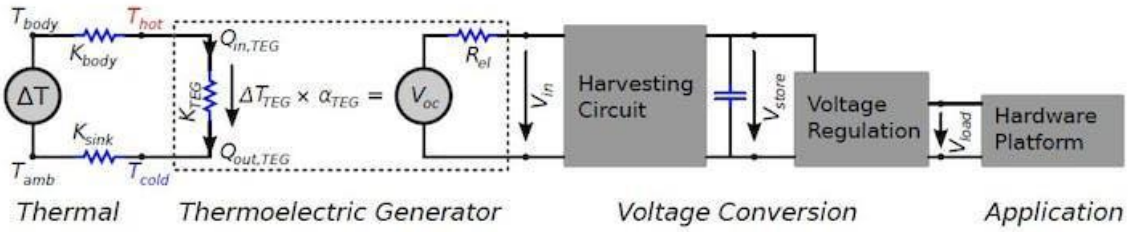
Body heat applied to a thermoelectric generator plus energy harvesting to produce power for a wearable device achieves both minimization of form factor and power consumption. nother consideration in powering wearable devices is the necessity to impose weight and size constraints, particularly if you initially choose a battery as the source of power. To limit size and weight you should use energy harvesting instead of the battery. The article points out that you can harvest energy from several environmental sources:

- Light, using photovoltaics
- Movement of the wearer
- Radio frequency energy (RF)
- Temperature differences using a thermoelectric generator (TEG)

An evaluation of these environmental sources reveals that photovoltaic or RF harvesters limit the application of zero-power wearables to environments where sufficient ambient light or RF emissions is provided to satisfy the energy budget. Movement-based harvesting systems require an active wearer and usually have unstable power generation characteristics. In contrast, the human body is a constant heat source and typically a temperature difference exists between body core and the environment.

Even in a scenario where the wearer is stationary and situated in a dark room (e.g., during sleep), energy can be produced. Lower ambient temperatures, the presence of air convection, or increased activity of the wearer can drastically increase the amount of accumulated energy. Because the voltages produced by thermal harvesting are typically too low to power wearable electronics, you must include a high-efficiency dc-dc converter into a wearable system.

Thermoelectric energy conversion of human body heat represents a promising alternative as it is largely independent of external factors. The average power harvested per square centimeter is higher using the thermal harvester than an equally sized solar cell. However, the produced voltage is used to directly charge a supercapacitor as an energy buffer and the device is only operational if the ambient temperature is lower than 25°C to 27°C. In one application a Thermoelectric Generator (TEG) on a human forehead powered a 2-channel EEG system with a power consumption of 0.8mW. You can harvest up to 30 μWcm^{-2} before dc-dc conversion (Voltage Regulation in *Fig. 1*). A two-stage custom dc-dc converter design is used to convert the voltage produced by the TEG to 2.75V. Due to the large thermal harvester, the system has limited wearability. Previous systems relied on custom designed and fabricated components, including the TEG and dc-dc circuits, to optimize the output power for a very specific application scenario. Application-specific components are necessary to obtain the power output and physical size required for a wearable sensor application. Plus, state-of-the-art thermal harvesters may be too bulky and uncomfortable to achieve true wearability.



Wearable devices have been used to monitor a variety of health and environmental measures and are now becoming increasingly popular. The performance and efficiency of flexible devices, however, pale in comparison to rigid devices, which have been superior in their ability to convert body heat into usable energy.

Hybrid power devices are combinations of different power technologies. Hybrid power plants often contain a renewable energy component such as photovoltaic (PV) that is combined with wind power, thermoelectric power, solar thermal power, or a system like battery storage or solar thermal storage. Thermoelectric generators are semiconductor devices that have no moving parts and convert heat directly into electricity. When combined with thermal storage they can provide electricity round the clock at as low as $0.06 per kilowatt-hour and could achieve 16% efficiency.

PV cells convert the UV and visible regions of the solar spectrum while the thermoelectric modules use the infrared region to produce electrical energy. Thus, combining both these systems in a hybrid system provides enhanced performance. While PV panels convert up to 20% of solar energy into electricity, the solar thermal collectors capitalise on the untapped heat energy of the PV system, thereby increasing the energy production efficiency while occupying less space

Global energy demand is likely to increase by 48% in the next 20 years due to population explosion. Currently 80% of energy needs are met by fossil fuels, which emit greenhouse gases that lead to global warming and climate change. Their negative environmental impact is leading to development of renewable energy sources like solar, geothermal, and hydro.

Photovoltaics

A photovoltaic cell is made of semiconductor materials that absorb photons of the sunlight and generate a flow of electrons. Photons are elementary particles generated by Sun that carry solar radiation at a speed of 300,000km/s. When the photons strike a semiconductor material like silicon, they release the electrons from its atoms, leaving behind a vacant space called 'hole.' The stray electrons move around looking for a hole to fill.

Generally, a PV cell is made up of two types of silicon. The silicon wafer that is exposed to the Sun is doped with atoms of phosphorus, which has one more electron than silicon. The back side of the cell is made of silicon doped with atoms of boron, which has one less electron than silicon.

The sandwich thus constructed works like a battery. The layer that has surplus electrons becomes the negative terminal (n) and the other side that has a deficit of electrons acts as the positive terminal (p). An electric field is created between the two layers at the junction.

On excitation by photons electrons are swept to the n-side by the electric field at the junction, while the holes drift to the p-side. Both the sides are provided with metallic electrical contacts to collect electrons and holes. Electrons then flow in the external circuit in the form of electrical energy. Fig. 1 shows how a PV cell works.

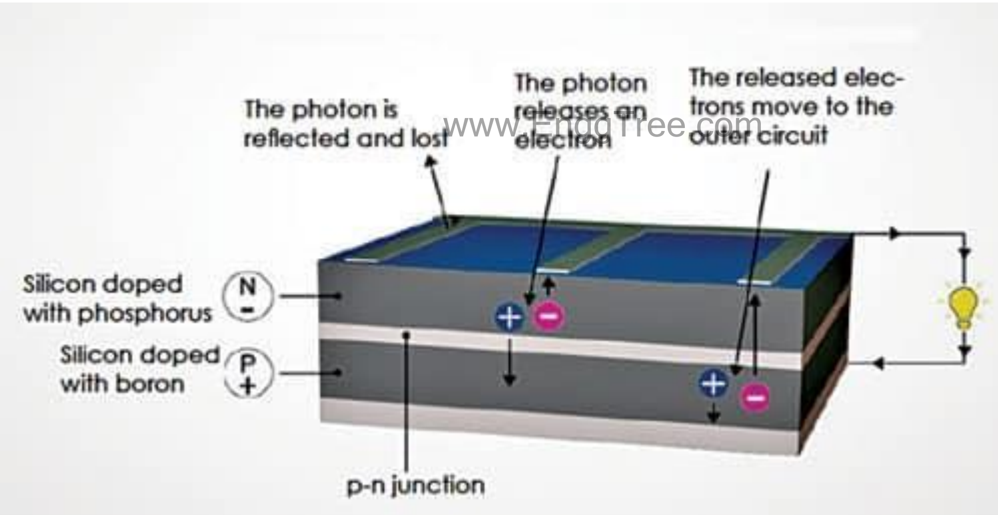


Fig. 1: **Working of a PV cell**

Thermoelectricity, as the name suggests, stands for the conversion of thermal energy (temperature difference) into electricity. It encompasses mainly two phenomena: the Seebeck effect and Peltier effect.

Seebeck effect is the phenomenon that a potential difference will appear between the two ends of a metal or semiconductor wire when they are kept at different temperatures. The potential difference is proportional to the temperature difference and the material's property known as Seebeck coefficient.

All materials are made of atoms, and atoms contain positively charged nucleus with negatively charged electrons moving around them. The electrons that are closer to the nucleus are bound more strongly, whereas the outer ones are loosely bound. When the temperature is uniform, the distribution of negative electrons is uniform and neutralises positive ions everywhere in the material, as shown in Fig. 2.

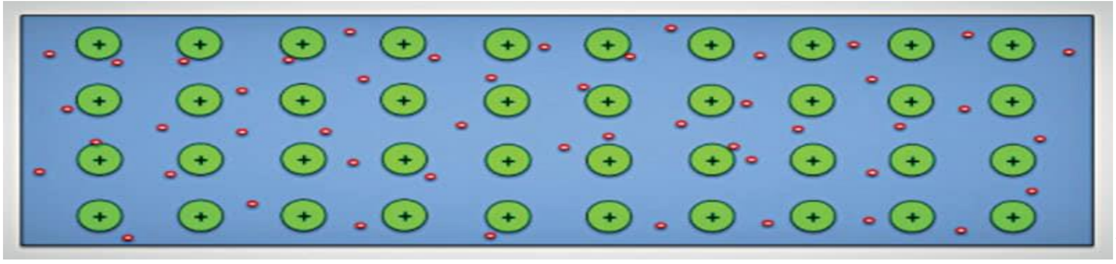


Fig. 2: Uniform distribution of neutral atoms

But when one end of the wire is heated and the other end is kept cool, electrons at the hot end gain more energy and higher speed than those at the cool end, which is indicated by the longer arrows in Fig. 3. So, at any instant more electrons move to the cold end than those moving back. So, the hot end becomes positively charged and the cold end becomes negatively charged, and current flows through the external conductor of a thermoelectric generator (TEG).

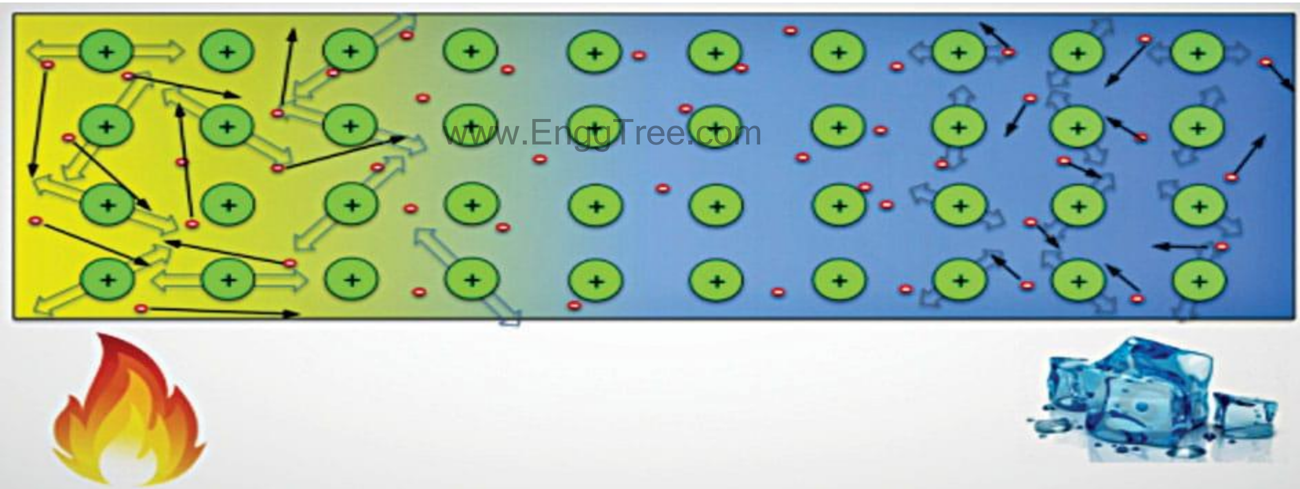


Fig. 3: Generation of potential difference due to heating in TEG

A single thermoelectric device is constructed from two solid-state devices that are usually made from bismuth telluride (Bi2Te3), as shown in Fig. 4. One of these pellets of semiconductor is doped with acceptor impurity to create a p-type component to have more positive charged carriers or holes, thus providing a positive Seebeck coefficient. The other is doped with donor impurity to produce an n-type component to have more negative charged carriers, thus providing a negative type of Seebeck coefficient. The two semiconductor components are then physically connected serially on one side, usually with a copper strip, and mounted between two ceramic outer plates that provide electric isolation and structural integrity.

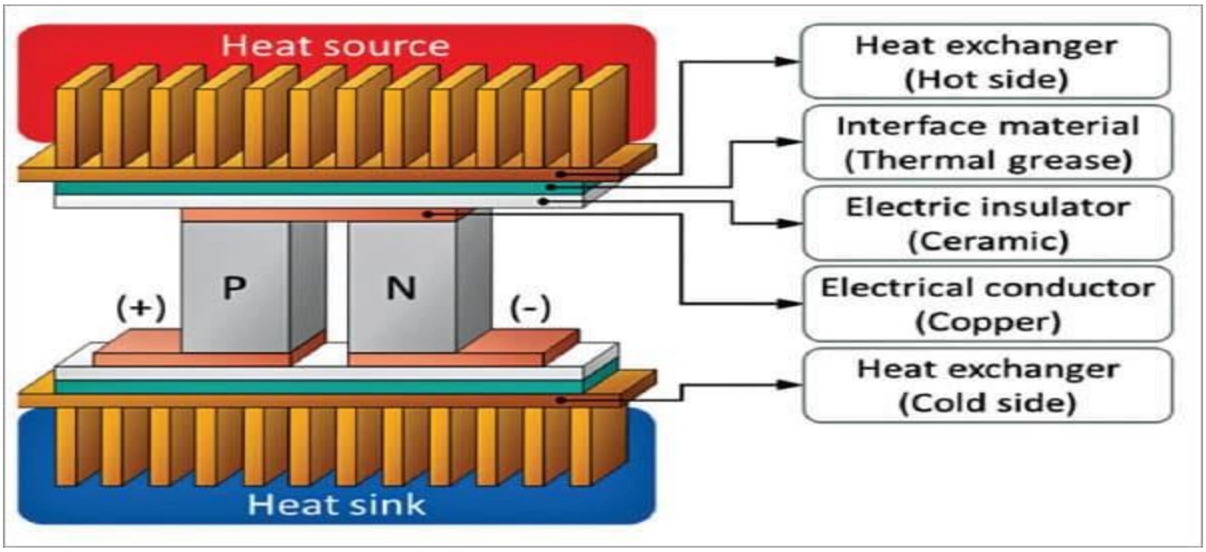


Fig. 4: Thermoelectric generator (TEG)

The Seebeck effect is a direct energy conversion of heat into a voltage potential. It occurs due to the movement of charge carriers within the semiconductor. Charge carriers diffuse away from the hot side of the semiconductor. This diffusion leads to a build-up of charge carriers at one end. This build-up of charge creates a voltage potential that is directly proportional to the temperature difference across the semiconductor.

The power generated in a TEG is single-phase DC that equals I2RL, where I is the current and RL is the load resistance. The output voltage and output power are increased either by increasing the temperature difference between the hot and cold ends or by connecting several TEGs in series, as shown in Fig. 5.

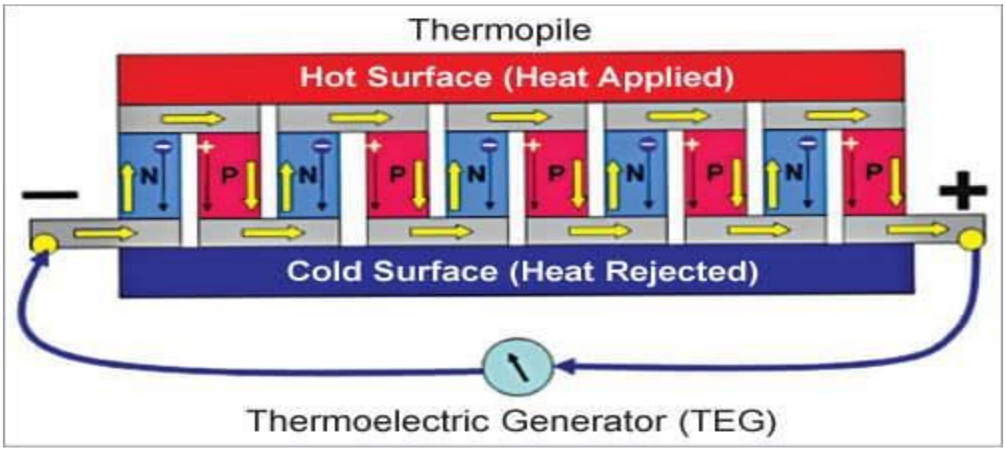


Fig. 5: Series-connected thermoelectric generator

The current flows as long as heat is applied to the hot junction. The process is reversible. If the hot and cold junctions are interchanged, the valence electrons flow in opposite direction and direction of the current changes. The thermoelectric effect allows converting waste heat into electric power.

By combining thermoelectric and PV effects, higher solar electricity conversion efficiency is possible. PV absorbs about 58% of solar energy between 200nm and 800nm wavelengths. The rest of the solar energy from 800nm to 2500nm cannot be converted to electricity by PV. But this spectrum of solar radiation can generate electricity through thermoelectric effect by heating TEG.

Thermoelectric figure-of-merit

The performance of thermoelectric materials is defined by unitless figure-of-merit as given below:

$ZT=\sigma S^2T/k$

where ZT is the thermoelectric figure-of-merit while σ, S, k, and T are electrical conductivity, the Seebeck coefficient, the thermal conductivity, and the absolute temperature, respectively.

The Seebeck coefficient of a material is the induced thermoelectric voltage per Kelvin generated in response to a temperature difference across the material, as induced by the Seebeck effect. It is often given in microvolts per Kelvin. The Seebeck coefficient depends on factors like temperature, work functions of the two TE materials, electron densities of the two components, and scattering mechanism with each solid. Performance of a TEG is determined by the Seebeck coefficient of the pair of materials forming the TEG.

Peltier Effect

In a circuit, when DC current flows through two dissimilar material, say copper and bismuth, the junction where the current passes from copper to bismuth would be hot and the junction where current passes from bismuth to copper would be cold. This effect, known as Peltier effect, is used to build devices like Peltier heater, solid-state refrigerator, and heat pump.

A good thermoelectric material should have following qualities:

1. Its Seebeck coefficient should be as high as possible. It is important to maximise energy conversion. The open circuit voltage generated by a TEG is proportional to the Seebeck coefficient and temperature difference across the TEG. Hence high Seebeck coefficient leads to a high voltage.
2. To minimise thermal loss through the thermoelectric material and to have large temperature difference across the TEG, thermal conductivity of the TE material should be as low as possible.
3. Its electrical conductivity should be as high as possible for reducing internal Joule heating losses of the thermoelectric elements.

A TEG's efficiency depends very much on the operating temperature difference between the junctions. The bigger the temperature difference, the more efficient the TEG.

There are **three main types of thermoelectric materials** used in thermoelectric generators:

1. **Bismuth telluride (Bi2Te3) alloy:** It is a semiconductor that has high electrical conductivity but is not good at transferring heat. The best working temperature of this class of material is below 450°C. Bismuth telluride materials with high figure of merit (ZT) and TEG modules, as shown in Fig. 6, have high conversion efficiency of more than 8% over temperatures of 25°C to 250°C and are widely utilised in energy generation and refrigeration.

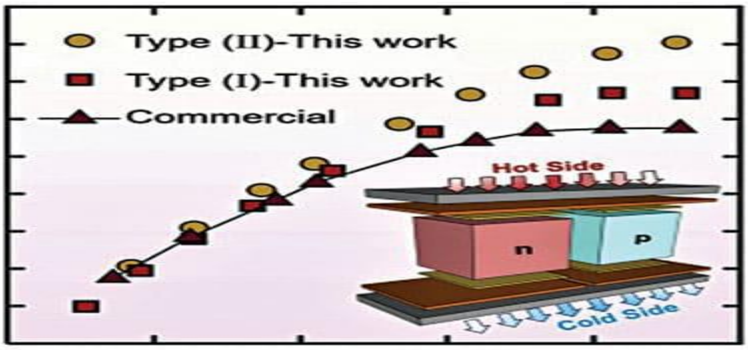


Fig. 6: Conversion efficiency of improved BiTe material

With improved techniques, p-type BiTe TE material that has average ZT of 1.08 and n-type BiTe with 0.84 ZT has been made. The significant enhancement in ZT could be achieved through compositional and defect engineering.

Type I module is constructed using p-type Bi0.5Sb1.5Te3 and n-type using Bi2Te2.7Se0.3S0.01. Type II material is constructed from p-type Bi0.4Sb1.6Te3 and n-type Bi2Te2.7Se0.3S0.01Cu0.01 materials. Fig. 7 and Fig. 8 show the Seebeck coefficient and figure of merit of these two types of improved BiTe materials, respectively.

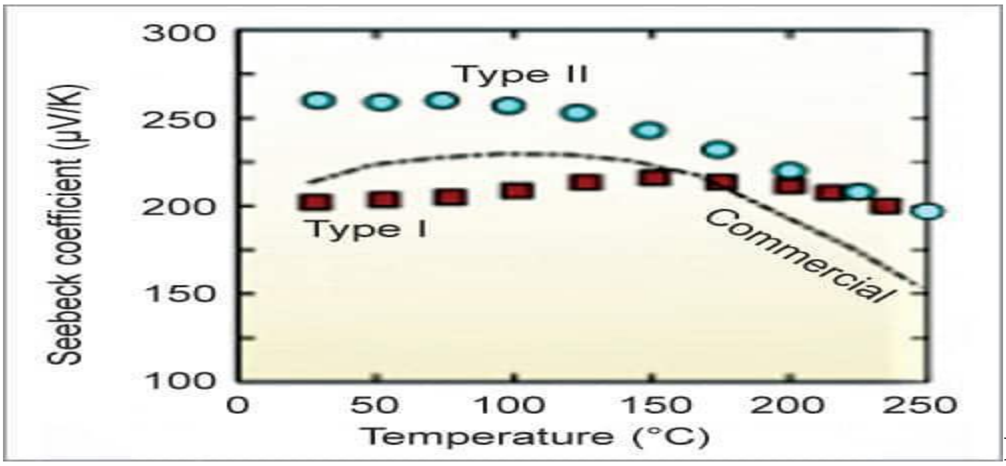


Fig. 7: Seebeck coefficient of improved Type I and Type II BiTe material

2. **Lead telluride (PbTe) alloy:** Low conversion efficiency is a big obstacle that impedes large scale application of TE materials for power generation. Lead telluride alloy is recognised as an excellent compound for power generation in the mid temperature range of 500-800°K. It has highly symmetric rock salt crystal structure, which is chemically and thermally stable. Lead telluride can be made either a p-type or n-type semiconductor.

   Recently researchers have enhanced the ZT of a sintered material to 1.8 (600°C) using a nanostructure forming technology. Further, an electrode material has been developed that contacts very well electrically and thermally with PbTe containing MgTe nanostructures, achieving a conversion efficiency of about 11% with hot side at 600°C and the cold side at 10°C.

   This breakthrough has made the way to convert waste heat and solar thermal power to large scale practical application. Because the nanostructures formed in the PbTe sintered material effectively scatter heat carrying phonons, but have no effect on the charge carrier transport, there is dramatic improvement in the ZT.

3. **Silicon-germanium alloy:** It is a kind of semiconductor that is often used for thermoelectricity generation with a working temperature around 1300°C. Combining Si and Ge allows to retain high electrical conductivity of both components and reduce the thermal conductivity due to the increased phonon scattering as Si and Ge have different lattice properties. Due to this reason Si-Ge alloys are currently the best TE material for high temperature application.

Conventional Si-Ge materials have ZT values of 0.9 and 0.5 at 1200K for n-type and p-type materials, respectively. By adopting nanocomposite approach reducing the grain size to around 5nm, ZT values can be increased by a factor of two and conversion efficiency can also be increased considerably. Ge is a scarce material and hence this alloy is costly. However, using only 5% of Ge it is possible to have Si-Ge alloy with improved performance.

The advantage of the newly developed nanocomposites is that its ZT values consistently remain above 1 over high temperature range between 600°C and 1000°C. Hence, these are the best TE materials for high temperature application for power generation by solar radiation, radioisotope devices, and waste heat recovery system. Table 2 shows the ZT values of bulk and improved nanostructured Si-Ge TE materials.

A thermoelectric device with a ZT of 1.25 will have an efficiency of about 10%. A segmented Si-Ge TE device over temperature range of 300K to 1300K will have an efficiency of about 12.1%.

Block diagram of a typical thermoelctric power harvesting system

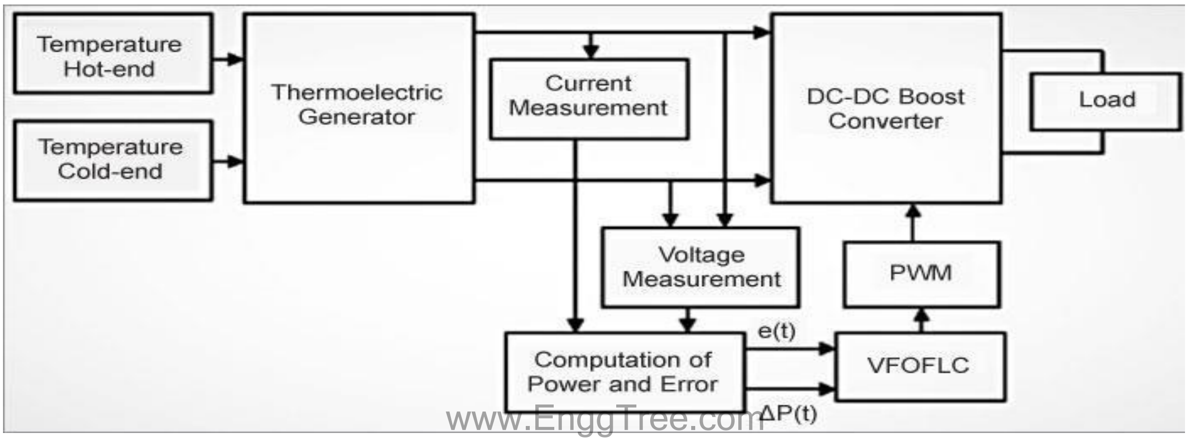


Fig. 10: Block diagram of thermoelectric power harvesting system

A thermoelectric power generation system has low energy conversion efficiency. According to the principle of maximum power transfer, the system would transfer the maximum power when the load resistance is equal to the internal resistance of the TEG. Based on this principle, several maximum power point tracking (MPPT) algorithms may be selected with different control logic to harvest the maximum power from the TEG. If a TEG is connected directly to the load, the load impedance will set the operating point which might result in the TEG output being less than the maximum output power.

The MPPT technique is considered an efficient mechanism to improve the performance of TEG by increasing the conversion efficiency. In this system, the operating point of the TEG is moved promptly towards an optimal point to increase energy harvesting by using a variable fractional order fuzzy logic controller (VFOFLC) based MPPT technique. The variable tracking step size is applied using a dynamic variable fractional factor whose value is calculated based on the voltage output of the TEG. The fraction order term introduced in the MPPT algorithm would contract or expand the input domain of the fuzzy logic controller to shorten the tracking time and maintain a steady-state output around the maximum power point.

Optimization of the TEG

It has been found that the output power is correlated with the geometry of the device. By changing the leg height and the number of thermoelectric pellets to an optimum value it is possible to maximise electric power or efficiency at given operating conditions. There is interdependence between optimal leg geometry and the electrical load resistance.

If number of legs is low, the energy conversion is low, because the load resistance (RL) is not sufficient to obtain an adequate high voltage and vice versa. A reduction of the leg length leads to a reduction of the electrical resistance, and an increase of the leg length leads to the higher temperature difference across the TEG. If the geometric parameters like leg length, number of semiconductor pellets, the base area ratio of the semiconductor columns are optimised, the output power and thermal efficiency are considerably improved.

The shape of the legs of TEG devices has considerable effect on the device performance. The conventional rectangular leg shape found in commercial TEGs is not the optimal shape for heat-to-power energy conversion. The hourglass shaped TE legs result in more than double the electrical potential and maximum power compared to conventional rectangular shape. The trapezoid leg with the largest cross-sectional area at the hot side results in about double the electrical potential and a 50% increase in the power output compared to the conventional rectangular shape. The electrical output power values, if optimised, can be 890% higher than a random value without optimisation.

Heat sink is required at the TEG when a high heat flow rate is applied on the hot side of the TEG. In order to have quick heat dissipation at the cold side cooling radiators are provided there, so that bigger temperature difference across the TEG can be obtained. The fins attached to the heat sinks are very important for enhancing the heat transfer at the hot and cold sides. The heat transfer increases when the number of fins are increased and the fin height is more, due to more heat transfer area. However, increase of heat transfer area is limited to an optimum value beyond which the change in the output electrical power becomes less significant.

The thermal resistance of the heat sink (Rhs) is:

$$R_{hs} = (T_{heat\ sink} - T_{amb})/Q_h$$

where, $T_{heat\ sink}$ is the sink temperature, T_{amb} is the environmental temperature, and Q_h is the heat flow. Experimental results show that increasing the thermal resistance of both cold and hot side heat sinks by 10% improves the electrical output power by 8%.

Aerogel

Aerogels are a class of synthetic porous materials derived from a gel, in which the liquid component has been replaced with a gas without collapsing the gel structure by freeze-drying. It can be made from silica, carbon, iron oxide, gold, copper, polymer, etc.

The final product is extremely porous (80-98% porosity) with very little solid material; up to 99.8% of the aerogel may have nothing but air. It has a typical density of about 0.001gm cm–3. Its thermal conductivity is extremely low, about 0.017W/mK, which makes the material an ideal insulator. It can be made transparent.

By reducing heat losses and simultaneously being transparent, aerogels allow a solar plant to operate at higher temperature and at higher efficiency without using any vacuum device. These advantages make an aerogel assisted solar thermal plant very economical and eliminates lot of maintenance problems.

Concentrated high-efficiency Solar Thermoelectric Generator

A solar thermoelectric generator (STEG) is a solid-state device that can convert solar energy at around 15% efficiency.

It has three sections: solar absorber, thermoelectric generator, and the thermal management system comprising insulation, heat exchangers, and vacuum/aerogel enclosure, etc.

There are no moving parts and there is no need of high-temperature operating fluids. Its robustness in harsh temperatures makes it very useful for standalone power conversion or making hybrid solar thermal power generator in conjunction with a PV system.

The efficiency of STEG depends on both the efficiency of solar absorber and on the thermoelectric efficiency of the device. There are mainly two approaches to increase the efficiency of STEG devices: increasing temperature difference between the hot and cold ends and using improved materials with ZT more than 1. Recently, several nanostructured materials have been developed that have higher ZT values suitable for STEG.

There are two routes to increase the temperature difference in a STEG: first, optical concentration of sunlight enabling to increase the heat flux at the absorber surface, and second by providing thermal concentration where the area of a highly thermally conducting absorber is greater than area of the thermoelectric legs increasing the heat flux through the legs.

It is possible to construct a durable STEG device with more than 15% efficiency using improved material consisting of a segmented n-type leg composed of skutterudite and La1Te4 and p-type leg of skutterudite and Yb14MnSb11, and also using nanostructured Bi2Sb3 based alloys (all these three types have an effective ZT of about 1.4 to 1.6 at 800K).

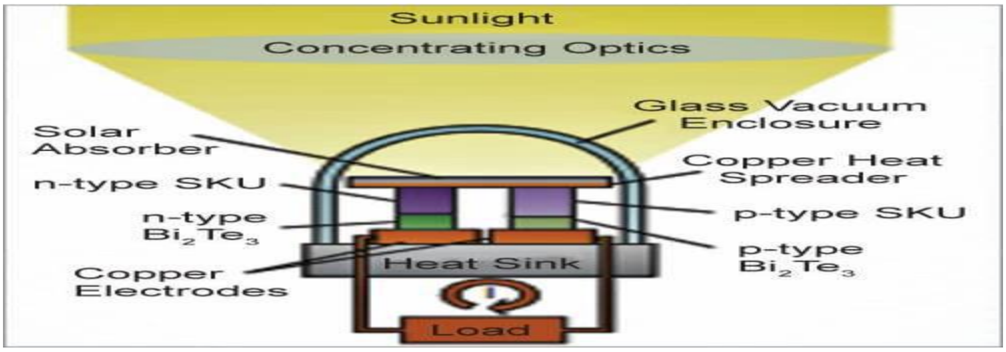


Fig. 11: Schematic arrangement of concentrated STEG system

Operating temperatures across Thot-Tcold=900°C–200°C are maintained using fresnel lens to concentrate sunlight. In order to reduce heat losses from the solar collector a vacuum system is provided, which is costly. Skutterudite is a type of arsenide mineral having general formula as TPn3, where T is a transition metal like Co, Rh, or Ir, and Pn is Sb, As, or P. Typical arrangement of STEG system is shown in Fig. 11 and Fig. 12.

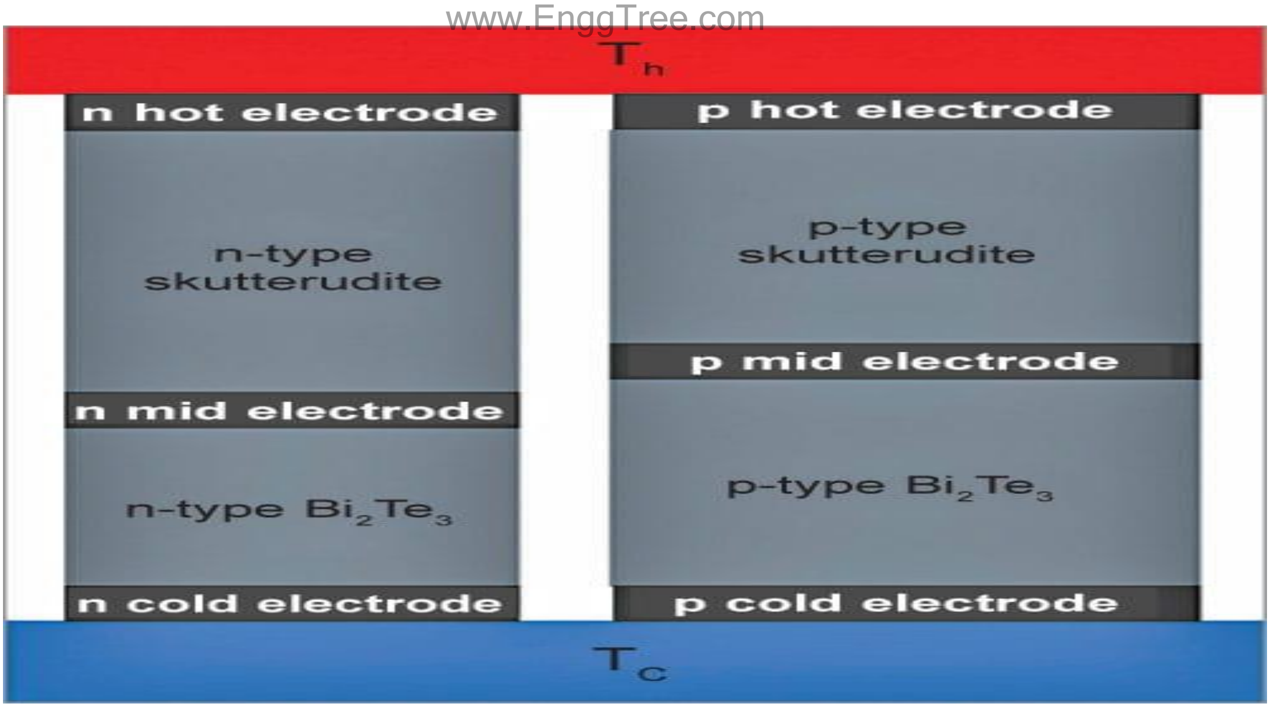


Fig. 12: Arrangement of composite segmented thermoelectric LEG

Another excellent way to reduce heat losses is by using high-temperature transparent aerogels for insulation instead of vacuum system, as shown in Fig. 13.

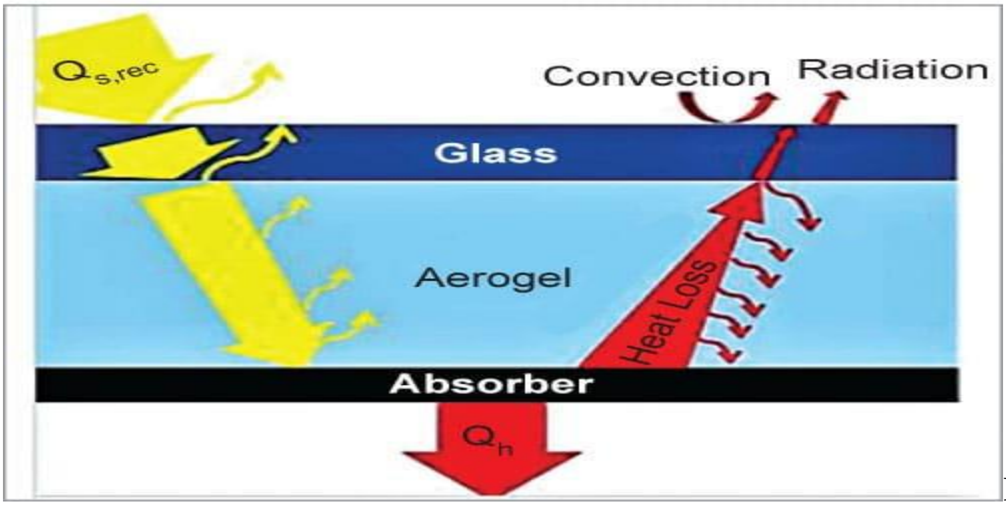


Fig. 13: Transparent aerogel for insulating STEG

Aerogel, being transparent but an excellent insulator, allows sunlight to enter but blocks the heat from escaping from the receiver of the STEG. It offers many advantages like higher efficiency, minimises heat loss, boosts solar thermal conversion, eliminates costly vacuum system and its maintenance cost. Due to efficient thermal transport system provided by aerogels, most of the solar radiation is absorbed by the cermet composite pad attached to the thermoelectric elements.

It is desirable to thermally insulate the TE legs to suppress lateral heat leaks that degrade thermal efficiency. Encapsulation of thermoelectric legs with aerogels prolongs the life of TE devices.

The primary cause of deterioration of most thermoelectric materials is thermal decomposition or sublimation at high operating temperatures. For example, aerogel present near the surface of skutterudite material, such as CoSb3, prevents transport of Sb vapour by establishing a highly localised equilibrium Sb-vapour atmosphere at the surface of skutterudite.

Some solar absorbers are painted with black paint to increase the heat absorption and are fabricated from metal dielectric multilayer cermet composites that are capable of withstanding more than 950°C.

Photovoltaic/thermoelectric Hybrid System

Solar light and its thermal energy can provide sufficient electricity to meet the global energy demand. The range of wavelengths that photovoltaic materials generally use to convert into electricity is between 400nm and 1200nm, the ultra-violet (UV) and visible range. Excess solar radiation is wasted as heat, which decreases the efficiency of PV cells and lowers their life.

TEGs are bidirectional devices that act as heat engines, converting the excess heat into electricity through the thermoelectric effect. Thermoelectric devices utilise the IR region of sunlight to generate electricity and reduce the amount of heat that PV cells dissipate. It is possible to combine PV cells and TEGs to make a hybrid system that can generate more energy. The overall power output of this system would be the sum of the power output from the PV module and the TEG.

The hybrid systems generally follow two configurations—with or without reflective components.

With reflective arrangement the spectral splitting method splits the solar spectrum into two bands. The spectrum below the 800nm cut-off wavelength gets transmitted to the PV module and above 800nm to the TEG. This system has a reflective component called wavelength segregator or prism, where the PV module and the TEG are installed perpendicular to each other. When sunlight passes through the prism, a part of the sunlight is reflected at cut-off wavelength of approximately 800nm and is absorbed by the solar cell. The radiation that is longer than the cut-off wavelength—above 800nm—is reflected to the TEG, as shown in Fig. 14.

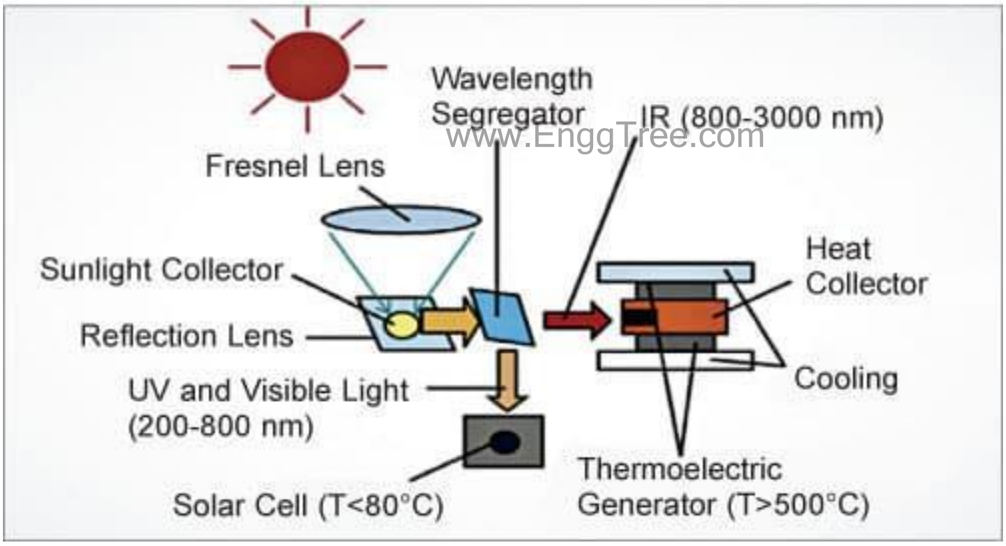


Fig. 14: Arrangement of hybrid pv/teg system using spectral splitting

The PV module and the TEG convert solar energy into electricity independently. A cooling system is installed on the TEG to maintain the temperature difference. A concentrator increases the light intensity and hence PV modules of reduced surface area can be installed, which results in a reduced installation and maintenance cost. The spectrum splitter allows for low operating temperature and hence maximising the conversion efficiency.

Thermoelectric legs have different values of ZT at different temperatures. Hence the TE material selected depends on the operating temperature. Generally, bismuth telluride is used under 500K, lead telluride between 500-900K, and germanium silicon above 900K operating temperatures.

In configurations without reflective component the PV module is placed as upper component and TEG device as lower component, as shown in Fig. 15. When sunlight falls on it, the PV device absorbs the UV and visible light and rest of the solar spectrum passes through the PV module to the underlying TEG. The IR radiation heats up the TEG top side creating a temperature difference with the cold side. The solar module is coated with tedlar PVF film that offers the best protection against UV, thermal, moisture, chemical and mechanical stress. Combination of PV and TE generators can make a very efficient device for solar energy utilisation. A PV/TE hybrid system with high concentration ratio and using multijunction PV and Bi2Te3 thermoelectric legs has conversion efficiency of about 32%. The direct electrical contribution of the TEG to the hybrid system’s efficiency is enhanced by increasing the Sun’s concentration by about 300 times. Even higher efficiency and power values can be achieved by using more advanced PV devices and improved TE materials, with a potential to reach 50% total efficiency.

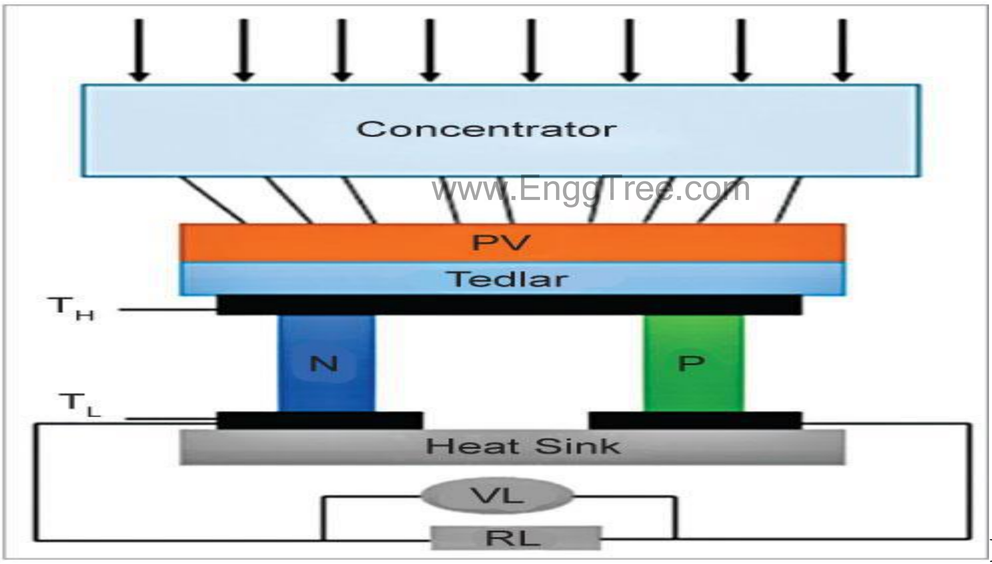


Fig. 15: Hybrid PV/TEG system without reflective component

Hybrid PV and Solar Thermal System

A technique that combines PV and solar thermal systems to efficiently convert solar radiation to electricity for immediate use and store the remaining inexpensive thermal energy (not utilised by PV) to convert to electricity on demand has been developed recently. It is called hybrid electric and thermal solar (HEATS) system. The prototype performs at 26.8% (with a potential to achieve 35.2%) solar to electricity efficiency and 81% dispatchability of electrical energy from thermal energy at an operating temperature of 775K using silicon PV cell (gallium arsenide PV cell can also be used).

HEATS contains a PV module as well as a thermal absorber to utilise the best of both. In this system photons in the PV band are directed to the PV cells whereas these are most efficiently converted into electricity. Low-energy photons (long wavelengths) that cannot be converted by PV cells and high-energy photons (short wavelengths), which would be converted inefficiently, are directed to the thermal absorber instead of being wasted.

This technique improves overall system efficiency and provides additional thermal energy, which can be stored at low cost to be used for electricity generation or for heating on demand. Dispatchability is the ratio of electricity generated from heat engine and total electricity generated by both heat engine and the PV modules. The arrangement of HEATS is shown in Fig. 16.

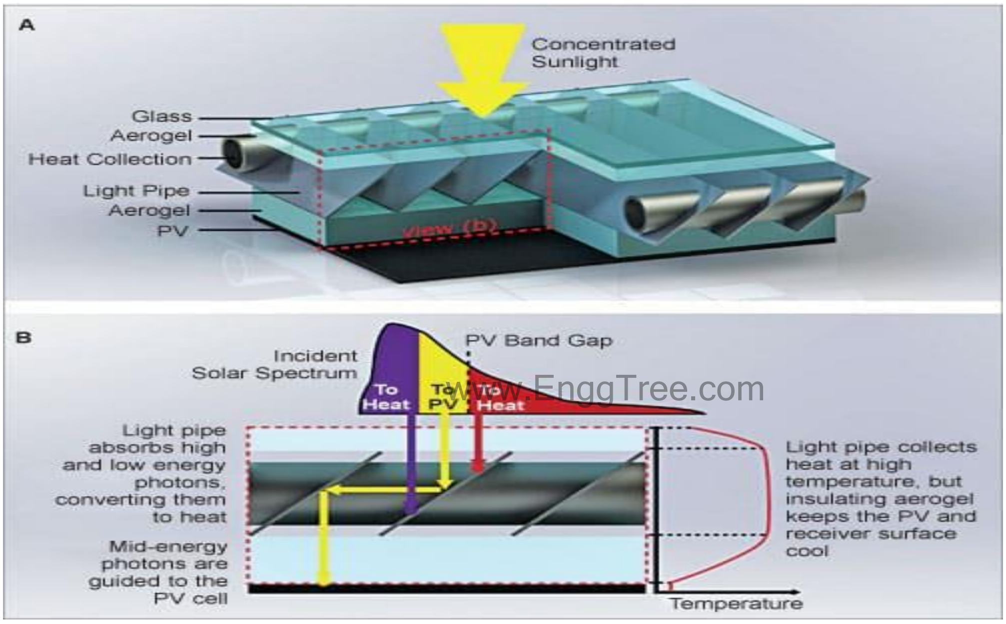


Fig. 16: Hybrid PV and solar thermal system

Fig. 16(A) shows the receiver concept with a cutaway section to show its internal structure. The HEATS receiver is used in conjunction with a solar concentrator, like a parabolic trough or a linear Fresnel reflector, to increase the intensity of solar radiation. The stacked structure consists of a glass protective cover, a thermally insulating transparent aerogel layer, the spectrally selective light pipe (SSLP), followed by another insulating transparent aerogel layer, and finally the PV module.

The SSLP structure consists of a series of parallel fins attached to the heat collection pipes carrying a heat transfer fluid like Therminol VP-1, which collects the thermal energy absorbed by the SSLP. The SSLP structure is formed from parallel fins made of a thermally conductive copper sheet substrate coated with a spectrally selective material in multilayers.

The SSLP absorbs high and low energy photons as thermal energy, while directing the mid energy photons to the PV module down below as shown in Fig. 16(B). Transparnt aerogel on either side allows the light to pass through but does not allow the heat to escape as it is an excellent insulator.

The aerogel layers serve to thermally insulate the SSLP from the PV module to keep the latter cool. It ensures that the SSLP can be operated at a high temperature without heat loss while the PV module and the glass cover remain at a safe low operating temperature. The transparent silica aerogels used have high solar transmittance of about 96% and low thermal conductivity of about 0.055W/m/K. As aerogels are not very strong, it is ensured that no load is transferred to it.

The advantages of hybrid PV-thermal system are mainly: (a) both solar thermal and PV cells can be housed in the same module and operated simultaneously, (b) the solar energy that would have been lost otherwise, if single PV module was used, can be recuperated usefully, and (c) the amount of energy that is generated per unit area by this tandem system is more and the payback period is less due to more energy extraction.

Thermopile

A thermopile is a device that converts heat into electricity by using the thermoelectric effect.

It consists of several thermocouples, which are pairs of wires made of different metals that generate a voltage when exposed to a temperature difference. Thermocouples are connected in series or sometimes in parallel to form a thermopile, which produces a higher voltage output than a single thermocouple. Thermopiles are used for various applications, such as measuring temperature, generating power, and detecting infrared radiation. A thermopile works on the principle of the thermoelectric effect, which is the direct conversion of temperature differences to electric voltage and vice versa. This effect was discovered by Thomas Seebeck in 1826, who observed that a circuit made of two different metals produced a voltage when one junction was heated and the other was cooled.

A thermopile is essentially a series of thermocouples, each of which consists of two wires of different metals with large thermoelectric power and opposite polarities.

Thermoelectric power is a measure of how much voltage a material generates per unit temperature difference. The wires are joined at two junctions, one hot and one cold. The hot junctions are placed in a region with higher temperatures, while the cold junctions are placed in a region with lower temperatures. The temperature difference between the hot and cold junctions causes an electric current to flow through the circuit, generating a voltage output.

The voltage output of a thermopile is proportional to the temperature difference across the device and the number of thermocouple pairs.

The proportionality constant is called the Seebeck coefficient, which is expressed in volts per kelvin (V/K) or millivolts per kelvin (mV/K). The Seebeck coefficient depends on the type and combination of metals used in the thermocouples.

The diagram below shows a simple thermopile with two sets of thermocouple pairs connected in series.

The two top thermocouple junctions are at temperature T1, while the two bottom thermocouple junctions are at temperature T2. The output voltage from the thermopile, ΔV, is directly proportional to the temperature difference, ΔT or T1 – T2, across the thermal resistance layer and the number of thermocouple pairs. The thermal resistance layer is a material that reduces the heat transfer between the hot and cold regions.

Diagram of a differential temperature thermopile

T1

```
|\
| \
|  \
|   \
|    \
|     \  ΔV
|      \
|       \
|        \
|         \
|          \
|           \
|            \
|             \
|              \
|               \
-------------------
   Thermal
  Resistance
   Layer
-------------------
|               /
|              /
|             /
|            /
|           /
|          /
|         /
|        /
|       /
|      /  ΔV
|     /
|    /
|   /
|  /
| /
|/
T2
```

Thermopiles can also be constructed with more than two sets of thermocouple pairs to increase the voltage output.

Thermopiles can be connected in parallel as well, but this configuration is less common because it increases the current output rather than the voltage output.

Thermopiles do not respond to absolute temperature, but only to temperature differences or gradients.

Therefore, they can be used to measure heat flux, which is the rate of heat transfer per unit area. Heat flux can be calculated by dividing the voltage output by the thermal resistance and the area of the device.
Thermopiles use infrared radiation as a means of heat transfer and are also used for non-contact temperature measurement.

Infrared radiation is electromagnetic radiation with wavelengths between 700 nm and 1 mm, which corresponds to temperatures between 300 K and 5000 K. Infrared radiation is emitted by any object with a nonzero temperature and can be detected by a thermopile sensor.

Types of Thermopile Sensors
A thermopile sensor is a device that uses one or more thermopiles to measure temperature or infrared radiation from an object or a source.

Thermopile sensors are based on non-contact measurement principles and have various advantages over contact-based sensors, such as higher accuracy, faster response time, wider range, and lower maintenance.

- There are different types of thermopile sensors, depending on the number, configuration, and material of the thermocouples, as well as the design of the infrared absorber and the filter. Some of the common types of thermopile sensors are: **Single-element thermopile sensor**: This type of sensor has only one thermopile with a single hot junction and a single cold junction. The hot junction is attached to a thin infrared absorber, usually a micro-machined membrane on a silicon chip. The cold junction is connected to a heat sink or a reference temperature. The sensor measures the temperature difference between the hot and cold junctions, which is proportional to the infrared radiation absorbed by the membrane. This type of sensor is suitable for measuring low to medium infrared radiation levels and has a fast response time.
- **Multi-element thermopile sensor**: This type of sensor has multiple thermopiles arranged in parallel or in series. Each thermopile has its own hot and cold junctions, which are connected to a common infrared absorber and a common heat sink. The sensor measures the sum of the voltage outputs from each thermopile, which is proportional to the total infrared radiation absorbed by the membrane. This type of sensor is suitable for measuring high infrared radiation levels and has a high sensitivity.
- **Array thermopile sensor**: This type of sensor has an array of thermopiles arranged in rows and columns on a substrate. Each thermopile has its own hot

and cold junctions, which are connected to individual infrared absorbers and heat sinks. The sensor measures the voltage output from each thermopile separately, which is proportional to the local infrared radiation absorbed by each absorber. This type of sensor can create a two-dimensional image of the infrared radiation distribution and can detect the position, shape, and movement of an object.

- **Pyroelectric thermopile sensor**: This type of sensor combines a pyroelectric material with a thermopile. A pyroelectric material is a material that generates an electric charge when heated or cooled. The pyroelectric material is attached to the hot junctions of the thermopiles, while the cold junctions are connected to a heat sink. The sensor measures the voltage output from the thermopiles plus the charge output from the pyroelectric material, which is proportional to the rate of change of infrared radiation absorbed by the material. This type of sensor can detect rapid changes in infrared radiation and can measure both static and dynamic temperatures.

Applications of Thermopile Sensors

Thermopile sensors have various applications in different fields, such as:

- **Medical devices**: Thermopile sensors are widely used in medical devices that measure body temperature, such as ear thermometers, forehead thermometers, tympanic thermometers, and thermal imaging cameras. Thermopile sensors can provide accurate and non-invasive temperature measurements without contact with the skin or mucous membranes.
- **Industrial processes**: Thermopile sensors are used in industrial processes that involve high temperatures, such as metal processing, glass manufacturing, plastic molding, welding, soldering, and laser cutting. Thermopile sensors can provide fast and reliable temperature measurements without contact with hot objects or surfaces.

- **Environmental monitoring**: Thermopile sensors are used in environmental monitoring devices that measure ambient temperature, humidity, air quality, soil moisture, fire detection, and solar radiation. Thermopile sensors can provide accurate and stable temperature measurements without interference from other factors.
- **Consumer electronics**: Thermopile sensors are used in consumer electronics devices that require temperature sensing or infrared detection, such as smartphones, tablets, laptops, cameras, remote controls, smart watches, gaming consoles, and virtual reality headsets. Thermopile sensors can provide low-cost and low-power solutions for various functions, such as face recognition, gesture control, proximity sensing, biometric authentication, and thermal imaging.

UNIT III WIRELESS HEALTH SYSTEMS 9

Need for wireless monitoring, Definition of Body area network, BAN and Healthcare, Technical Challenges- System security and reliability, BAN Architecture – Introduction, Wireless communication Techniques.

3.1 Need for wireless monitoring

Wireless monitoring through wearable devices could be useful for hospitalized patients, particularly those who are unstable or at higher risk for serious complications such as critically ill patients. This review aims at summarizing current evidence regarding the use of wireless monitoring in the ICU setting.

Wireless sensor network (WSN) technologies have the potential to change our lifestyle with different applications in fields such as healthcare, entertainment, travel, retail, industry, dependent care and emergency management, in addition to many other areas. The combination of wireless sensors and sensor networks with computing and artificial intelligence research have built a cross-disciplinary concept of ambient intelligence in order to overcome the challenges we face in everyday life.

3.2 Definition of Body area network

Body Area Network (BAN) technology uses small, low power wireless devices that can be carried or embedded inside or on the body. Applications include but are not limited to:

- Health and wellness monitoring
- Sports training (e.g., to measure performance)
- Personalized medicine (e.g., heart monitors)
- Personal safety (e.g., fall detection)

A number of wireless BAN communication technologies have been implemented based on the existing radio technologies. However, if BAN technology is to achieve its full potential, it needs a more specific and dedicated technology, which is optimized for BAN. For example, solutions for monitoring people during exercise one or two hours a day, or a few days a week, may not be suitable for 24/7 monitoring as a part of the Internet of Things (IoT) concept.

3.3 BAN and Healthcare

Body Area Network (BAN) is a technology that allows communication between ultra-small and ultra low-power intelligent sensors/devices that are located on the body surface or implanted inside the body. In addition, the wearable/implantable nodes can communicate to a controller device that is located in the vicinity of the body. These radio-enabled sensors can be used to continuously gather a variety of important health and/or physiological data. Radio-enabled implantable medical devices offer a revolutionary set of applications among which we can point to smart pills for precision drug delivery, intelligent endoscope capsules, glucose monitors and eye pressure sensing systems. Similarly, wearable sensors allow for various medical/physiological monitoring (e.g. electrocardiogram, temperature, respiration, heart rate, and blood pressure), disability assistance, human performance management, etc.

Wearable devices that work outside the confines of the hospital without expert medical assistance must fulfill a number of characteristics:

- Usability: The device has to be worn on a continuous basis and must therefore be small and lightweight. The challenge is to compress the device size down.
- Power consumption: The device should have low power consumption, reducing the need for frequent re-charging and disruptions in monitoring.
- Design: The device must be elegant without the need to attach long wires and electrodes from the device to the patient and from the device to the mobile gateway that transmits data (to the remote medical care unit).
- Cost: If a patient is required to purchase the unit, it should cost sub US$200 to be affordable or for the hospital to give it away free as part of medical care.

Devices that fulfill these conditions can expect to become popular. Manufacturers will find that users are able to easily integrate such devices into their daily lives for maximum benefit.

The typical set of parameters that the device must monitor include heart activity, fetal heart rate, skin resistance, skin temperature, refractive index of blood etc. Based on what the device is required to measure and monitor, its components would include:

- Bio sensors: Application specific bio sensors that emit signals indicating measured parameters
- Analog-to-digital converters: Application specific analog front end to digitize the sensor signals. The device may also be equipped with signal conditioning circuitry.

- General purpose micro controller: To process signals for the device to function. Signals could indicate battery levels, failure, etc. or signals received from accelerometer, displays and switches, memory and connectivity solutions.
- Wireless interface: In most instances, the device will connect to a mobile gateway over a Body Area Network (BAN) or the newer Bluetooth LE (low energy) suitable for continuous transfer of medical data.
- Memory: In modern wearable devices, the data is sent in real-time to a mobile gateway (smart phone or a tablet) and then to the patient's remote health care provider. These devices can also store data in off line mode, synchronizing the data when the device goes online.
- Power management: The device design must ensure that energy consumption is minimized for longer uninterrupted device deployment and stand by time.

3.4 Technical Challenges

Effectiveness of the WBAN is important from both patients and healthcare perspective. As the time passes, challenges to the emerging technologies increases along with the advancements. There is variety of challenges faced by WBAN as explain below. These challenges are classified in six major classes such as energy, mobility, security and communications (i.e., networking, QoS and cooperation).

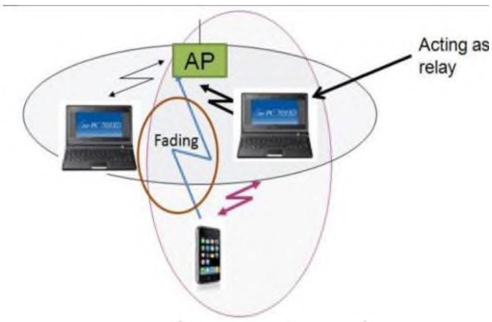
A. **Energy Requirements**: Since, most of the devices in WBAN are using the wireless medium, therefore they are portable. Such devices are small in size and carry power source too. Hence, the power is always limited. Wireless natures made them roam free, meaning the devices are free to move. The power to the device of the network is provided with the help of batteries. Things are not simplified by allowing the power from battery but is encompasses some more challenges of power management of the battery supplies especially in case of implants. Since the sensors that are implanted in the body are so small that the battery cannot sustain more than a month. Removing the implants and re-installation require even more management of the complications generated. Different parameters that alter the power consumption include communication bandwidth and processing power. There is need to have better scheduling algorithm along with better power management schemes.

B. **WBAN Security**: In any network, communication data is of worth importance. In case of WBAN, it becomes more critical as it has been connected to the Physical system. These communication channels are very much visible to the attacker and if not securely implemented it could any of the attack including eavesdropping on traffic between the nodes, message injection, message replay, spoofing and off course compromise the integrity of physical devices. Upon successful attack, such actions not only invade privacy but may lead to catastrophic situation.

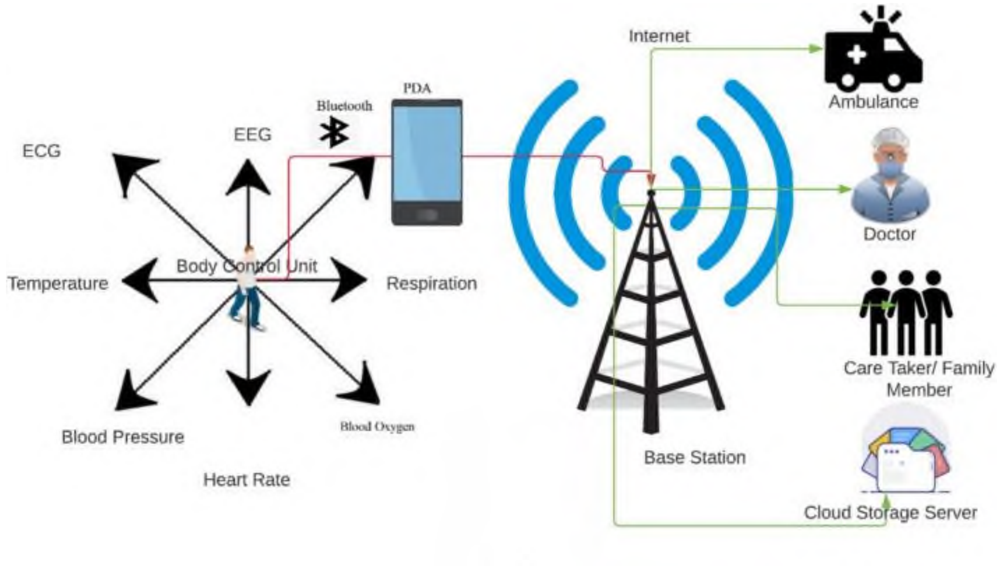
C. **Mobility Support:** WBAN provides two major advantages, i.e., portable monitoring and location independence. Regardless of the application, these are the key factors due to which WBAN is potential candidate in many venues. But these two advantages put some special limitations i.e., mobility. Mobility can pose serious problem in some application like E-Health care even posture do effect the communication. The mobility is defined between the user and the WBAN as a seamless link. One of the major issues is to reach to sink, which may be single or multi hop. Message is flooded to all nodes to reach sink node and the path with minimum delay is selected. Reliable multipath routing is another solution proposed. A path list is maintained depending upon different factors of the routing and the link is established accordingly.

D. **Quality of Service:** Quality of Service (QoS) is the requirements fulfilled by system as requested by the users. For more life critical system, timeliness may be the parameter for the quality. System, that cannot fulfill the said requirement, falls short of providing the QoS. Same is true for other factors like bandwidth, latency, jitter, robustness, trustworthiness, adaptability. Similarly, seamless roaming and end to end wireless connection between the body nodes and the sink nodes is another QoS factor.

E. **Cooperation between Nodes:** When the intermediate nodes help source destination pair in communication, the cooperation occurs. The intermediate nodes may refer as helper or relay as shown in Fig. Cooperation offers a good solution for many of the limitations in WBAN such as distance, mobility, coverage and channel impairments.



3.5 System security and reliability



Sensor nodes/actuators represent essentially the wireless sensor network, and the sensor node senses acoustic factors including temperature, pressure, sound, pulse rate, ECG, blood pressure, and heart rate of the human body. In healthcare, this form of sensor network is known as a wireless body area network (WBAN)

Wireless body area networks consist of sensors, biological parameters, body control unit, personal device assistant, transmission factor, and user access. Figure shows that the wireless body area network along with the sensor senses the biological factors continuously in order to obtain the human health information from the body control unit. The electrocardiogram (ECG) sensor records the patient's electric impulse as it passes through the heart muscle. This assists in monitoring the patient's heartbeat, which is used to track various movements such as resting and moving. The temperature of the human body's ears, skin, and forehead are detected by the body temperature sensor.

The pressure of blood as it travels through the arteries is measured by blood pressure and the pulse wave is measured by the heart rate sensor as it pumps blood through the patient's body. The saturation level of oxygen in the blood is measured with a pulse oximeter. The airflow sensor can be positioned near the human body's nasal to assess the body's respiration. The collected information will be transferred and stored in the personal device assistants (PDA) and later transmitted to the base station. From the base station, the data will be transferred to the respective user applications such as cloud databases, ambulances, family members, and doctors via the Internet.

A cloud database's purpose is to store the patient's data on a server so that the doctor can access it and then send the patient's information to the user via the internet. Star topology is used in the body area network. The body control unit acts as a central node and then each sensor will sense and communicate to the center node. The center node interfaces the human body by using Bluetooth or ZigBee or Personal Device Assistants (PDA), and then the patient's information can be accessed by the doctors using the Internet.

Security Issues in WBAN

The purpose of network security is to protect data from threats during data transmission. There are two forms of attacks in network security: active and passive attacks, both of which contribute to the detection of malicious data. An active attack is primarily focused on data and has a significant impact on the system's operation. A passive attack damages or modifies data but does not degrade information resources. The security flaws are applied at various levels. Each layer of the TCP/IP layered architecture generates attacks. IP attacks are introduced in the second layer (logic link control), resulting in address spoofing for incorrect communication. Internet Control Message Protocol (ICMP) attacks is generated in the media access control layer, which results in sniffing and man-in-the-middle attacks. In the third network layer, routing attacks such as blackhole and eavesdropping attacks are created. TCP attacks are originated in the transport layer, resulting in high synchronization flooding in data communication. Application layer attacks are generated in the OSI model's application layer, resulting in authentication issues such as accessing the user's username and password

A denial of service (DoS) attack will restrict data from authorized users and prevent them from accessing their resources. Because of the week password, distributed denial of service (DDoS) attacks is generated. The main difference between a DOS and a DDOS attack is that a DOS attack targets a single host at a time, but a DDoS attack targets numerous hosts simultaneously. These types of attacks will degrade network performance.

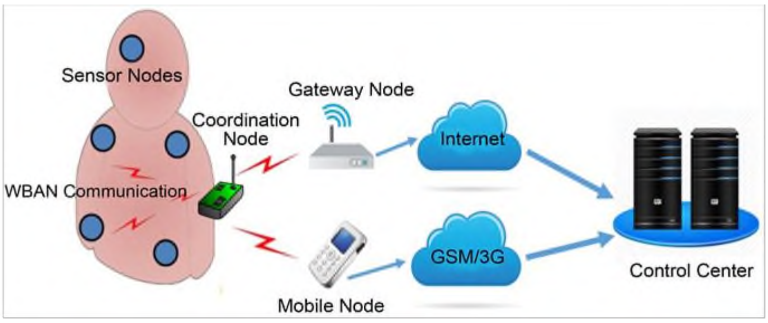
The term "reliability" refers to the fact that health-care practitioners receive monitoring data in a timely and accurate manner. WBAN sensors must be capable of viewing and detecting essential active signs of human health; therefore, reliability is critical. WBAN sensors must be capable of viewing and detecting essential active signs of human health; therefore, reliability is critical

3.6 BAN Architecture

WBAN is designed with special purpose sensor which can autonomously connect with various sensors and appliances, located inside and outside of a human body.

Below Figure demonstrates a simple WBAN architecture where the architecture is divided into several sections. Here we have classified the network architecture into four sections. The first section is the WBAN part which consists of several numbers of sensor nodes. These nodes are cheap and low-power nodes with inertial and physiological sensors, strategically placed on the human body. All the sensors can be used for continuous monitoring of movement, vital parameters like heart rate, ECG, Blood pressure etc. and the surrounding environment. There are vast monitoring systems are being used already based on wired connections. Any wired connection in a monitoring system can be problematic and awkward worn by a person and could restrict his mobility. So, WBAN can be a very effective solution in this area especially in a healthcare system where a patient needs to be monitored continuously and requires mobility.

The next section is the coordination node where the entire sensor nodes will directly connected with a coordination node known as Central Control Unit (CCU). CCU takes the responsibility to collect information from the sensor nodes and to deliver to the next section. For monitoring human body activities



there is no such wireless technology is fixed for targeting WBAN. Most popular wireless technologies used for medical monitoring system are WLAN, WiFi, GSM, 3G, 4G,WPAN (Bluetooth, ZigBee) etc. . Except Cellular network standard all of these technologies are commonly available for short distance communication. WMTS (Wireless

Medical Telemetry Service) and Ultra-Wide Band are another technology that could be used for body monitoring system as they operate in low transmission power.

The third section is the WBAN communication which will act as a gateway to transfer the information to the destination. A mobile node can be a gateway to a remote station to send Mobile Message to a cellular network using GSM/3G/4G. A router or a PC can be a remote node to communicate via email or other service using Ethernet which is shown in Figure.

The last section will be a control center consists of end node devices such as Mobile phone for message, PC for monitoring and email and server for storing the information in the database.

WBAN Requirements and Workflow

Before you begin to format your paper, first write and save the content as a separate text file. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads—the template will do that for you.

Requirements for Wireless Medical Sensors in WBAN

Wireless medical sensors should satisfy the following main requirements such as

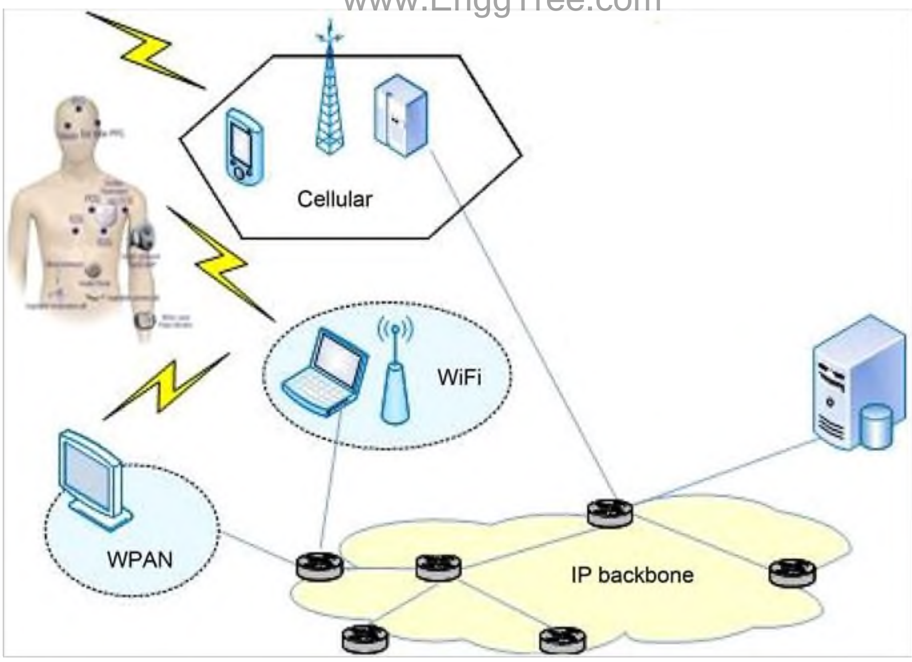


Figure . A Typical WBAN communication.

wearability, reliability, security, and interoperability :

Wearibility: To achieve non-invasive and unobtrusive continuous monitoring Wearibility is a very important issue. These sensors must be lightweight and small. Size and weight of sensors are mainly determined by the size and weight of batteries . But, a battery's capacity is directly proportional to its size.

Reliability: Reliable communication in WBANs is of paramount importance for any WBAN application. So the designer should target a reliable communication technique which will ensure uninterrupted communication and optimal throughput. A careful trade-off between communication and computation is very crucial for a reliable system design.

Security: Another important issue is the security of the network. All the wireless medical sensors must meet the requirements of privacy and should ensure data integrity and authentication.

Interoperability: Wireless medical sensors should allow users to easily build a robust WBAN. Standards governing that interaction of wireless medical sensors will help vendor competition and eventually lead to more accessible systems .

Monitoring Sensors

Wireless body area network is a system which can continuously monitor a person's activities. Based on the operating environments the monitoring sensors can be classified into two types.

v Wearable sensor devices worked on the human body surface.

v Implantable devices operated inside human body

Wearable sensor devices allow the individual to follow closely the changes in her or his functions and in the surrounding environment and provide feedback for maintaining optimal and instant status. For example ECG, EEG, Blood pressure sensor can be used to monitor a critical patient, GPS sensor can be used to locate an area and different types of sensor that can be used to measure the distance, temperature, movement etc.

To measure heath parameters, implantable sensors are planted in close contact with the skin, and sometimes even inside the human body. Implantable biosensors are an important class of biosensors based on their ability to continuously measure metabolite levels, without the need for person interference and regardless of the person's physiological state (sleep, rest, etc.) . the implantable biosensors have great impact to diabetes and trauma care patients, as well as soldiers in action (military). Figure focuses on the sensor nodes with wireless capabilities.

Traffic Types

In a WBAN traffic can be divided into three categories such as:

v Normal traffic

v Emergency traffic

v On-demand traffic

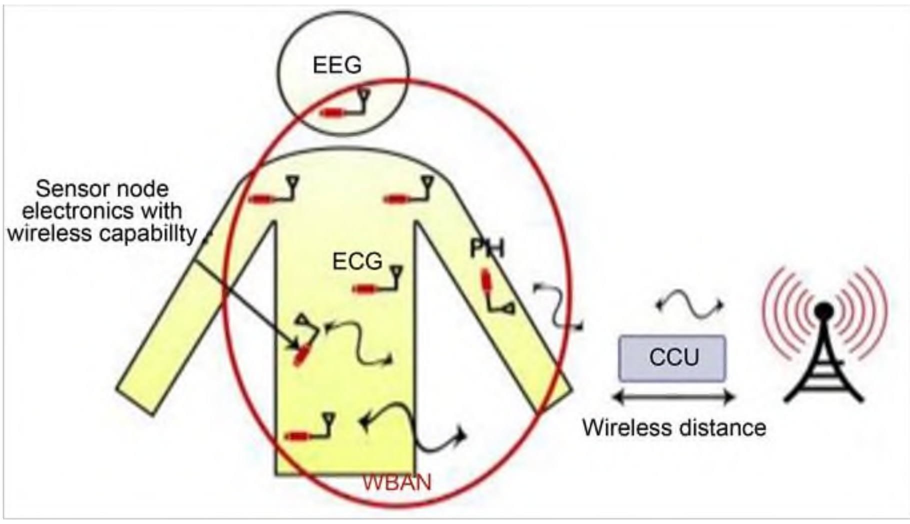


Figure . Sensor nodes in WBAN.

Normal traffic is the data traffic which is used to monitor the normal condition of a person without any criticality and on demand events. Emergency traffic is initiated by nodes when they exceed a predefined threshold or in any emergency situation. Such type of traffic is totally unpredictable.

On-demand traffic is initiated by the authorized personnel like doctor or consultant to acquire certain information for diagnostic purpose .

Work Flow

Figure shows the work flow chart of WBAN. In the flowchart workflow is divided into two sections. First section is the WBAN where all the sensors devices will collect data and process them to the control center. While processing if any error occurs then it will read data again from the sensor and will forward for processing.

The control center will send the data to the desired location. If any problem occurs then it will generate an error where resend option should be needed again.

WBAN Standards and Technologies

As WBAN is a short range wireless networks so different types of wireless short range technologies can be involved in different stages. In this segment we will describe most common technologies such as Bluetooth, ZigBee, WiFi, IEEE 802.15.6 etc. that can be used to deploy WBAN.

Bluetooth

Bluetooth is an IEEE 802.15.1 standard commonly known as WPAN (Wireless Personal Area Network). Bluetooth technology was designed as a short range wireless communication standard, anticipated to form a network with security and low power consumption. A typical Bluetooth network forms a Piconet where a Bluetooth device works as a master and another seven Bluetooth devices

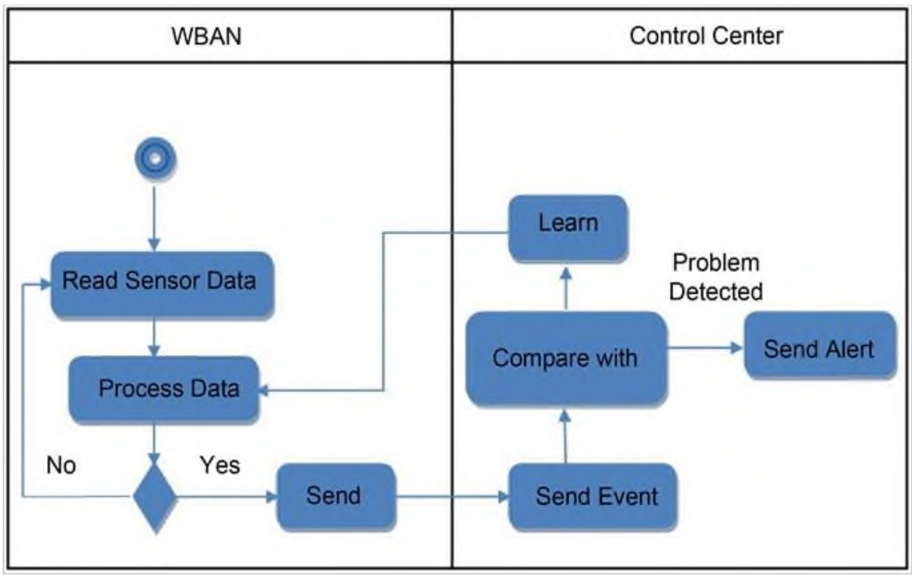


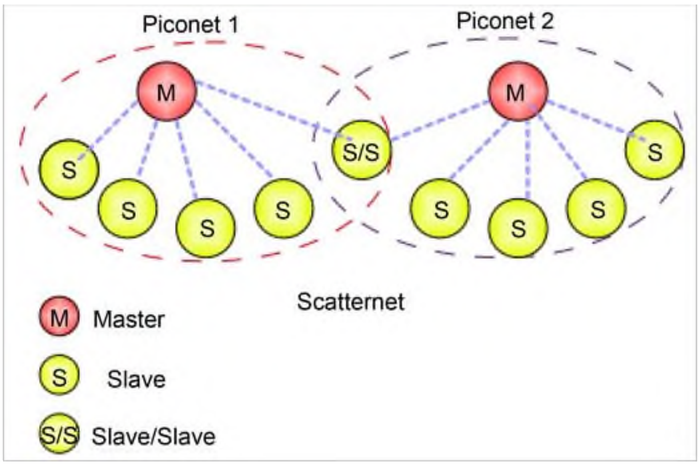
Figure Working flowchart of WBAN.

work as slaves which gives each device to communicate with each other simultaneously. Another type of Bluetooth network can be formed with more than one Piconet known as Scatternet. In Scatternet a node of a Piconet (can be a master or a slave) joins as a slave in another Piconet. Figure shows how a Piconet and Scatternet are formed using Bluetooth nodes. Though, the basic Bluetooth protocol does not support relaying but it is possible to join together numerous Piconet into a large Scatternet, and to expand the physical size of the network beyond Bluetooth's limited range using this method.

Bluetooth devices operate in the 2.4 GHz ISM band (Industrial, Scientific and Medical band), utilizing frequency hopping among 79 1 MHz channels at a nominal rate of 1600 hops/sec to avoid interference. It is classified with three classes of devices with coverage ranging from 1 to 100 m and different transmission powers ranging from 1 mW to 100 mW with 3 Mbps data rate. A very key feature of Bluetooth is that all the Bluetooth devices can communication with each other in NLOS condition. Bluetooth is suitable for short distance data transmission applications such as between servers of WBANs or between a WBAN and a personal computer.

ZigBee

ZigBee is an IEEE 802.15.4 standardized solutions for wireless telecommunications designed for sensors and controls, and suitable for use in harsh or isolated conditions. One of the biggest advantages of ZigBee network is its low power consumption. Figure shows a typical ZigBee network topology which consist of three kinds of devices or nodes such as coordinator, router and end device. One coordinator exists in every ZigBee network. It starts the network and handles management functions as well as data routing functions. End devices are devices that are battery-powered due to their low-power consumption. They are in standby mode most of the time and become active to collect and transmit data.



Bluetooth network.

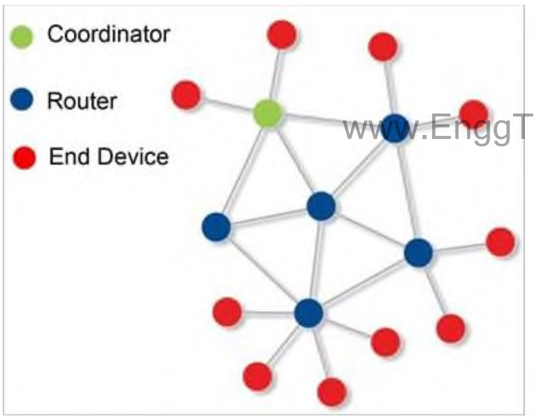


Figure ZigBee network.

Devices such as sensors are configured as end devices. They are connected to the network through the routers. Routers help to carry data across multi-hop ZigBee networks. In some cases ZigBee network topology are formed without routers when the network is point to point and point to multipoint.

ZigBee is aimed at RF applications that require low data rate, long battery lifespan and secure networking. Through the standby mode, ZigBee enabled devices can be operational for several years. ZigBee-based wireless devices operate in three different frequency bands such as 868 MHz, 915 MHz, and 2.4 GHz. Therefore, one substantial drawback of using ZigBee network for WBAN applications is due to interference with wireless local area network (WLAN) transmission, especially at 2.4 GHz. As ZigBee devices operate at low data rate so it can be unsuitable for large-scale and real time WBAN applications. But, it can be very much suitable for personal use like assisted living, health monitoring, sports, environment etc. within a modest range between 50 - 70 meters

WiFi

WiFi is an IEEE 802.11 standard for wireless local area network (WLAN). Generally WiFi technology comes with four standards (802.11 a/b/g/n) that runs in ISM band 2.4 and 5 GHz with a modest coverage of 100 meter. Wi-Fi permits users to transfer data at broadband speed when connected to an access point (AP) or in ad hoc mode. Fig shows a WiFi network where WiFi sensor nodes and users can transfer data using internet by standard WiFi router. In some modified version, WiFi devices can be used in data acquisition applications that allow a direct communications between the sensors and the smart phones/ PC even without an intermediate router.

WiFi is preferably suitable for large amount of data transfers with high-speed wireless connectivity that allows videoconferencing, voice calls and video streaming. An important advantage is that all smart phones, tablets and laptops have Wi-Fi integrated; however the main disadvantage of this technology is high energy consumption.

IEEE 802.15.6 WBAN

IEEE 802.15.6 is the latest addition in WPAN which is known as WBAN standard that provides various medical and non medical applications and supports communications inside and around the human body. This standard supports communication inside and outside of human body which can be used for different medical and non medical applications such as e-Healthcare monitoring, sports, environment etc.

IEEE 802.15.6 standard is classified by three physical layer standards. Each standard uses different frequency bands for data transmission with data rate 10 Mbps maximum. First one is Narrowband (NB) which operates within the range of 400, 800, 900 MHz and 2.3, 2.4 GHz bands. The Human Body Communication (HBC) is another standard which operates at range of 50 MHz. The Ultra Wideband (UWB) technology operates between 3.1 GHz to 10.6 GHz which supports high bandwidth in short range communication.

3.7 Introduction Wireless communication Techniques

In today's world, wireless communication has a major application in sharing of information anywhere and at anytime. We can use wireless networks in the form of WLAN or Wi-Fi in various fields such as education, healthcare, and industrial sector. As the technology is growing, the demands of users as well as the demand of ubiquitous networking is increasing. WBAN(Wireless Body Area Network) allows the user to move another without having the restriction of a cable for sharing information.

The communication in body sensor networks is of 2 types:

1. In-body communication
2. On-body communication

In-body communication is the communication between sensor nodes that are implanted inside human body. The MICS (Medical Implant Communication System) communication can be used only for in-body communication. On-body communication occurs between wearable devices which consist of sensor nodes. The ISM (Industrial Scientific and Medical) band and UWB (Ultra-wideband) communication can be used only for on-body communication.

A body area network (BAN), also referred to as a wireless body area network (WBAN) or a body sensor network (BSN) or a medical body area network (MBAN), is a wireless network of wearable computing devices. BAN devices may be embedded inside the body, implants, may be surface-mounted on the body in a fixed position Wearable technology or may be accompanied devices which humans can carry in different positions, in clothes pockets, by hand or in various bags. A WBAN system can use WPAN wireless technologies as gateways to reach longer ranges. Through gateway devices, it is possible to connect the wearable devices on the human body to the internet. This way, medical professionals can access patient data online using the internet independent of the patient location. In modern technology wireless communication provides a lot of possibilities to be able to share its information to each other at anytime and anywhere. Intelligent mobile communication network and WLAN, Wi-Fi are applied to various sectors such as education; health care service and industry in order to provide people a convenient way to communicate with each other. As the demand of ubiquitous network is increased, the devices for home, office and other information devices that can communicate wireless in short range have been getting more attention. The standard and technique development of ubiquitous network has rapidly put itself into the world market.

Wireless Body Area Network (WBAN) is becoming a special application of such technique. WBAN differs with other wireless sensor networks (WSN) with some significant points. First difference between a WBAN and WSN is mobility. In WBAN user can move with sensor nodes with same mobility pattern whereas WSN is generally used to be stationary. Energy consumption is much less in WBAN than other WSNs arrangement. In addition, WBAN sensor devices are found cheaper than WSNs. For reliability, node complexity and density, WBAN nodes are however traditional. WSNs do not tackle specific requirements associated with the interaction between the network and the human body . The WBAN performs like Virtual Doctor Server, by keeping the different responsibilities like- maintain the history of the patient, giving advices to the patient in general/emergency (first aid help from second person) case etc. To understand the communication approach of this emerging WBAN technology, we first need to know the conceptual structure of WBAN so that, one can easily know the flow of communication within the system and to the outside world, this has been achieved by the demonstration of a simple WBAN communication architecture. Where this architecture is mainly comprised with three different layers namely: Tier 1, Tier 2 and Tier3 and these are further described better in the given figure

UNIT IV SMART TEXTILE 9

Introduction to smart textile- Passive smart textile, active smart textile. Fabrication Techniques-Conductive Fibres, Treated Conductive Fibres, Conductive Fabrics, Conductive Inks.Case study-smart fabric for monitoring biological parameters - ECG, respiration.

4.1 Introduction to smart textile

The term "Smart Textiles" refers to a broad field of studies and products which extends there functionality and there use. Smart Textiles are defined as textile products such as fibers, filaments, and yarn which are woven, knitted or non-woven which can interact with the environment or wearer. The combination of textile with electronics which is all known as e-textiles can be applicable to the development of smart material.

"Smart textiles are the fabrics that have been developed with new technologies that provide added value to the wearer"

Smart textile is the material which can react to the environment. These are the fabrics which can enable digital components and electronics in itself. Pailes-Friedman of the Pratt Institute states that "what makes smart fabrics revolutionary is that have the ability to do many things that traditional fabrics cannot, including communicate, transform, conduct energy and even grow". The smart textile can sense and react to environmental conditions or stimuli from mechanical, thermal, chemical, electrical, magnetic or other sources. Smart textiles must contain three components i.e. sensors, actuators and control units. Smart textile presents a challenge in several fields such as the medical, sports, military and aerospace.

Types of smart textiles

Smart textiles can be divided into four types based on their functions.

1. Passive smart materials: These are the material which only senses the environmental conditions or stimuli.

These are just sensors such as changing colour, shape, thermal and electrical resistivity.

g. a shirt with in-built thermistors to log body temperature over time.

2. Active smart material: These are the material which can both sense and respond to the external conditions or stimuli.

If actuators are integrated into the passive smart textile, it becomes an active smart textile as it may respond to a particular stimulus.

g. the shirt senses the surrounding temperature. It reacts in the form of rolling up of sleeves when the temperature gets high.

3. Very smart materials: These are materials are able to execute triple functions; first there are sensors which can receive signals, secondly, they are able to give reaction based on the received

singles; thirdly they can adapt and changes the shape, size, colour or act according to the given function.

4. Materials with the even higher level of intelligence develop artificial intelligence to the computers.

These kinds of materials are not fully achieved in the current investigation of human beings.

This may be achieved with research and development in the field of textile and electronics. By using the smart fabrics or smart materials with advancement in computer interface this can be possible.

Materials used

The materials which are used to manufacture products of wearable smart textile can interact, communicate and sense.

* Metal fibers
* Conductive Inks
* Chromic materials
* Coating with nanoparticles
* Organic semiconductors
* Shape memory materials
* Optical fibers
* Quantum tunneling composites
* Inherently conductive polymers

Conductive threads are mainly used in technical areas like garments, military apparels, medical application and electronic manufacturing. These conductive yarns and fibers are made by mixing pure metallic or natural fibers with conductive materials. Stainless steel filament, metallic silk, organza, special carbon fibers etc are used for manufacturing of fabric sensors. Materials like metallic, conductive polymers, optical fibers supply electrical conductivity, sensing capabilities and data transmission. These materials are resilient, light in weight, flexible, inexpensive and easy to process.

Applications

1. Thermotron

Thermotron of UNITIKA is a particular fabric which is able to absorb sunlight and convert the light energy into thermal energy. It stores heat without wasting it. Inside the thermotron, there are microparticles of zirconium carbide which allow the fabric to absorb and filter sunlight. The inner layer of the fabric holds the heat generated by the fabric and prevents it from going in surrounding atmosphere, thus providing a favorable effect on the human body. It offers a comfortable, waterproof yet breathable wearing experience.

2. Stone Island

Stone island is a jacket which is made to give information about surrounding temperature. It's a liquid crystal heat sensitive coating. At 27 degree census, the molecules which are present in the coating undergo a rotation which modifying the light course. As a result of the colour of the garment gradually begins to change from the dark colour to the much lighter and brighter colour of the fabric base. When the garment returns to its normal temperature, it recovers its original dark coating colour.

3. Polar seal

Feeling cold would be the thing about past there's a product called polar seal which gives instant heat at the touch of a button. There are three different warming levels high, med and low. There are two heating zones one in the upper back and lower back so that we can feel warm in winter. These are easy to use and are tested in alpine conditions. These are flexible, lightweight, breathable and water resistant which makes them ideal for sports or outdoor. These can be worn on gloves or inside shirts. These can keep warm up to 8 hrs in a single charge.

4. ZeroI

Zerol is a cap which is built-in with bone conduction speakers. We don't have to use earphones to listen to music or to make phone calls. As it is a cap our ears are never blocked. It is water resistant, because of which we can also use it while it's raining.

5. ORII

Orii is a ring, by using it we are able to have called. Orii is a voice assistant ring that turns our finger into smartphone all through just a touch to the ear. It uses bone conduction and bone conduction has been used in many medical grade devices. To adjust the ring there are silicon pads incorporated in design which are durable and allergy proof. It has been packed in such a way that it sends vibrations through your finger directly into your ear, so only you can hear. So that allows you to talk and listen just through your finger. There is dual noise-canceling microphone and bone conduction, we can hear and talk even in loud places. By using this we are able to do things like navigation, alarms, translation, texting, weather, messaging, calling, timer, map routes etc. it is water resistant. It has the custom notification, there are four LED lights that can tell us what kind of messages are coming through.

6. Lumo Run

Self-motivation can be runners greatest assets but self-evaluation can be greatest challenge luco run are for those who want to get trained by themselves. Luco run is a motion sensor that collects data and provides motivation all while you run and it fits in a waistband of your shorts. Luco run analyses running biomechanics then suggest judgments on your form that maximises true potential by avoiding any injury. You can access data anywhere which gives full post analyses on the smart phone. We don't need any goggles, smartwatch, wristband no cables.

7. AIO Sleeve

Aio sleeve is a sleeve which can be worn in one hand and gives information which only doctors can give. It gives you self- analyses, sleep duration, quality of sleep on your mobile phone. It can play your favorite music. While workout it measures heartbeat, ECG, steps/distance as well as calories counter. While work it measures your stress level. All these things we are able to see just on your smartphone anytime any place.

4.2 PASSIVE SMART TEXTILES

These fabrics have functions beyond what you would normally expect clothing to do. However, they do not use electronics or internet connection at all.

This also means that these fabrics don't contain sensors or wires. They do not need to change because of the conditions around them. All you need to do is wear a piece of clothing made with a passive smart textile and know that it is working.

A passive smart textile's functions are going to be much simpler than those of an active smart textile. This is because the state of the fabric will never actually change. There are no electronics involved in these fabrics whatsoever.

This means that all of its functions will allow it to remain in a static state the entire time it's worn.

On the topic of static, preventing static cling is one function that passive smart textiles can have. There's nothing more frustrating than pulling laundry out of the dryer to find out it's all stuck together by static cling. Anti-static textiles can help reduce this effect.

You might also have anti-microbial textiles. These fabrics aim to reduce how often you get sick by preventing viruses and bacteria from remaining on your clothes. This helps promote the health and well-being of the wearer.

Another way to promote health and well-being is by protecting yourself from harmful UV rays. This can help prevent sunburns and skin cancer. And this is also a function that passive smart textiles can have.

4.3 ACTIVE SMART TEXTILES

On the other hand, active smart textiles are closer to what you probably think of when you talk about smart technology. These fabrics will actually change to adjust the conditions of the wearer. Some can even connect to apps and computer software.

In other words, these fabrics actively do something to make the wearer's life more comfortable or convenient, rather than the fabric itself being what makes it smart as a passive smart textile does.

The applications of active smart textiles can be much more varied. This is because there are many different ways that these fabrics can be changed and adjusted.

First of all, the healthcare industry may find some of these fabrics useful. Smart textiles can monitor a patient's heart rate, for example. This can alert nurses to any potential problems earlier enough to help.

The military can also use some of these fabrics. They can use wires integrated into the fabric to transport data from one place to another quickly. This means that military strategies can be updated in real-time.

They can also be used for disaster relief. Some of these textiles can be used as power sources for housing during natural disasters. This means that no matter what happens, people will have a warm place to stay.

Finally, these fabrics can also be connected to the internet. This can help tell you all sorts of things like heart rate and blood pressure right on your smartphone. But it can also be used for fun activities, such as gaming.

4.4 Fabrication Techniques

Different fabrication techniques like knitting, weaving, and embroidery are used to convert raw materials like conductive fibers, yarns, polymers, and polymer composites into smart textiles. Smart electronic textiles are applied in every field of life due to their novel and unique properties.

The term 'smart textiles' is used to describe materials that are advanced in their structure, composition and 'behaviour' in special conditions. Their 'intelligence' is classified into three subgroups:

•Passive smart textiles, which are sensors and can only sense the environment;

•Active smart textiles, which can sense stimuli from the environment and also react to them; simultaneously with the sensor function, they also play an actuator role;

•Very smart textiles, which are able to adapt their behaviour to the circumstances.

4.5 Conductive Fibres

Conductive polymer-based electrochromic fabrics show promising applications in new intelligent displays, flexible smart wearables, and military camouflage, thanks to their flexibility, light weight, high degree of controllability, and wide range of color change.

The textile structures which can conduct electricity are called conductive textiles. It may be either made using conductive fibres or by depositing conductive layers onto non-conductive textiles.

A conductive fabric can conduct electricity and made with metal strands woven into the construction of the textile. It can be inhibited the static charge generated on fabric, to avoid uncomfortable feelings and electrical shocks also.

Methods of producing conductive textiles are summarized as follows:

- Adding carbon or metals in different forms such as wires, fibres or particles.
- Using inherently conductive polymers.
- Coating with conductive substances.

Types of Conductive Textiles:

Generally, four kinds of conductive textile as follow:

1. Anti-static textiles
2. EM shielding textiles
3. E-textiles
4. Functional coatings

1. Anti-static textiles:

Static electricity can the build-up of electric charge on the surface of objects. Which can be caused many problems for textile materials, manufacturing and handling the product. In dry textile process, fibres and fabrics can tend to generate electro-static charges from friction. When fibres and fabrics are moving at high speeds on different surfaces, (like: conveyer belts, transport bands, driving cords, etc) causing fibres and yarns to repel each other. These static charges can be produced electrical shocks and caused the ignition of flammable substances. Two techniques are known to prevent static electricity in textiles. One is to create a conducting surface and another is to produce a hydrophilic surface. In these ways antistatic textiles are produced to avoid the potential hazards caused by static charge or, electricity.

2. EM shielding:

Electro Magnetic shielding (EMs) is the process of restricting the diffusion of electromagnetic fields into a space. In this process, electrically or magnetically conductive barrier is used. Shielding is common technique for protecting electrical equipment and human beings from the radiating electro-magnetic fields. This barrier can be rigid or flexible. When an EM beam passes through an object, the electro-magnetic beam interacts with molecules of the object and this interaction may take place as absorption, reflection, polarization, refraction, diffraction through the object. EM Shielding textiles materials can be found in the form of woven, knitted, and nonwoven fabric also. The major components of these fabrics are fibres and yarns. To achieve an effective shielding behaviour, these fibres should be electrically conductive. Conductive yarns can be made by blending conductive fibres with conventional staple fibres, twisting conductive or insulator filaments together. For example, conductive metallic yarn (such as: silver, copper, etc.) can be wrapped with insulating textile materials to create hybrid yarns. Which could be integrated into woven or knitted structures. Hybrid yarns or metallic fibre can be integrated into these designs as warp. Electromagnetic shielding effectiveness of the fabric decreased with the increase in fabric openness.

3. E-textiles:

Electrically conductive fibres and yarns have attracted great interest because of their distinguished features including reasonable electrical conductivity, flexibility, electrostatic discharge, and EM interference protection. Conductive textile fibres are the primary component for wearable smart textiles introduced particularly for different applications such as sensors, electromagnetic interference shielding, electrostatic discharge, and data transfer in clothing. Therefore, the demand for electrically conductive fibres and yarns is ever-growing. The development of novel conductive fibres becomes crucial with technological improvement in wearable electronics such as wearable displays, solar cells, actuators, data managing devices, and biomedical sensors. E-textiles play a critical role in selecting the conductivity of smart textile electronics. Textile applications such as lighting, considerable current is necessary and low ohmic fibres are preferred. On another hand, for certain sensing or heating applications lower conductivity would work better. So, it requires fibres exhibiting lower electrical conductivity. E-textiles need flexible and mechanically stable conducting materials to ensure electronic capabilities in apparel.

4. Functional coatings:

For many applications, functional coating is the material interfaces and surfaces that provide beneficial functionality over their intrinsic bulk characteristics. Hence, coatings provide a versatile method of modifying textiles with conductive properties. Subsequently, the textile fabric acts as a supporting structure or carrier material for the conductive finish. Conventional methods such as dip coating or roll coating are typically used to apply bulk coatings in the form of a saturation or lamination that covers the entire “surface” of the textile. However, as will be presented herein, the advent of nano-technology in textile research, the development of novel process techniques, and the advancement of inks and coating formulations affords the opportunity to apply coatings to increasingly finer structures.

Properties of Conductive Textiles:

Physical properties:

- Low weight,
- High strength,
- Flexibility,
- Durability,
- Elasticity,
- Heat insulation,
- Water absorbency,
- Dyeability,
- Drape,
- Soft handling,

The development of devices on textiles such as sensors[1], photodetectors[2], transistors[3], electro-luminescent devices[4], supercapacitors[5] and solar cells[6] is attracting great interest and has led to the emergence of the field of smart textiles. Smart textiles can find an enormous range of applications in several fields, including healthcare, military and fashion[7]. Since the concept of textiles is much wider than clothes and garments, the applications can extend to aviation, automotive and transport, construction, geo-textiles and packaging. While most commercial applications of smart textiles rely on conventional hardware simply mounted onto textiles, the integration of specific functionalities directly on textile fibres promises to revolutionize the field of wearable electronics. With the recent advances in nanotechnology and materials engineering, different functionalities can now be incorporated into textile fibres, such as antibacterial properties, static elimination, and electric conductivity[8].

Conducting fibres are an important component of any e-textile, not only because they can be used as lightweight wiring for simple textile-based electronic components, but also because they can provide a platform for building electronic devices directly on textile fibres. For instance, such fibres can be used as gate electrodes for field-effect transistors, or bottom electrodes for light-emitting diodes and photovoltaic devices. Conductive textile fibres are currently used as a stronger and more flexible weight-saving material in the aviation sector, where the aircraft weight and fuel consumption are reduced by replacing metal wiring with electrically conductive cotton fibres like ARACON®. The most common approach to produce conductive fibres consists in mixing an insulating polymeric matrix with a conductive component, which can be a conducting polymer such as PEDOT:PSS[9], silver nanowires[10], nanocarbon fillers[11], or their hybrids[12–15]. These composite fibres are usually produced by wet-spinning of the polymer with a suspension of the active conducting material, or via electrospinning[16], techniques that require a large consumption of expensive materials and that can cause the loss of flexibility and transparency. A different approach relies on polymer-free fabrication of conducting fibres, but the methods include the use of strong acids and coagulants[17], which greatly limits the potential for scaling up and commercialization. Another strategy is to impregnate fibres with conductive materials after they have been manufactured. This method has been used for fibres, yarns and fabrics that are highly porous with a complex structure of microfibrils, such as cellulosic fibres. These inks and dyes make use of several types of conductive materials, such as aluminium18, carbon nanotubes19, and graphene20, and have been in the base of demonstrations of wearable and stretchable electronics, including integration onto surfaces of live plants and insects21, 22. One of the limitations of this methodology is that such multifilament fibres and fabrics, compared to fibres coated prior or during manufacturing, tend to lose the conductive filling more easily if not completely encapsulated, and can pose end-of-life environmental concerns.

A more practicable emerging strategy to prepare conductive textile fibres is to coat insulating fibres with conductive atomically thin two dimensional layers such as graphene23. Graphene, a monoatomic carbon layer, is the strongest known material, the best electrical and thermal conductor which is also mechanically flexible and transparent24. Thus, it represents a radical alternative to conventional technologies as it can bend, stretch, compress, twist and deform into complex shapes while maintaining the same levels of performance and reliability25. There are already several examples of graphene-based textiles with different functionalities and for different applications26. The coating we propose is performed by electrostatic adhesion of graphene at the surface of monofilament fibres and does not involve impregnating an agglomerate of fibres. The adhesion of the graphene coating to the textile fibres is strong and durable, and a straightforward passivation can be achieved by encapsulation with an insulating polymeric layer. This method was developed for tape-shaped polypropylene (PP) and bio-based polylactic acid (PLA) fibres, two polymers with widespread use in the textile industry27. This approach depends on the size of the graphene sample, usually in the centimetre range, and although this might not be suitable for electronic wiring, it is appropriate to build electronic devices directly on textile fibres.

In this work, we demonstrate that graphene can be transferred to a large variety of thermoplastic monofilament textile fibres of different types and shapes. To further advance the development of this technique, it is important to understand the various factors that can influence the conductivity achieved by coating textile fibres with graphene. Surface topography and chemical nature seem to be determinant in the conductivity achieved. On the other hand, cracks and tears in the graphene coating will result in a decrease in conductivity, and therefore it

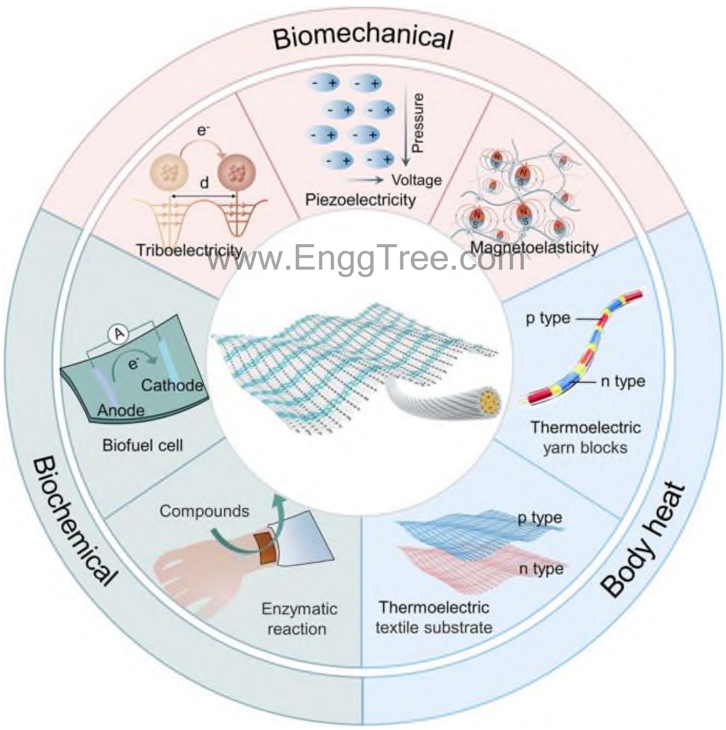
is important to establish their origin. Thus, our present study aims at: (1) establishing how the above-mentioned factors actually influence the quality of the graphene coverage and how it correlates with the resulting conductivity; and (2) explore the suitability of our coating method for different materials, sizes and shapes.Raman spectra of fibres of the three materials (PP2, PE and PLA2), before and after the graphene transfer, are shown in Fig. 1e. For all graphene-coated fibres it was possible to identify the graphene G band at 1585 cm^{-1} . The
2D peak was clearly visible for graphene-coated PP1 and PLA2, at 2685 cm^{-1}
, as well as a small D peak for PE and PLA2. These values match those found for G and 2D bands of the same type of graphene transferred to SiO_2 (see Supplementary Fig. S2; more extended Raman spectra of the graphene-coated fibres is shown in Supplementary Fig. S3, along with details of the G and 2D peaks and corresponding integrations for PP2, PE and PLA2).

To study the factors that lead to the observed differences in sheet resistance, it is important to understand the influence of the topography of the fibres on the effectiveness of the graphene coating. A non-contact optical method was used to determine the macroscopic surface parameters of the untreated fibres. The images obtained are shown in Supplementary Figs S4, S5 and S6, and the parameters are listed in Supplementary Table S1. Figure 2 shows the Atomic Force Microscopy (AFM) amplitude and topography for 5×5μm images of the PP fibres before coating and corresponding height profiles taken at the highlighted lines parallel to the extrusion axis. Compared to PP1, PP2 fibres show considerable differences in terms of AFM topography. PP2 does indeed have a smoother height profile (Fig. 2a, right) with less pronounced height differences than PP1 (Fig. 2a, left). The UVO treatment created a fine roughness throughout the whole surface, which seems to create more points where the graphene sheet can effectively adhere to the surface of the fibre (Fig. 2a, middle). The same conclusions are valid for larger and smaller AFM scanning areas (30×30 μm and 1×1 μm images, see Supplementary Fig. S7). Although in terms of overall thickness and surface features, PP1 and PP2 are very similar (see Supplementary Table S1), in a smaller scale AFM shows that PP2 has areas with less pronounced features than PP1, which is also in accordance with the smaller Kurtosis value in PP2. A similar study was performed for the PLA-based fibres PLA1 and
PLA2 (Fig. 2b and Supplementary Fig. S8), showing that the changes in polymer source grade do not have a substantial impact on the surface morphology in the AFM

scale. However, the difference in roughness is much more significant macroscopically, with PLA2 is rougher than PLA1, showing visible ridges perpendicular to the extrusion lines (Supplementary Fig. S5). On the other hand, we found that the UVO treatment does change the surface of PLA-fibres significantly (Fig. 2b, middle). All three monofilament tape-shaped samples, PP2, PLA2 and PE were also subjected to UVO treatment. Both PLA1 and PLA2 fibres often appeared to be damaged after UVO-treatment, particularly towards the edges, where propagating cracks and microfibrils tearing from the sample were clearly visible to the naked eye (see Supplementary Fig. S8, top middle, where a loose microfibril is clearly noticeable). The damage induced by the UVO treatment is even more severe in PLA2 fibres. The protuberances that are observed on the fibres as a consequence of the UVO treatment are probably a sign of that degradation, and biodegradable polymers like those based on PLA are prone to be damaged even more rapidly. These protuberances can be thermally caused or appear due to the chemical reactions of oxygen radicals at the surface of the polymer. Attempted coating of these UVO-treated PLA2 fibres with graphene was unsuccessful, as all the samples remained insulating after the graphene transfer. The immersion in warm acetone during the PMMA ((poly(methyl methacrylate)) cleaning step seemed to damage the fibres even further, causing them to curl and shrink. It should be noted that the UVO treatment was performed under the same conditions for all fibres, and even though the bio-based PLA1 fibres also showed some signs of quicker degradation when subjected to the UVO treatment, it was still possible to achieve considerably low sheet resistance. The fact that PLA2 fibres are slightly smaller than PLA1, 1.0 mm wide and 0.07 mm thick, compared to 1.2 mm wide and 0.1 mm thick, may also account for the fact that the formers are more fragile and easily degradable.

Case study-smart fabric for monitoring biological parameters

Merging electronics with textiles has become an emerging trend since textiles hold magnificent wearing comfort and user-friendliness compared with conventional wearable bioelectronics. Smart textiles can be effectively integrated into our daily wearing to convert on-body biomechanical, biochemical, and body heat energy into electrical signals for long-term, real-time monitoring of physiological states, showing compelling medical and economic benefits. This review summarizes the current progress in self-powered biomonitoring textiles along three pathways: biomechanical, body heat, and biochemical energy conversion. Finally, it also presents promising directions and challenges in the field, as well as insights into future development. This review aims to highlight the frontiers of smart textiles for self-powered biomonitoring, which could contribute to revolutionizing our traditional healthcare into a personalized model.



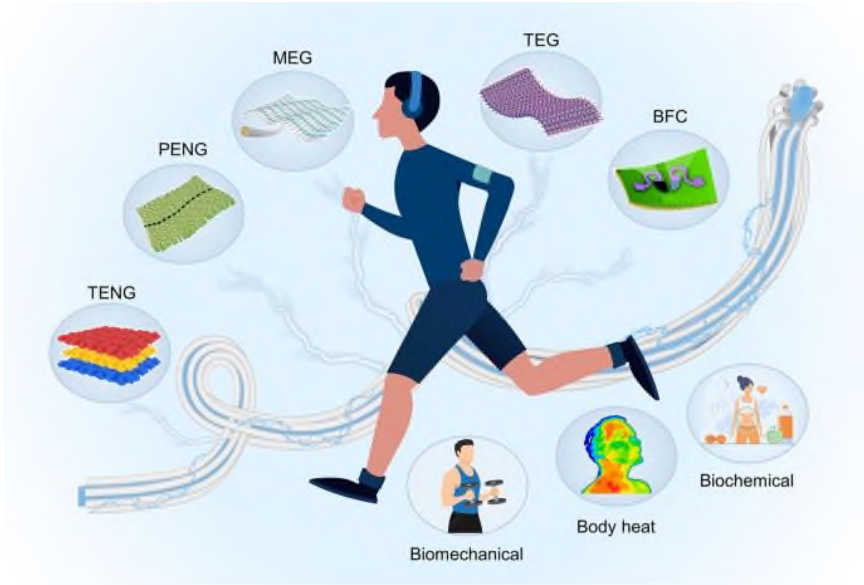
Self-powered biomonitoring textiles via biomechanical, body heat, and biochemical energy conversion are discussed in this work. Platform technologies, including piezoelectric nanogenerators (PENGs), triboelectric nanogenerators (TENGs), and magnetoelastic generators (MEGs) for biomechanical energy conversion, thermoelectric generators (TEGs) for boy heat energy conversion, and biofuel cells (BFCs) for biochemical energy conversion, are systematically introduced and discussed in a textile form. Working in a self-powered manner with greatly improved wearing comfort, the smart biomonitoring textiles pave a compelling road to personalized healthcare.

Highlights

- Self-powered biomonitoring textiles via biomechanical, body heat, and biochemical energy conversion are discussed.
- Platform technologies, including PENG, TENG, MEG, TEG and BFC are systematically introduced.
- Self-powered biomonitoring textiles pave a compelling road to personalized healthcare

Textiles, which have been a part of human civilization for thousands of years, are made from both natural materials such as silk and cotton, and synthetic materials such as polyamide and polyester. These materials can be made into textile bioelectronic devices via scalable weaving, knitting, braid, printing, and electrospinning, showing great wearing comfort and breathability. Conventional fiber fabrication techniques include coating, spinning, and thermal drawing. These various types of fibers can also be arranged into different architectures and structures in textiles endowing them with excellent flexibility, breathability, abrasion resistance, and material integration. An increasing number of platform technologies, including electroluminescent piezoresistive thermoelectric and photovoltaic platforms have been utilized to develop smart healthcare textiles Among them, self-powered biomonitoring textiles that rely on piezoelectric triboelectric magnetoelastic and electrochemical approaches offer unique and compelling features that have attracted significant attention. Self-powered textiles have the capability of sustainably converting the renewable energy from the human body such as biomechanical, body heat, and biochemical energy into electrical signals for healthcare purposes. They not only weaken the dependance of wearable bioelectronics on power supply, but they also provide highly sensitive and real-time information to monitor human physiological states. Additionally, self-powered textiles are also environmentally friendly, simple to manufacture, inexpensive, which can be effectively integrated into daily wear such as clothing, masks, wristbands, and other garments for continuous monitoring.

We will begin by briefly discussing the physiological signals that can be monitored. Then, we will present the progress of self-powered biomonitoring textiles which utilize the on-body renewable energy sources: biomechanical, body heat, and biochemical energy (Fig.). We will illustrate the mechanisms of each of these self-powered textiles and describe how they can monitor various physiological parameters. Finally, we will discuss the challenges within the community of self-powered biomonitoring textiles. This review provides a critical analysis of the current advances in smart biomonitoring textiles and the insights into remaining challenges and future directions.



Platform technologies for self-powered biomonitoring textiles. For self-powered biomechanical sensing, we have systematically introduced PENGs, TENGs and MEGs. The TEGs and BFCs are introduced for self-powered boy temperature and biochemical sensing, respectively. This review provides a critical analysis of the current advances in smart textiles working in the self-powered manner and the insights into remaining challenges and future directions, paving a compelling road to personalized healthcare

ECG Respiration

Wearable light textiles are gaining widespread interest in application for measurement and monitoring of biophysical parameters. Fiber optic sensors, in particular Bragg Grating (FBG) sensors, can be a competitive method for monitoring of respiratory behavior for chest and abdomen regions since the sensors are able to convert physical movement into wavelength shift. This study aims to show the performance of elastic belts with integrated optical fibers during the breathing activities done by two volunteers. Additionally, the work aims to determine how the positions of the volunteers affect the breathing pattern detected by optical fibers. As a reference, commercial mobile application for sensing vibration is used. The obtained results show that the FBGs are able to detect chest and abdomen movements during breathing and consequently reconstruct the breathing pattern. The accuracy of the results varies for two volunteers but remains consistent.

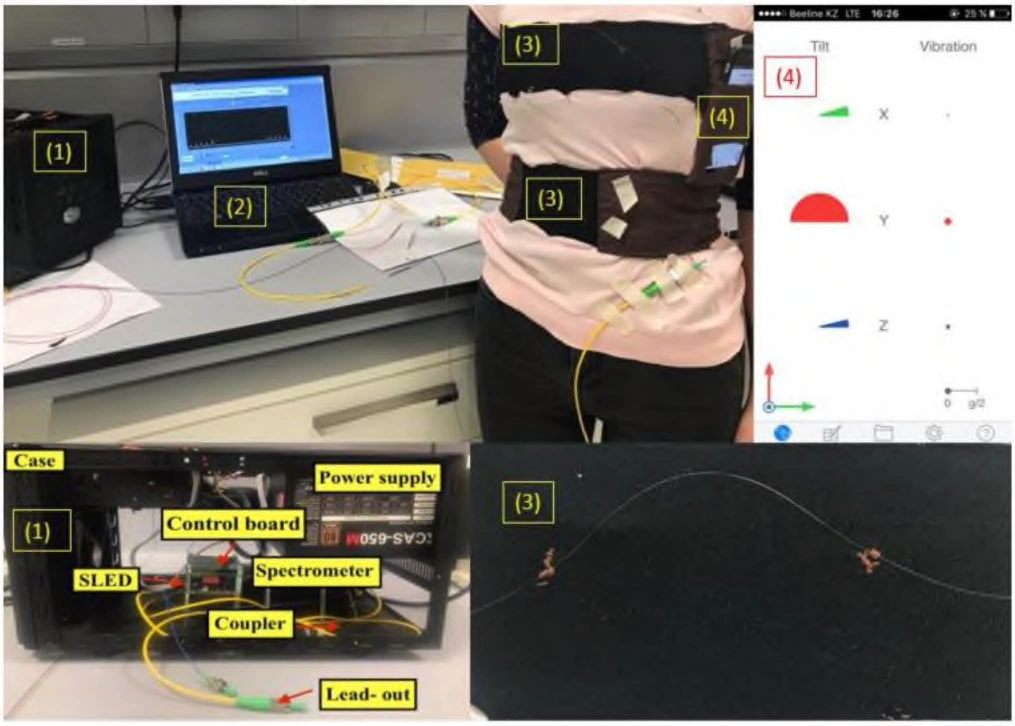
Wireless devices have pushed forward medical science to an advanced level in which people have access to a personalized drug delivery, a remote healthcare including simple diagnostics and data-logging operations outside of hospitals, and a continuous monitoring of biophysical parameters such as blood pressure, body temperature, breathing rate, etc. Low-cost miniature technologies help to prevent sudden infant death syndrome, heart-related diseases and provide minimal invasive continuous monitoring.

For example, Skrzetuska and Wojciechowski studied the ability of T-shirts equipped with a printed respiratory rate sensor to monitor the breathing pattern of two volunteers and the influence of the environmental humidity and temperature on the output of the sensor. The authors have tried several configurations of printed sensor and identified the most optimal shape and size of the sensor. The breathing of volunteers were monitored during physical activities and rest. The sensing technology were able to identify breaths but the external climate conditions were found to have an effect on the accuracy of the results.

Joyashiki and Wada proposed to monitor breathing pattern by a body-conducted sound sensor placed on the neck. The performance of the sensor was compared with two other sensors, namely air-coupled microphone and acceleration sensor. A data analysis technique based on signal processing was developed. The authors came to the conclusion that body-conducted sensor performs better in four different types of the experiments. Schatz et al. studied the application of five different types of depth sensors for breathing rate monitoring and usage of this data for the sleep apnea identification. All of the sensors output were compared with the reference sensor and two of the five sensors have been found appropriate for sleep apnea determination.

The aim of the experiments is to study the feasibility of the FBGs arrays for breathing pattern monitoring application. The breathing pattern is measured at the two locations of the body (abdomen and chest) by two arrays of 5 FBGs.This allows to apply a diversity technique, which is used in communication systems to achieve better accuracy of detection by combining the outputs from several different sensing points. The breathing pattern has been measured in four different positions of the volunteers (sitting, lying, staying or running). Two volunteers have participated in the initial experiments: 23-years old woman, height 165 cm, weight 52 kg and 24-years old man, height 171 cm, weight 72 kg. The volunteers wore T-shirts with two specially designed belts located on the abdomen and chest regions. They have been asked to breath for 23 seconds in different positions: staying, sitting, lying and running. The results of the the strain change detected by FBGs have been compared with the output of a reference sensor, which is a mobile application for acceleration and vibration measurement. The mobile phone with the application has been attached to the upper belt.

The experimental setup, which is illustrated in Figure, consists of the (1) I-MON interrogator connected to (2) PC with evaluation software, (3) T-shirt with two belts each equipped with an array of 5 FBGs, (4) mobile phone with VibSensor application.


(1)
(2)
(3)
(4)
(3)
Tilt
Vibration
(4)
X
Y
Z
Case
(1)
Power supply
Control board
SLED
Spectrometer
Coupler
Lead- out
(3)

UNIT V APPLICATIONS OF WEARABLE SYSTEMS

Medical Diagnostics, Medical Monitoring-Patients with chronic disease, Hospital patients, Elderly patients, neural recording, Gait analysis, Sports Medicine.

APPLICATIONS OF WEARABLE SYSTEMS:

In Medical Diagnostics:

Wearable technologies can be innovative solutions for healthcare problems. Some wearable technology applications are designed for prevention of diseases and maintenance of health, such as weight control and physical activity monitoring. Wearable devices are also used for patient management and disease management. The wearable applications can directly impact clinical decision making.

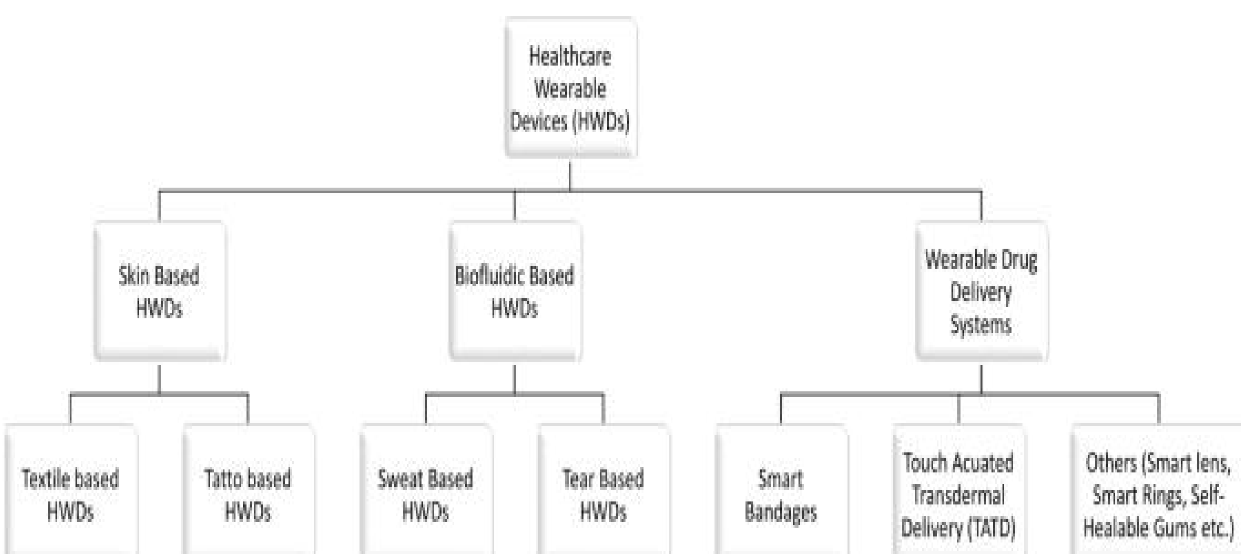
Wearable technologies enable the continuous monitoring of human physical activities and behaviors, as well as physiological and biochemical parameters during daily life. The most commonly measured data include vital signs such as heart rate, blood pressure, and body temperature, as well as blood oxygen saturation, posture, and physical activities through the use of electrocardiogram (ECG), ballistocardiogram (BCG) and other devices. Potentially, wearable photo or video devices could provide additional clinical information. Wearable devices can be attached to shoes, eyeglasses, earrings, clothing, gloves and watches. Wearable devices also may evolve to be skin-attachable devices. Sensors can be embedded into the environment, such as chairs, car seats and mattresses. A smartphone is typically used to collect information and transmit it to a remote server for storage and analysis. There are two major types of wearable devices that are used for studying gait patterns. Some devices have been developed for healthcare professionals to monitor walking patterns, including the accelerometer, multi-angle video recorders, and gyroscopes. Other devices have been developed for health consumers, including on-wrist activity trackers (such as Fitbit) and mobile phone apps and add-ons. Wearable devices and data analysis algorithms are often used together to perform gait assessment tasks in different scenarios.

Continuous and real-time monitoring is essential for better management of patients with chronic illnesses, including, cardiovascular diseases, diabetes, and neurological disorders. According to the World Health Organization (WHO), chronic diseases account for three quarters (75%) of all deaths around the world and impose high economic burdens. Therefore, different strategies are required for the monitoring and diagnosis of such diseases and an effective strategy in this regard is HWDs. Wearable devices are defined as devices, which are worn on the human body or on clothing. They consist of a target receptor and a transducer. A receptor recognizes the target analyte and responds accordingly. The transducer then convert the receptor's response into a useful signal. Several studies have reported applications of wearable devices in different fields; as a result, these devices have shown promising results in the field of healthcare due to their ability of deformability and compliance. These HWDs provide a better understanding of the changes inside a human body and can help in preventing and treating diseases.

Biosensors were initially used as invasive devices for controlled lab settings before their integration into wearable sensors. In 1956, Leland C. Clark, known as the "father of biosensors", was the first to use electrodes for the detection of the level of oxygen in blood. This device was meant for the continuous and real-time detection of oxygen in operating room settings during the cardiovascular surgery. The introduction of electrodes for healthcare purposes later led to the discovery of potentiometric biosensor for the detection of urea in 1969 by Guilbault and Montalvo, Jr. The introduction of electrodes for healthcare lead to the commercialization of the first glucose analyzer in 1975 based upon Leland C. Clark's electrochemical biosensor. With the miniaturization of electronics that leads to the micro and nanoelectronics and advancements in material sciences, integrated HWDs came into existence. These HWDs consists of electronic devices for the acquisition, processing and sharing of data. Conventional rigid and heavy electronic devices, for example, Printed Circuit Boards (PCBs) are not a suitable choice for HWDs therefore, significant advancements have been made in recent years in electronic devices in terms of their material, fabrication techniques, processing circuits and transceivers to enhance their compliance with HWDs. Recent advancements in HWD materials include biocompatible flexible materials for example, polyethylene naphthalate, polyethylene terephthalate (PET), Ecoflex, and Polydimethylsiloxane (PDMS), silicone-based materials, and thin film polymers for example, parylene[2,7,8]. These materials have high flexibility and stretchability, which makes them suitable substrates for HWDs. Ecoflex and PDMS have elongation limits of 900% and 400%, respectively, where Ecoflex has Young's modulus close to human skin. In comparison to conventional devices, these flexible electronic devices are not only low cost but are also power efficient in their consumption, which allow uninterrupted acquisition of data over long time. With emergence of communication modules like Bluetooth, Near Field Communication (NFC), Wi-Fi and Wireless body area networks (WBAN), visualization and sharing of the data in real time has become possible with HWDs. These HWDs help in measuring different parameters and biopotentials. These biopotentials include electrocardiogram (ECG), which is a measure of heart performance, electromyogram (EMG) which is a measure of the activity of muscles in response to nerve stimulation, electroencephalogram (EEG), which is a measure of the performance of brain activity and electrooculogram (EOG), which records eye movements. These HWDs are extensively employed as noninvasive devices and particularly in point-of-care (POC) settings. Furthermore, the noninvasive nature of wearable devices has made therapeutic procedures simple and has decreased the risk of infection, which was previously related to blood.

The POC wearable devices have revolutionized the healthcare system by decreasing the load on hospitals and by providing more reliable and timely information. For this purpose, different types of wearable devices have been employed, e.g., epidermal-based wearables, flexible wearables, and textile-based wearables. Wearables can be employed for different body parts, e.g., head-based wearables, eye-based wearables, and wrist-based wearables. These wearables monitor different psychological and physiological parameters that can be used for the diagnoses of different diseases13. In fact, wearable devices can be integrated with different sampling platforms for sensing different chemical parameters from bodily fluids e.g., saliva, blood, urine, sweat, etc. Additionally, these HWDs can be used for the delivery of drugs in a more controlled and efficient manner in comparison to traditional drug delivery systems

Classification of Healthcare Wearable Devices (HWDs).



Skin-based wearable devices

As skin covers most of the human body, it serves as an optimal mode for noninvasive healthcare wearable devices. Skin-based wearable devices can be used for physiological and psychological monitoring essential for the treatment of different diseases, for example cardiovascular and neuromuscular diseases. Additionally, it can also be used for the diagnosis of different diseases using qualitative and quantitative analysis of skin secretions, such as sweat. Based on the type of skin contact skin-based wearable devices can be either textile based or epidermal based. Textile-based wearable devices involve embedding essential sensors in clothes whereas epidermal-based wearable devices involve the direct attachment of wearables to the skin like a tattoo, generally known as electronic skin (e-skin). The following sections highlight the applications of textile-based HWDs and tattoo-based HWDs for the monitoring and diagnosing of different diseases.

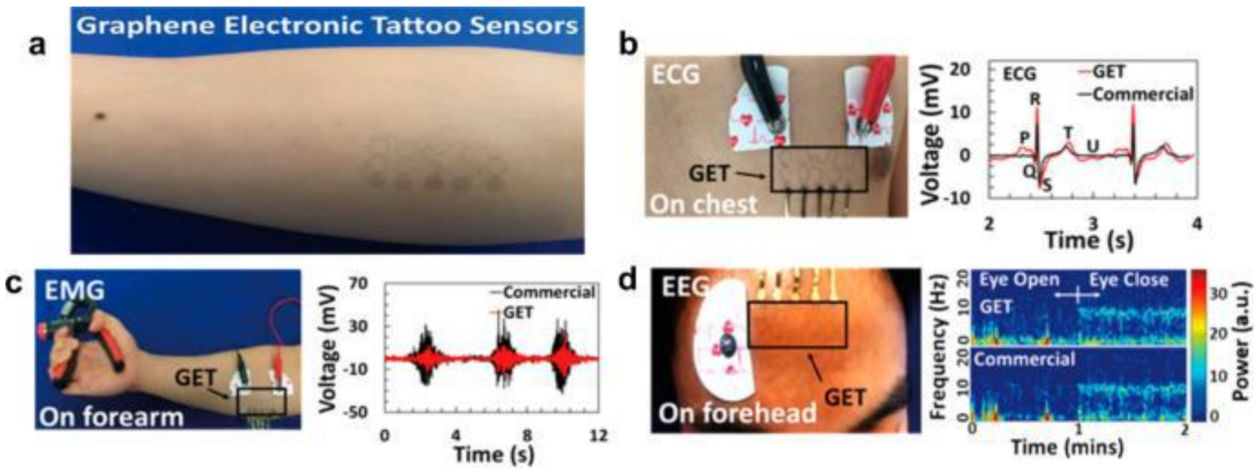
Textile-based HWDs

Textiles have been around for centuries and are readily available. Traditionally, textiles and clothing have been perceived as keeping humans warm and for esthetics. Due to their accessibility and comfortability, they can be used for sensing important parameters, such as body temperature, heart rate, and respiration rate. Such HWDs are commonly known as electronic textiles or e-textiles. E-textiles are clothes embedded with sensors and conductive materials. The stretchable nature and large-scale skin contact make textiles an optimal medium for HWDs. With the emergence of graphene, carbon nanotubes, and nanowires, a number of efforts have been made to incorporate sensors into clothing for continuous monitoring. One such effort is by Yapici et al. who have developed an intelligent textile-based HWD for the monitoring of ECG. Traditionally, ECG is monitored by using gel-based Ag/AgCl electrode cables, which are not comfortable for the wearer. For textile-based ECG monitoring, graphene functionalized cloth has been embedded with ECG sensors. Graphene has been used for this purpose because of its excellent material properties and high correlation with conventional gel-based ECG monitoring. A comparison of the traditional Ag/AgCl electrodes with the ECG HWD . It can be seen that graphene functionalized textile electrodes highly correlates with the conventional Ag/AgCl ECG electrodes with a maximum correlation of 97.0%. However, the graphene functionalized e-textile electrodes for ECG has higher electrode-skin impedance (87.5–55 kΩ) than the conventional Ag/AgCl electrodes (50.9–20 kΩ), which distorts the ECG and requires additional components like buffer amplifiers and adaptive filters[23]. Similarly, Arquilla et al. have tested textile electrodes for ECG monitoring using HWDs. They have developed a chest-based ECG system by sewing ECG electrodes into the textile instead of using gel electrodes. This sensor system has been applied on eight different subjects (five males and three females) to validate the accuracy of textile-based ECG with the traditional gel-based ECG electrode. Differences between the heart rate and R–R intervals of ECGs from both systems were minimal and are shown in Fig. 2b–d. The statistical parameters for differences in heart rate are $t = -0.70$ and $p > 0.5$ and $t = 1.43$ and $p > 0.1$ for R–R interval and with a high correlation coefficient of 0.94. However, this ECG sensor has not been tested during movement, which imposes considerable challenges in maintaining the skin-electrode contact and hence is mandatory for continuous ECG monitoring.Moreover, Wicaksono et al. have also developed an electronic textile comfortable suit (E-TeCS). The E-TeCS provides temperature sensing of skin with a precision of 0.1 °C as well as heart and respiration rates at a precision rate of 0.0012^{-2} using inertial sensing. Additionally, washability and degradability tests were also conducted for the E-TeCS and high rigidity along with confirmation for no flakes or discoloration up to ten cycles of washing were observed, which makes it suitable for everyday use. Likewise, the use of HWDs can also be extended for other bipotential signals like EEG and EOG, which are required to be monitored for the treatment and diagnosis of different diseases. Gao et al. have developed a multisensory textile-based HWD for the simultaneous detection of EEG from the forehead and sweat rate. This wearable utilizes silver (Ag) as a conductive material embedded inside the textile electrode to record an EEG. The multisensor wearable consists of an EEG recording module and SHT20 chip for the relative humidity measurement. It has eight channels that allow independent recording of the EEG using different electrodes and the relative humidity is used to for the indirect measurement of the sweat rate. The multisensory HWD was compared with traditional Ag based wet electrodes used for EEG measurement and was highly correlated. Alpha rhythm is a standard electrical brain response with frequencies ranging from 8 to 15 Hz and usually more evident while eyes are closed. Correlation coefficients of 93.04% and 81.69% between the two electrodes have been found, in closed and opened eyes conditions, respectively. However, the skin-electrode impedance of the multisensory HWD decreases in the presence of sweat from 30–20 to 6 kΩ in comparison to standard Ag wet electrodes that maintains small skin-electrode impedance irrespective of sweat. Moreover, electrodes embedded inside the textile can also be used for EMG, which measures the electrical activity of muscles in response to nerve stimulation and is used for the detection of muscle or motor neuron abnormalities. Pino et al. have proposed a wearable shirt to monitor EMG that provides essential feedback during exercise30. The wearable shirt is shown in the These EMG signals are then sent to monitoring system using Bluetooth for signal processing.

Textile-based HWDs experience distortion in their results due to loose contact between skin and HWD. This requires additional signal processing techniques on raw data for acquiring clean signals. Moreover, textile-based HWDs provide comfortability along with real-time and continuous monitoring of the wearer, but their stability decreases with repeated washing due to the involvement of bio-recognizable molecules. The instability involved with textile-based HWDs may be partially resolved with tattoo-based HWDs.

skin or tattoo-based HWDs

Traditionally, tattoos have been perceived as a form of body art because of its pliability and compliance. These properties can be used for monitoring and diagnostic purposes. Currently, e-skins are widely used for the detection of electrical and physical parameters such as ECG, EEG, and EMG. Of these, the ECG is easiest to detect because of its high amplitude, of the order of ~1 mV. This allows an accurate, noninvasive detection of heart signals through the skin. In cardiovascular arrhythmias like tachycardia and bradycardia, ECG is the first point of reference for diagnosis and treatment. As mentioned, earlier, conventional ECG monitors require the attachment of gel-based electrode cables along with external electronic instrumentations for signal acquisition and can be uncomfortable for the wearer. Furthermore, these ECG monitors are mostly used in controlled lab or hospital settings and therefore cannot be carried with the wearer at all times. Many patients suffering from heart disease would benefit from continuous monitoring of their heart rhythm but a daily visit to a hospital poses an economic and scheduling burden. Moreover, tattoo-based ECG monitoring systems can resolve the instability and sensitivity issues of textile-based ECG monitors, due to their miniaturization and stretchability. They are also more flexible and comfortable for the wearer. A notable example of a tattoo-based HWDs ECG monitor is described by Ameri et al. It consists of miniaturized electronic components built on a graphene/polymethylmethacrylate (Gr/PMMA) bilayer substrate. The graphene electronic tattoo (GET) is fabricated using a wet transfer, dry patterning method and has 463 ± 30 nm thickness with ~85% optical transparency and more than 40% stretchability. The high stretchability and optical transparency make it light enough to be embossed on skin, like a tattoo. It binds to the skin using Van der Waals forces, which makes it mechanically invisible for the wearer. The GET is a comprehensive epidermal electronic system that is effective for different biopotentials like ECG, EMG, and EEG. This HWD reports a clean ECG with high signal to noise ratio, comparable to conventional bulk gel-based electrodes. The module also works for other electrophysiological parameters, for example, EEG and EMG by embossing it on different parts of the body. Moreover, it has low skin impedance, comparable with Ag electrode, for 52 h, however, 96 h after its application, crack starts to appear during the test, which increases its skin impedance, making it unsuitable for further use

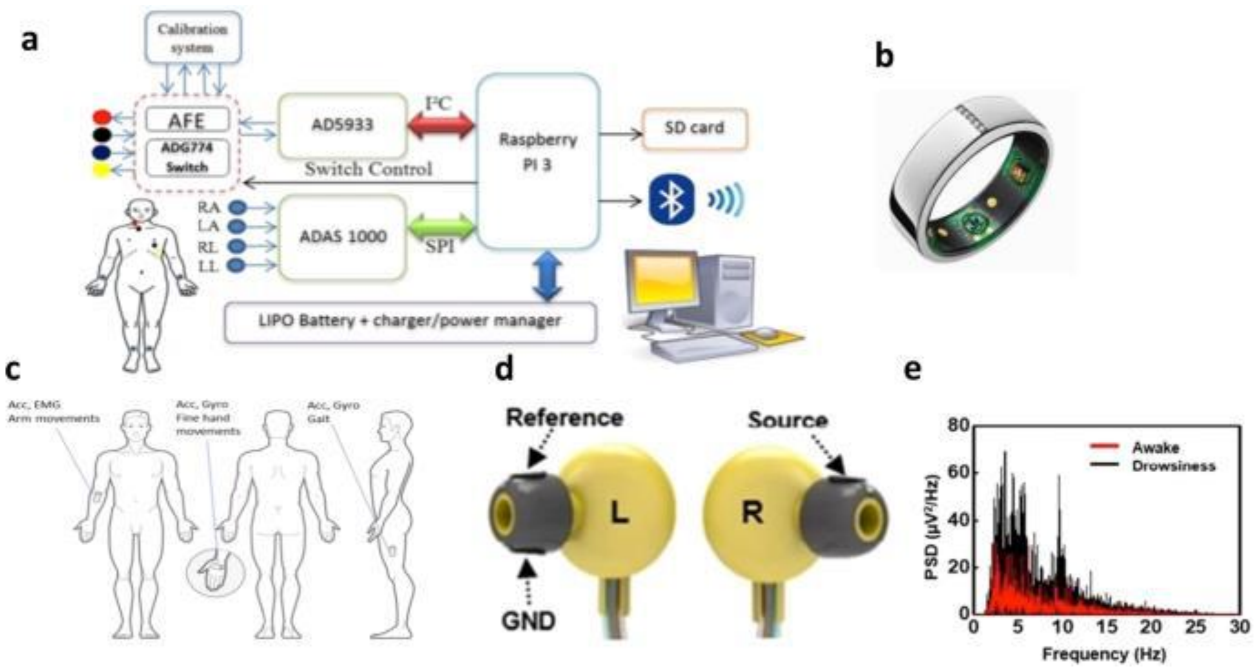


Moreover, Dae et al. used a self-powered piezoelectric sensor for the continuous and real-time monitoring of the arterial pulse34. The arterial pulse is a measure of heart's contraction rate, which is a component of cardiac output (heart rate × stroke volume)34,35. A piezoelectric sensor converts the pressure created due to arterial pulses into electrical pulses. In-time detection of the abnormalities in atrial pulses could lead to the prevention of serious cardiac diseases. Monitoring arterial pressure may potentially help in the diagnosis of cardiac and blood diseases36,37. This self-powered tattoo-based HWDs is POC in nature and mitigates the high-power consumption required by conventional arterial monitors. Moreover, data are shared wirelessly in case of any abnormality detected in arterial pressure signals using smartphone modality. It utilizes $BaTiO_3$ and Pb $[Zr_x, Ti_{1-x}]$ O_3 (PZT), active materials for the microelectromechanical sensors, due to their high piezoelectric coefficients. A thin layer of plastic was covered with PZT using laser lift-off technique (ILLO), which is an inorganic based technique for transferring polymers on surfaces38. The ultrathin layer of PZT adheres to the epidermis and responds to changes in arterial pulses. The self-powered PZT sensor was used for the detection of arterial pulses before and after the exercise. Before exercising, V_{pp} of the arterial pulse is 81.5 mV whereas after exercising its amplitude is 100 mV, an increase of ~22% due to the increase in heart rate after the exercise. The same wearable was used for experiments in monitoring human respiratory activities, trachea movement and heart rhythm. These experiments have shown a sensitivity of ≈0.018 kPa^{-1} and response time of ≈60 ms with excellent mechanical stability. However, the self-powered tattoo requires biocompatible piezoelectric material for clinical trials34.

Furthermore, it is estimated that over one billion people worldwide have hypertension, or elevated blood pressure (BP). Out of 1 billion, two-thirds are in developing countries who also lack adequate healthcare facilities39. Daily monitoring of BP is essential for these patients as hypertension is often asymptomatic. Due to the lack of monitoring, hypertension is one of the major causes of premature death across the world39. Traditionally, BP monitors are based on auscultative techniques with an inflatable cuff and on first and fifth Korotkoff sounds40. This measures systolic blood pressure (SBP), a number that represents the pressure in arteries when the heart muscle contracts, and diastolic blood pressure (DBP), a number that represents the pressure when the heart muscle relaxes40. Accurate BP measurement requires trained technicians, which adds to the challenge to meet the WHO target to reduce hypertension by 25% by 2025. However, HWDs can provide a suitable wearable for the POC setting to help achieve the aforementioned target. One such wearable is described by Luo et al. who has developed a cuff-less BP measuring device for real time, continuous measurement of blood pressure using tattoo-based HWD41. The HWD integrates a thin flexible piezoelectric sensor (FPS) with epidermal ECG sensor for the cuff-less measurement of BP, which is much more comfortable than its conventional counterpart. The patch uses beat-to-beat BP measurements from ECG along with a parametric model, which is very sensitive to minute changes in physiological signals in the epidermis. The epidermal signals and ECG signals were obtained using the piezoelectric patch along with SBP and DBP. Average BP values for conventional cuff-based BP monitor and cuff-less BP HWD were evaluated, and they were found to be comparable. The conventional cuff-based BP monitor showed SBP = 123.8 ± 5.7 mmHg and DBP = 86.8 ± 4.4 mmHg, while cuff-less BP HWD showed SBP = 130.3 ± 0.5 mmHg and DBP = 86.5 ± 0.5 mmHg. These results indicate that cuff-less BP wearable provides high correlation with a conventional BP monitor for both SBP and DBP values. Additionally, the patch utilizes only 3 nW of power, in comparison to photoplethysmogram (PPG) based devices that consumes tens of milliwatts of power, making it more efficient and optimal for home-based settings in low and middle-income countries

Other competitive skin-based HWDs including wearable vests, smart rings, and earphones

There are other skin-based biosensors, which are not textile or tattoo based. Various wrist bands, such as smartwatches, wearable vests, skin patches, and implantable HWDs, use different monitoring biomarkers. Schreiner et al. and Leonard et al. have monitored respiratory rate, an essential parameter for many respiratory and cardiovascular diseases by using alternative wearable technologies35,44. Schreiner et al. proposed a chest-based wearable to monitor respiratory rate using pulse oximetry[44]. Similarly, heart failure is another clinical syndrome, which requires continuous monitoring. A structural abnormality, which hinders heart from not pumping sufficient blood to fulfill the needs of the body, heart failure affects about 26 million people globally[45]. Heart failure requires real time, continuous monitoring, which increases the economic burden; HWDs can facilitate the daily monitoring of such patients. A number of HWDs have been reported that go beyond diagnosing or monitoring heart failure but can predict it days before it even occurs[31,44,46,47,48]. Hafid et al. proposed a wearable system to predict heart failure using multiple parameters, such as thoracic impedance, heart rate, ECG, and blood oxygen level[48]. All of these parameters are measured noninvasively using electronic circuitry, a schematic of which is shown in Fig. 4a. The most important parameter may be the thoracic impedance, which is the measure of the resistance to the flow of ions due to the retention of fluid in the thoracic region of the human body[49]. Days before heart failure symptoms such as shortness of breath are noted by the patient, fluid is retained in the lungs, which decreases thoracic impedance[48]. The wearable system tracks the thoracic impedance and other parameters including heart rate, ECG and level of oxygen in the blood. If the respective values exceed the safe threshold, the HWD generates an alert using wireless transmission over a cloud server to the wearer and to the medical provider. The clinician can then make necessary interventions. However, the prognosis module has inefficient power consumption taking it 8 h to charge and can only measure continuously for 5 h, which limits its utility as a HWD for continuous monitoring at all times[48]. Similarly, another HWD, Oura Ring monitors key physiological parameters to help the wearer have a restful sleep[50]. Oura Ring is a metallic ring, as shown in Fig. 4b, with miniaturized sensors to monitor physiological parameters, such as heart rate, body temperature, and breathing[51]. These parameters can be monitored for illnesses like cold, flu, and even the novel Coronavirus 2019 (SARS-CoV-2). Severe acute respiratory syndrome (SARS) outbroke in 2003 and the Middle East respiratory syndrome (MERS) in 2012; SARS-CoV-2 is the third and the most recent of coronaviruses[52,53]. SARS-CoV-2 has currently become a global pandemic with 66 million cases and 1.54 million deaths worldwide[54]. Oura Ring utilizes the aforementioned parameters to potentially detect symptoms of SARS-CoV-2 in home settings. The wearable ring detects common SARS-CoV-2 symptoms such as fever, cough, fatigue, and difficulty breathing with 90% accuracy[55]. Moreover, the ring has a battery life of 4–7 days, depending upon the usage, and takes only 20–80 min to recharge[56].



There are also HWDs for use in the oral cavity. Kim et al. have developed a mouthguard for the monitoring of saliva uric acid57. Similarly, Mannoor et al. have developed an oral cavity HWD for the detection of bacteria on tooth enamel58. The HWD is based on graphene because of its high strength ($42\,Nm^{-1}$) and Young's Modulus (~1 TPa)59. Antimicrobial peptides (AMPs) were probed on graphene for the detection of bacteria at a single cell level. Moreover, the resonant coil excludes the need of an external power source making it miniaturized and power efficient. Results have been reported for the Escherichia coli (E. coli) bacterium, a foodborne infection. E. coli is commonly found in the intestines of humans and warm blooded animals60. If food is contaminated with E. coli, it can cause severe diseases such as gastroenteritis (food poisoning)61. The graphene-based nanosensor is attached to the tooth and can remotely monitor respiration and bacteria from the saliva based upon the change in its resistance58. Odorranin-HP AMP has been probed for the detection of E. coli because of its strong activity towards this organism. As soon as E. coli binds with the AMP immobilized graphene, the resistance of graphene decreases and helps in detecting E. coli with a limit of detection of 1 bacterium $\mu L^{[-1}$ 58. Results are justified with fluorescent images for the presence of E. coli. Similar experiments were performed for the detection of helicobacter pylori (H. pylori), a gram-negative bacterium usually found in saliva, and stomach. H. pylori is one of the leading cause for over 90% of stomach cancers and duodenal ulcers62,63. The lower limit for the detection of H. pylori is ~100 H. pylori cells using tooth enamel HWD and shows linear relation with its logarithmic concentration.

Furthermore, neurological diseases can also be managed efficiently with continuous monitoring. EEG, EOG, and motion monitoring can be used to diagnose and keep track of severe neurological diseases, like epilepsy, Parkinson's disease (PD) and Alzheimer's disease (AD). HWDs like ocular wearables can be used for the indirect detection of neurological diseases using EOG[64]. Wearable sensors have been used for the monitoring of patients with PD[65,66]. PD is a neurological disease that involves muscular rigidity and marked by bradykinesia or slow movement[67]. It is the second most common degenerative disease after Alzheimer's, and it is estimated that 10 million people around the world are affected with PD[68,69]. Lima et al. have used body fall sensors for quantifying the probability of falling in PD patients in home-based settings. The study shows that the ratio of falling nearly doubles in PD patients in comparison to healthy individuals[70]. Similarly, Lonini et al. have also developed an intelligent system based on machine learning algorithms for the detection of PD symptoms like bradykinesia and tremor (involuntary movements)[71,72]. Different motion sensors like, accelerometers, gyrometers, electromyography, and inertial sensors, are used as shown in Fig. 4c[71]. For the detection of aforementioned symptoms, subjects performed different tasks like, typing and walking, over a course of time. Using machine learning algorithms based on statistical ensembles along with convolutional neural networks the clinician could detect bradykinesia and tremor. However, the study was conducted on a limited number of participants (19) and therefore was unable to infer generalized conclusions about the detection of dyskinesia (impaired voluntary movement), another significant symptom of PD[71,73]. Similarly, dementia is another neurological disease, which is characterized by memory loss and difficulty in solving problems. There are 50 million cases worldwide and every year there are 10 million new cases of dementia[74,75]. Alzheimer's disease is the most common form of dementia. Almost 60–70% of dementia patients are diagnosed with Alzheimer's disease[74]. Monitoring of significant moments can help to support the care of dementia patients and HWDs can be employed for this purpose. Kwan et al. proposed a wearable, based on intelligent assistive technology (IAT) where IAT is an adaptive and assistive technology, integrated with advanced environment techniques of artificial intelligence (AI)[76]. The wearable is tailored to an individual's physiological responses[77]. These physiological responses consist of heart rate, electrodermal activity-responsible for the emotional arousal and skin temperature. These signals are extracted using the autonomic nervous system (ANS) and using a triple point sensor (TPS), which can be worn on the fingertips using a Velcro strap. The IAT detects significant emotional events based upon their physiological response and provides feedback to dementia patients. Considering the importance of EEG in daily routine, portable, and flexible earphones have been developed by Lee et al. for the acquisition of EEG[78]. The earphones consist of three electrodes (Reference, Source and Ground) made up of a mixture of carbon nanotubes (CNTs), polydimethylsiloxane (PDMS) and silver nanowires (AgNW), as shown in Fig. 4d78. The earphones are incapsulated in a plastic frame containing electronics, for example, conductive elastomers, signal transducers, and metal strip with soft earbuds for the convenient recording of EEG along with listening music at the same time. The earphones successfully differentiated the state of drowsiness from the awake state using the three-electrode system and results were communicated to a smartphone using a Bluetooth circuit as shown in Fig. 4e. However, as the earphones measure the EEG in crosstalk with music, EEG signals have low signal to noise ratio (SNR) and therefore requires additional amplifiers with post signal processing techniques for signal enhancement

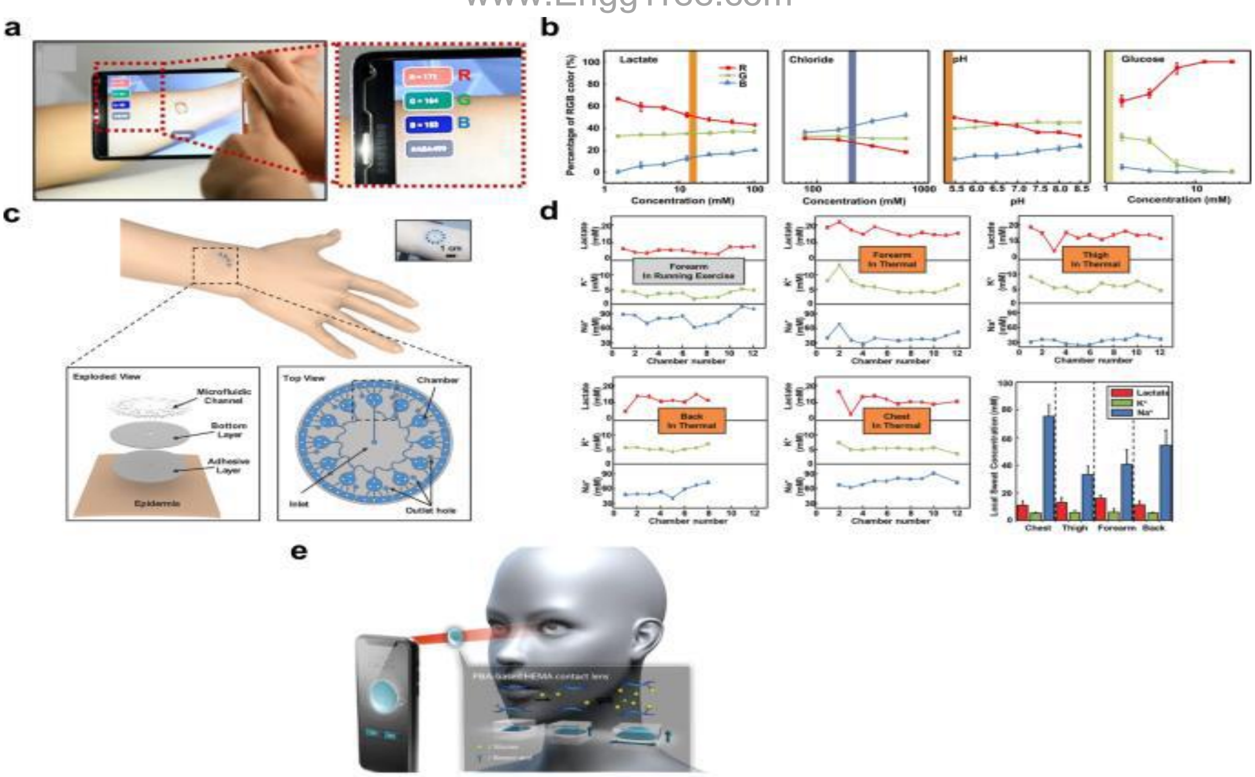
Biofluidic-based HWDs

Body secretions like sweat, saliva, tears, and urine contain important biomarkers that are essential for monitoring and diagnostic purposes. HWDs can be used directly or through their integration with other platforms, for example, microfluidic platforms can be integrated for the extraction of useful information from different biofluids79. Microfluidic platforms of different materials can be used in HWDs for example, polymer-based microfluidic devices, paper-based microfluidic devices, and micro-sized needles known as microneedles80,81. The following sections highlight recent efforts in biofluidic-based HWDs classified according to the type of biofluids.

Sweat-based HWDs

Epidermal biofluids like sweat is an important indicator of changes taking place inside human body and hence can serve as an important parameter for the chemical and biological sensing. Sweat is composed of different biomarkers, for example, metabolites (e.g., glucose, lactate, urea etc.), proteins, nucleotides, and electrolytes such as chlorine, sodium etc. which have important diagnostic implications32. Sweat is readily available for chemical sensing and is distributed across the skin with more than 100 glands cm^{-2} 32. Therefore, sweat can be used for the extraction of different chemical and biological parameters using HWDs to provide monitoring and diagnostics in POC settings82. Koh et al. have developed a flexible, soft, and stretchable device, based on microfluidics, for the colorimetric sensing of sweat biomarkers as shown in Fig. 5a83. This HWD is capable of quantifying electrolytes, like chloride and hydronium ions, that are essential for monitoring in cystic fibrosis, a chronic inherited disease that affects the respiratory and digestive systems, by forming a thick mucus that can block lungs and can obstruct the pancreas84. People with cystic fibrosis tend to have a shorter life span than healthy individuals85. The microfluidic HWD can also provide quantification of glucose and lactate levels, which are essential for diabetic patients along with the loss of pH, sweat rate, and total sweat loss. When the perspiration starts, the sweat is transferred into microfluidic reservoirs, where chromogenic reagents, like a mixture of glucose oxide and horseradish peroxide (HRP) for glucose level, respond to aforementioned biomarkers. Images of the change in color of the chemical analytes can be captured using a smartphone for the quantification of the concentration of chloride, hydronium ions, glucose, and lactate levels, as shown in Fig. 5b[83,86,87]. The HWD continuously measures the concentrations of aforementioned electrolytes in excellent agreement with the laboratory analysis of the sweat. They have demonstrated the flexible microfluidic HWD for human studies on the fitness cycle in a controlled environment and for long distance bicycle racing in outdoor settings, to justify the absence of the leakage of fluid and any discomfort due to the microfluidic HWD during real life arid conditions. The microfluidic device is fabricated using the soft lithographic technique with PDMS as a material[83]. Soft lithography offers high resolution, of the order of submicrometers, and due to its simplicity and flexibility it has been a widely used technique for fabricating biosensors[83,88,89]. However, it is a labor intensive and manually operated process[88].

Fig. 5: Biofluidic-based HWDs.



A similar soft microfluidic based HWD was developed by Choi et al. that uses microreservoirs for the detection of sodium, potassium, and lactate concentrations from sweat along with their temporal variations[90]. This wearable is a skin-like soft microfluidic platform that takes 1.8 µL volume of sweat from an area 0.03 cm^2 of skin in 0.8 min of sweating at 0.60 µL min^{-1} rate as shown in Fig. 5c. The Fig. 5d shows different concentrations of sodium, potassium, and lactate at different body locations and at different chambers of the wearable. Concentrations of these analytes show variations at different times and at different spatial positions on the body and propose optimal spatial positions for the attachment of the wearable for sweat analysis. Paper-based microfluidic devices, commonly known as microfluidic paper-based analytical devices (µPADs), are another promising technique for fabricating biofluidic-based HWDs. µPADs are biocompatible, low cost and offer high capillary action[91,92]. The multisensing patch for sweat monitoring by Anastasova et al. is a µPADs[91]. The patch consists of microneedles of 50 µm diameter and measures the concentration of lactate, pH using sodium ions and temperature using amperometric sensing. The HWD demonstrates sensitivity of 71.90 ± 0.8 mV $unit^{-1}$ and 56 ± 1 mV $unit^{-1}$ for pH and sodium ions respectively with a response time of around ~90 s. The wearable transmits data wirelessly for real-time monitoring of sweat in home-based settings. Moreover, the HWD ensures user compliance with overall thickness of as low as 180 µm with double sided adhesion to ensure firm adhesion of the patch to skin. Another notable µPADs is a Smart Wearable Sweat Patch (SWSP) sensor[92]. SWSP consists of paper substrates, fluorescent sensing probes and microchannels[92]. The microchannels are made up of cotton to absorb sweat from the skin and to transport them to sensing probes to quantify analytes. The HWD measures the concentrations of glucose, lactate, and chloride ions from the sweat by quantifying the intensity of the fluorescent from each analyte, using a smartphone[92]. The device offers excellent statistical results for the identification of aforementioned analytes from sweat with limit of detection of 7 µm, 0.4 mM, and 5 mM and correlate coefficients of 0.990, 0.988, and 0.994 for glucose, lactate, and chloride ions, respectively. The device is low cost (~$0.3) but cannot be used to measure concentrations of aforementioned analytes in real time[92].

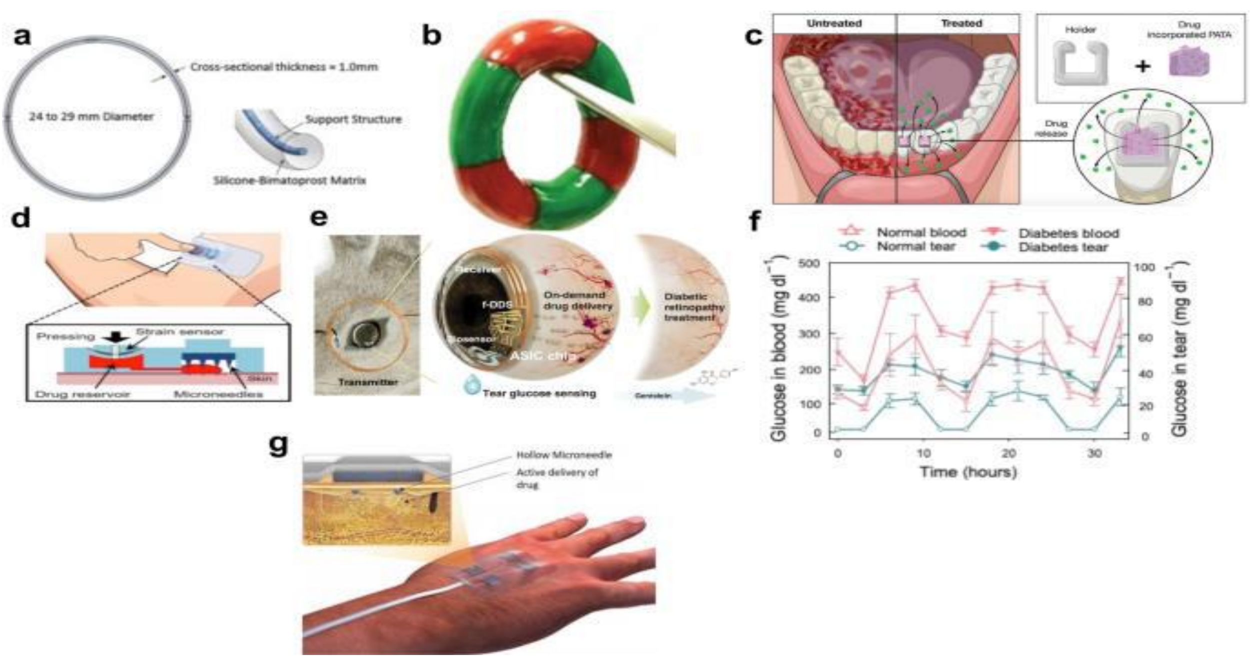
Tears-based HWDs

Tears are another important biofluid for the purpose of diagnosis and monitoring of different diseases. One such disease is diabetes and a number of HWDs have been developed for its diagnosis. Diabetes is a chronic metabolic diseases, with elevated levels of glucose or blood sugar, which can lead to serious damage to the heart, eye, kidneys, nerve, and blood vessels[93]. Globally, patients with diabetes have increased from 108 million to 463 million in 2020 and if necessary interventions are not taken then it is expected to increase, especially in middle and low-income countries[93,94]. Prevention of the complications of diabetes, as proposed by WHO, includes a healthy lifestyle with continuous monitoring of glucose levels. Traditional portable glucometers were developed to measure the concentration of glucose in blood. However, it involves finger sticks that is uncomfortable for the patient and can lead to infections related to blood pathogens. Urine can also be used for blood glucose measurement, however, it is difficult to handle and can impose limitations when used at home-based settings. HWDs provide a convenient and comfortable wearable for measuring the blood sugar and instead of blood and urine, tears can be used for the glucose measurement. Sen et al. measured the concentration of glucose in tear samples and related it to the concentration of glucose from blood samples, which justified the efficacy of tears for glucose measurement[95]. It was shown that levels of glucose were much higher in tears for a diabetic patient as compared to blood and urine samples in healthy individuals. Therefore, several other HWDs have been developed in the past for the measurement of glucose using tears. Notable examples are commercialized products, like Triggerfish that monitors the intraocular pressure of glaucoma patients and Google lens for the diagnosis of diabetes by Google in collaboration with Novartis[96,97]. Lin et al. have developed a smart contact lens for the diagnosis and continuous monitoring of diabetes using tears[98]. The lens is made up of phenylboronic acid (PBA), a non-enzyme, and Hydroxyethyl methacrylate (HEMA), a monomer. It utilizes the reversible covalent interaction of the PBA-HEMA-based contact lens with glucose for the monitoring of diabetes. The PBA-HEMA based contact lens swells in the presence of glucose and thereby increases its thickness. The contact lens thickness increases simultaneously with the increase in glucose level, at a linear rate, as shown in Fig. 5e[98]. The HWD has shown an excellent agreement in sensing the glucose[98]. It can be seen that the thickness of the lens increases linearly as the concentration of glucose increases from 0 to 20 mM within 15 min. The contact lens does not require embedded power circuits and additional photosensors; however, it only utilizes a smartphone for the detection of the change in thickness of lens. The smartphone captures the light reflected by the light-emitting diode on the smart lens. Images captured are then analyzed using an inbuilt software for the detection of glucose levels, as shown in Fig. 5e[98]. The noninvasive nature of the lens and integration with a smartphone, makes it a suitable sensor for monitoring diabetes at home settings. The lens is lightweight, flexible, and transparent to ensure the patient's vision without obstruction. Moreover, integration with smartphone ensures the portability of the HWD to enhance the patient's compliance with HWD[98].

As discussed, microfluidic based devices offer low cost and suitable platforms for biofluidic-based HWDs; however, they have inherent limitations[99,100]. These limitations include fluid leakage, contamination, and blockage due to debris and limited flexible materials make them inconvenient for the wearer99. However, with more flexible materials along with adequate flow rate optimization, these challenges can be overcome to fabricate low-cost microfluidics based HWDs.

Wearable drug delivery systems

As previously discussed, biodegradable and biocompatible materials are available due to advancements in materials. Such materials can be used for drug delivery systems, which can deliver drugs in a controlled manner101,102. One application of drug delivery, is bimatoprost, using an ocular ring made up of polypropylene for the treatment of glaucoma101. Glaucoma is an eye condition that damages the optic nerve and is the leading cause of blindness worldwide103. Bimatoprost is a medication generally used for the treatment of glaucoma, but fluctuations in its usage can minimize its efficacy. Therefore, the ocular ring, which is covered with silicone-bimatoprost matrix, slowly releases bimatoprost in a controlled manner, as shown in Fig. 6a. Similarly, Al-Shahbazi et al. have developed a self-healable and moldable gum for the personalized drug delivery104. The gum is made up of two materials, polyvinyl alcohol (PVA) and tannic acid (TA), collectively referred to as PATA, which belongs to a human friendly group of materials and makes it a bioactive material. The polymeric gum developed, as shown in the Fig. 6b, has high strength, stretchability, flexibility, toughness, and self-healing properties. The gum has been found to display antibacterial and anti-inflammatory properties and is flexible enough to be molded into any shape suitable for using it in wearables.



Similarly, Kim et al. have developed a touch actuated transdermal delivery (TATD) wearable for controlled drug delivery105. The TATD provides quantitative permeation control of the drug delivery in accordance with the force exerted by the touch on a wearable patch. The HWD consists of drug reservoirs that are refillable in nature, strain sensors for force detection, and microneedles for drug release as shown in Fig. 6d105. With mathematical models between the force exerted and the quantity of drug released, a controlled drug delivery has been observed, which enables a real-time drug regulation. Similarly, Di et al. have also developed a mechanical force based drug delivery system106. This HWD consists of a stretchable elastomer with drug reservoirs in the form of polymeric nanoparticles loaded with drugs. These nanoparticles can be loaded with antibacterial drugs or anti-inflammatory drugs. Likewise, the HWD produces encouraging results with anticancer therapy. The drug is released in a controlled manner by applying tensile strain on the elastomer and the rate of release of drug is per Poisson's ratio. The HWD is a skin mountable device and can be administered by the motion of muscles or joints, tendons or by external force using hands.

Moreover, T. Ly et al. have utilized the Bluetooth technology for the controlled release of insulin107. The Bluetooth enabled insulin pump is tubeless in nature and can hold up to 200 units of U-100 insulin. It consists of cannula insertion and automated priming along with a personalized diabetes manager, portable for the remote control of insulin delivery. In another report, Keum et al. have developed a smart contact lens for the detection of glucose levels from tears and for delivering drug for diabetic retinopathy therapy97. The contact lens is 14 mm in diameter, 200 μm in thickness with 8.0 mm radius curvature is based upon an ultrathin, biocompatible polymer and contains miniaturized electrical circuits along with a microcontroller chip for the continuous monitoring of glucose level from a tear. The contact lens as shown in the Fig. 6e, consists of an electrochemical biosensor, a drug delivery system, a resonant inductive coupling to copper for wireless transfer of power from an external transmitter coil, an integrated microcontroller chip and a radio frequency (RF) system for communication. The biosensor contains three electrodes: Reference Electrode (RE), Working Electrode (WE), and Counter Electrode (CE) for the detection of glucose. Results in Fig. 6f show a comparison of glucose levels in blood and tears between healthy and diabetic individuals and it can be seen that at all times the difference in the level of glucose in both diabetic and healthy individuals, for both tears and blood, are high enough to diagnose diabetes from tears. Moreover, the contact lens has an integrated drug delivery system that allows an on-demand, controlled delivery of an antidiabetic drug. The delivery of the drug is controlled by on/off control of voltage. Drug delivery is electrically controlled using a gold (Au) membrane. Drug reservoirs are covered with Au anode electrode, a thin layer of Au membrane, which dissolves in phosphate buffer solution (PBS) in 40 *s*. When a voltage of 1.8 V is applied, the drug is delivered, and results are then shared by the wireless transmission using an RF module, which makes it a suitable HWD at POC. Furthermore, Derakhshandeh et al. have proposed a smart bandage for the treatment of chronic wounds108. The bandage consists of microneedles, as shown in the Fig. 6g, for the delivery of pharmacological agents and vascular endothelial growth factors (VEGF) on the targeted wound. The bandage delivers the drug in a controlled and wireless manner. Moreover, the microneedles were fabricated using a 3D printer on polymeric substrate and microchannels were fabricated using PDMS. The smart bandage was experimented by delivering VEGF to chronic dermal wounds of diabetic mice and showed an increased closure of the wound and hair growth in comparison to topical delivery of therapeutics108.

As shown, structures like nanotubes, nanopores and nanoparticles can be used in wearables to deliver drugs; however, their size and structure is specific to a drug therefore, they are only limited in administrating a specific drug. Moreover, wearable drug delivery systems based on aforementioned carriers cannot be administered in patients of all age groups as nanotubes and nanoparticles have been found to be difficult to administer to infants and older adults109. Ocular wearable drug delivery systems like the smart contact lens for diabetes treatment, have low bioavailability and have limited volume of drug (~30 µL) to administer due to the limited precorneal surface area, which decreases the efficacy of the drug110. Furthermore, more advancements in drugs are required in developing wearable drug delivery systems with accurate targeted delivery of drug, as many drugs are not been able to cross the blood brain barrier (BBB)111. Moreover, the limited biodiversity of drugs limits the effectiveness of the wearable drug delivery systems112.

Commercially available HWDs

In recent times, a number of HWDs have been commercially available in the market. Biocompatibility, accuracy, comfortability, and uninterrupted battery performance are essential factors for successful commercializarion of HWDs. This section highlights some of the most recent commercially available HWDs for the continuous monitoring of different biomarkers. The major focus of the commercially available HWDs has been on the motion trackers113. Human movement assessment plays an important role for the biomechanics and gait analysis and therefore can be used for diagnosing neurological and psychological diseases. Moreover, motion trackers can keep a track of step counts, which helps in maintaining a record of calories burned. Therefore, a number of such devices are available in the market for this purpose and the most widely used are Misfit Shine, Fitbit Inspire 2, Withings and Apple Smart

Watch. Misfit, an American based consumer electronics company, has introduced the Misfit Shine that keeps record of steps count, sleep hours, distance covered, and calories burnt. It has a nonchargeable battery that lasts for 6 months and needs replacement every 6 months. Fitbit, an American based fitness company, has introduced a number of fitness wearables[114]. Fitbit Inspire 2 is one of the recent additions for the real-time and continuous monitoring of vital signs like heart rate, activity, and sleep monitoring. It allows 10 days of charging capacity for continuous monitoring[113]. Moreover, Withings Pulse, is a smart fitness tracker by Withings, a French electronics consumer company[115]. Withings Pulse allows 24/7 monitoring of heart rate and also keeps a track of sleep hours. Its battery lasts for 20 days and is water resistant to up to 50 m[113]. In contrast to aforementioned fitness wearables, Apple watch comes with features like irregular rhythm notifications, ECG application, and blood oxygen application. Irregular rhythms in heart rate may be suggestive of atrial fibrillation, where atrial fibrillation can lead to stroke, heart failure, and other heart related complications[116]. However, Apple watch cannot constantly look for atrial fibrillation and cannot detect all instances of atrial fibrillation. It only sends notification if irregular rhythms are detected repeatedly[116]. The authenticity of the Apple watch for the detection of atrial fibrillation was confirmed by a study conducted on 419,297 participants at Stanford[117]. In this study participants were monitored with Apple watch and on the reciept of a notification for irregular rhythm, were monitored for 90 days for atrial fibrillation using ECG patch. The study diagnosed 34% participants with atrial fibrillation using the early detection by Apple watch and 84% of irregular rhythm notifications were found in accordance with the atrial fibrillation[117]. Moreover, the ECG application keeps a track of the irregular rhythm using a built-in electrical heart sensor and provides notification of atrial fibrillation or normal sinus rhythm. Moreover, it also records the level of oxygen in blood, which helps in the continuous monitoring of hypoxemia, and conditions like asthma, and emphysema[116,118]. However, the blood oxygen application is available only in selected regions[116]. Table 1 summarizes the aforementioned health and fitness trackers based on human motion.

As discussed, ECG is a vital sign that plays an important role in diagnosing and preventing cardiovascular diseases. A number of smart wearables have been introduced in the market for ECG monitoring of ECG. ePatch is an FDA approved, commercially available ECG patch. ePatch is a 3 lead ECG sensor that consists of a sensor housed inside an adhesive patch[119]. The patch can store ECG recordings continuously for 72 hours and results can be analyzed on computer software transmitted using a USB cable[119]. However, the recent advancements in ECG monitors are in leadless acquisition of ECG and LifeTouch sensor is a one such HWD[119,120]. It offers continuous measurement of respiration rate, heart rate, and ECG for verification purposes. Moreover, Savvy is another leadless HWD commercially available HWD for the real-time monitoring of ECG[121]. It is POC in nature and consists of a sensor that attaches with the skin with two adhesive electrodes[119]. These two electrodes are used for measuring ECG during measurement mode and for charging the sensor in charging mode. The battery life of Savvy is up to 20 days[119]. The HWD is housed inside a biocompatible and flexible plastic covering for enduring user's movement. The ECG from the Savvy can be visualized in real time on a mobile application (MobECG), which also allows a summary of the ECG that can be stored or shared with the patient's medical provider[119]. Similarly, ZIO XT and SEEQ are two other important commercially available HWDs for the monitoring of ECG[119]. However, unlike Savvy, ZIO XT, and SEEQ cannot be reused and do not have rechargeable batteries. ZIO XT does not report results in real time; however, it stores data for 14 days after which the ECG patch is returned to the company for data analysis. Similarly, SEEQ, does not report data in real time but instead data is transmitted with the company's cloud and the ECG reporting time depends on the processing time by the company. Table 2 shows some of the commercially available HWDs for ECG monitoring.

Considering the growing market of patients with diabetes, a number of HWDs have been introduced for the continuous monitoring of glucose. Such devices are generally known as CGM, continuous glucose monitor[122]. Notable CGMs are Dexcom G6, Abbott's FreeStyle Libre System, and Medtronic Guardian Connect[123,124,125]. Dexcom G6 consists of a sensor, transmitter, and a receiver[122,123]. With an automatic applicator, the sensor wire is inserted just under the skin of wearer where sensor measures the glucose readings. However, Dexcom G6 takes 2 hours of calibration after insertion. Readings from the G6 CGM are transmitted to the receiver where they can be visualized by the user in real time on the Dexcom mobile application. However, the application is only compatible with selected mobile devices. Dexcom G6 is one of the few CGMs commercially available along with Abbott's FreeStyle Libre System to measure accurate glucose readings if the patient is taking acetaminophen. Acetaminophen is an analgesic medicine that interferes with CGS and causes inaccurate glucose readings[122,126]. Abbott's FreeStyle Libre comes with a sensor and a reader where sensor is a small minimally invasive device to measure glucose from blood and sends data to the reader where the glucose levels can be visualized. Abbott's CGM placement can only work accurately if placed at the back of the upper arm and unlike Dexcom G6 it takes 12 h to calibrate[122,124]. Similarly, Medtronic Guardian connect is another CGM which like aforementioned CGMs consists of a sensor but does not contain a reader. The sensor takes 12 h for calibration and can send data directly to a mobile application instead of a reader device. An important feature about Guardian Connect is its Sugar IQ[122]. Sugar IQ helps user in understanding the glucose patterns based on their daily glucose trends along with insulin intake. It is the only CGM to send predictive notifications 10–60 min beforehand. It can be seen that these CGMs are costly in comparison to the widely used invasive blood-based glucose meters and it is recommended to follow blood-based glucose meters in case CGMs readings do not match with the symptoms.

Medical Monitoring:

In medicine, monitoring is the observation of a disease, condition or one or several medical parameters over time.

It can be performed by continuously measuring certain parameters by using a medical monitor (for example, by continuously measuring vital signs by a bedside monitor), and/or by repeatedly performing medical tests (such as blood glucose monitoring with a glucose meter in people with diabetes mellitus).

Transmitting data from a monitor to a distant monitoring station is known as telemetry or biotelemetry.

Classification by target parameter

Monitoring can be classified by the target of interest, including:

- **Cardiac monitoring**, which generally refers to continuous electrocardiography with assessment of the patient's condition relative to their cardiac rhythm. A small monitor worn by an ambulatory patient for this purpose is known as a Holter monitor. Cardiac monitoring can also involve cardiac output monitoring via an invasive Swan-Ganz catheter.
- **Hemodynamic monitoring**, which monitors the blood pressure and blood flow within the circulatory system. Blood pressure can be measured either invasively through an inserted blood pressure transducer assembly, or noninvasively with an inflatable blood pressure cuff.
- **Respiratory monitoring**, such as:
  - Pulse oximetry which involves measurement of the saturated percentage of oxygen in the blood, referred to as SpO2, and measured by an infrared finger cuff
  - Capnography, which involves CO_2 measurements, referred to as EtCO2 or end-tidal carbon dioxide concentration. The respiratory rate monitored as such is called AWRR or airway respiratory rate)
  - Respiratory rate monitoring through a thoracic transducer belt, an ECG channel or via capnography
- **Neurological monitoring**, such as of intracranial pressure. Also, there are special patient monitors which incorporate the monitoring of brain waves (electroencephalography), gas anesthetic concentrations, bispectral index (BIS), etc. They are usually incorporated into anesthesia machines. In neurosurgery intensive care units, brain EEG monitors have a larger multichannel capability and can monitor other physiological events, as well.
- **Blood glucose monitoring**

- **Childbirth monitoring**
- **Body temperature monitoring** through an adhesive pad containing a thermoelectric transducer.
- Cancer therapy monitoring through circulating tumor cells[1]

Vital parameters

Monitoring of vital parameters can include several of the ones mentioned above, and most commonly include at least blood pressure and heart rate, and preferably also pulse oximetry and respiratory rate. Multimodal monitors that simultaneously measure and display the relevant vital parameters are commonly integrated into the bedside monitors in critical care units, and the anesthetic machines in operating rooms. These allow for continuous monitoring of a patient, with medical staff being continuously informed of the changes in general condition of a patient. Some monitors can even warn of pending fatal cardiac conditions before visible signs are noticeable to clinical staff, such as atrial fibrillation or premature ventricular contraction (PVC)

Medical monitoring with chronic diseases,hospital patient and elderly patients

A medical monitor or physiological monitor is a medical device used for monitoring. It can consist of one or more sensors, processing components, display devices (which are sometimes in themselves called "monitors"), as well as communication links for displaying or recording the results elsewhere through a monitoring network

Components

Sensor

Sensors of medical monitors include biosensors and mechanical sensors. For example, photodiode is used in pulse oximetry, Pressure sensor used in Non Invasive bood pressure measurement.

Translating component

The translating component of medical monitors is responsible for converting the signals from the sensors to a format that can be shown on the display device or transferred to an external display or recording device.

Display device

Physiological data are displayed continuously on a CRT, LED or LCD screen as data channels along the time axis, They may be accompanied by numerical readouts of computed parameters on the original data, such as maximum, minimum and average values, pulse and respiratory frequencies, and so on.

Besides the tracings of physiological parameters along time (X axis), digital medical displays have automated numeric readouts of the peak and/or average parameters displayed on the screen.

Modern medical display devices commonly use digital signal processing (DSP), which has the advantages of miniaturization, portability, and multi-parameter displays that can track many different vital signs at once.

Old analog patient displays, in contrast, were based on oscilloscopes, and had one channel only, usually reserved for electrocardiographic monitoring (ECG). Therefore, medical monitors tended to be highly specialized. One monitor would track a patient's blood pressure, while another would measure pulse oximetry, another the ECG. Later analog models had a second or third channel displayed on the same screen, usually to monitor respiration movements and blood pressure. These machines were widely used and saved many lives, but they had several restrictions, including sensitivity to electrical interference, base level fluctuations and absence of numeric readouts and alarms.

Communication links

Several models of multi-parameter monitors are networkable, i.e., they can send their output to a central ICU monitoring station, where a single staff member can observe and respond to several bedside monitors simultaneously. Ambulatory telemetry can also be achieved by portable, battery-operated models which are carried by the patient and which transmit their data via a wireless data connection.

Digital monitoring has created the possibility, which is being fully developed, of integrating the physiological data from the patient monitoring networks into the emerging hospital electronic health record and digital charting systems, using appropriate health care standards which have been developed for this purpose by organizations such as IEEE and HL7. This newer method of charting patient data reduces the likelihood of human documentation error and will eventually reduce overall paper consumption. In addition, automated ECG interpretation incorporates diagnostic codes automatically into the charts. Medical monitor's embedded software can take care of the data coding according to these standards and send messages to the medical records application, which decodes them and incorporates the data into the adequate fields.

Long-distance connectivity can avail for telemedicine, which involves provision of clinical health care at a distance.

Other components

A medical monitor can also have the function to produce an alarm (such as using audible signals) to alert the staff when certain criteria are set, such as when some parameter exceeds of falls the level limits.

Mobile appliances

An entirely new scope is opened with mobile carried monitors, even such in sub-skin carriage. This class of monitors delivers information gathered in body-area networking (BAN) to e.g. smart phones and implemented autonomous agents.

Interpretation of monitored parameters

Monitoring of clinical parameters is primarily intended to detect changes (or absence of changes) in the clinical status of an individual. For example, the parameter of oxygen saturation is usually monitored to detect changes in respiratory capability of an individual.

Change in status versus test variability

When monitoring a clinical parameters, differences between test results (or values of a continuously monitored parameter after a time interval) can reflect either (or both) an actual change in the status of the condition or a test-retest variability of the test method.

In practice, the possibility that a difference is due to test-retest variability can almost certainly be excluded if the difference is larger than a predefined "critical difference". This "critical difference" (CD) is calculated as:

$$CD = K \times \sqrt{CV_a^2 + CV_i^2}$$

, where

- K, is a factor dependent on the preferred probability level. Usually, it is set at 2.77, which reflects a 95% prediction interval, in which case there is less than 5% probability that a test result would become higher or lower than the critical difference by test-retest variability in the absence of other factors.
- CV_a is the analytical variation
- CV_i is the intra-individual variability

For example, if a patient has a hemoglobin level of 100 g/L, the analytical variation (CV_a) is 1.8% and the intra-individual variability CV_i is 2.2%, then the critical difference is 8.1 g/L. Thus, for changes of less than 8 g/L since a previous test, the possibility that the change is completely caused by test-retest variability may need to be considered in addition to considering effects of, for example, diseases or treatments.

Examples and applications

The development cycle in medicine is extremely long, up to 20 years, because of the need for U.S. Food and Drug Administration (FDA) approvals, therefore many of monitoring medicine solutions are not available today in conventional medicine.

Blood glucose monitoring

In vivo blood glucose monitoring devices can transmit data to a computer that can assist with daily life suggestions for lifestyle or nutrition and with the physician can make suggestions for further study in people who are at risk and help prevent diabetes mellitus type 2 .

Stress monitoring

Bio sensors may provide warnings when stress levels signs are rising before human can notice it and provide alerts and suggestions. Deep neural network models using photoplethysmography imaging (PPGI) data from mobile cameras can assess stress levels with a high degree of accuracy (86%).

Serotonin biosensor

Future serotonin biosensors may assist with mood disorders and depression.

Continuous blood test based nutrition

In the field of evidence-based nutrition, a lab-on-a-chip implant that can run 24/7 blood tests may provide a continuous results and a computer can provide nutrition suggestions or alerts.

Psychiatrist-on-a-chip

In clinical brain sciences drug delivery and in vivo Bio-MEMS based biosensors may assist with preventing and early treatment of mental disorders

Epilepsy monitoring

In epilepsy, next generations of long-term video-EEG monitoring may predict epileptic seizure and prevent them with changes of daily life activity like sleep, stress, nutrition and mood management.

Toxicity monitoring

Smart biosensors may detect toxic materials such mercury and lead and provide alerts.

Remote patient monitoring for chronic disease management

Remote patient monitoring for chronic disease management is an effective solution for patients with chronic disease. According to the Journal of Medical Internet Research, telemonitoring is a valid alternative to usual care, reducing mortality and improving disease self-management in patients who report satisfaction and adherence. Because chronic diseases are the leading cause of death and disability nationwide.

A remote patient monitoring program uses technology to transmit data from a patient's home to the clinician for review and intervention. The patient is provided with an RPM medical device that allows them to measure specific vital signs from the comfort of their homes. Clinicians receive that information in real-time and can access it whenever they want.

By implementing RPM, clinicians can significantly reduce healthcare costs and promote better allocation of resources for improving chronic disease management. Here are 3 reasons why remote patient monitoring can transform chronic disease management:

1). Promotes Early Identification of Chronic Disease

Most patients only see their doctor when their condition becomes problematic, or it's time for their next appointment. But what if something goes wrong in-between visits? If the patient doesn't know what to look for, complications will continue to develop.

Remote patient monitoring for chronic disease management promotes better care in-between visits. By keeping track of patients' vital signs regularly, clinicians will better understand their patients' conditions and be alerted immediately if medical attention is necessary. The RPM device sends real-time readings to the remote patient monitoring platform for the clinician to access immediately.

Clinicians will automatically be alerted for quick action when a patient's reading is above or below the set threshold. RPM promotes the early identification of chronic diseases. Furthermore, the earlier complications are identified, the sooner patients can get treatment and minimize the progression of chronic disease.

2). RPM Prompts Adjustments to Treatment Plans

Another way remote patient monitoring helps improve chronic care management is through timely adjustments to treatment plans. Through the RPM portal, clinicians can check how their patients are doing whenever they want. As a result, they can see how their patients respond to medications and adjust prescriptions as necessary.

Without RPM, many patients go months with an ineffective or unoptimized treatment plan. Remote patient monitoring in chronic disease management can help patients find a treatment plan that works for them while reducing chronic disease progression.

3). Remote Patient Monitoring Increases Patient Engagement

We all know how to live healthier lives, but it's challenging to consistently apply those practices to your everyday life. Remote patient monitoring is about expanding healthcare outside the conventional hospital setting and into the patient's daily lifestyle. It helps patients feel supported in managing their health. Because they know that their care providers regularly check their health data, patients are more likely to engage in healthier lifestyle choices and adhere to their management plans.

Patients play an essential role in remote patient monitoring for chronic disease management. They're responsible for taking their vital sign measurement at least 16 days a month. While this provides clinicians with valuable insight, it also helps the patients engage and better understand their condition. Regular measurements allow patients to recognize a normal range for their bodies. They can see if their health is improving or worsening over time and how changes to their lifestyle choices affect their readings.

The better the patient understands their condition and engages, the more likely they are to practice healthier behaviors, keep an eye out for complications, and communicate with their clinician.

Using Remote Patient Monitoring for Chronic Disease Management

Using RPM, chronic disease patients are much less likely to be admitted into hospitals, use emergency departments, and require complicated procedures. This significantly reduces healthcare costs.

Remote patient monitoring improves the management of various chronic diseases, including:

- Stroke
- Heart disease
- Diabetes
- Chronic heart failure
- Kidney disease
- Chronic obstructive pulmonary disorder

Depending on the patient's condition, different vital signs must be monitored. For example, individuals at risk of stroke or kidney disease will benefit from using a blood pressure monitor, while those with diabetes will need to keep an eye on their blood glucose levels.

1. Remote Patient Monitoring Blood Pressure Monitors

Blood pressure monitors are RPM devices that help individuals with hypertension ensure their blood pressure stays within a healthy range. Hypertension is a major risk factor for many chronic diseases like heart failure and stroke. Clinicians can identify complications early and provide prompt treatment by effectively keeping track of a patient's blood pressure between visits. A blood pressure monitor will display systolic blood pressure, diastolic blood pressure, and heart rate.

The top number is the systolic blood pressure measurement. This indicates the amount of pressure in the arteries when your heart is beating. According to the American Heart Association, any reading above 130 mmHg is considered hypertensive. The second number is the diastolic blood pressure measurement. This is the amount of pressure in between heartbeats. Any reading above 80 mmHg is considered hypertensive.

How to Use

Most top RPM digital blood pressure monitor devices are very user-friendly, making them ideal for remote use. Tenovi's BPM works right out of the box, eliminating the hassle of device setup.

For the best results, encourage your patients to:

- Relax for about 5 minutes before
- Sit comfortably and avoid crossing their legs
- Keep their arm rested on top of a table or armrest
- Empty their bladder
- Measure around the same time every day
- Avoid eating, exercise, caffeine, and alcohol for at least half an hour before
- Take the measurement twice, about a minute apart, to ensure accuracy, and then average the numbers

To use a blood pressure monitor, wrap the cuff around the upper arm (ensure the cuff is on bare skin, not clothing) and press the middle button. The cuff will start inflating, take the blood pressure measurement, and then automatically send the data to the RPM platform.

2. Remote Patient Monitoring Scales

Weight gain of 3 or more pounds in a single day can indicate congestive heart failure. Congestive heart failure occurs when the heart cannot efficiently pump blood throughout the body. At-risk individuals typically experience shortness of breath, tightness in the chest, and dizziness. While it is entirely normal for weight to fluctuate, weight gain in at-risk patients can serve as a precursor to more serious conditions. By monitoring a patient's body weight, clinicians can quickly identify signs of heart failure and focus on early management.

How to use

All the patient has to do is step on the scale to turn it on and wait for the reading. The information will automatically send to the clinician, and the RPM device will turn off on its own.

For the most accurate results, advise patients to:

- Weigh themselves at the same time every day (preferably the morning)
- Avoid eating or drinking right before the weigh-in
- Wear the same clothing for each weigh-in or weigh without clothes on

Regular bodyweight measurements can help healthcare providers evaluate the effectiveness of a patient's management plan and, if necessary, quickly make adjustments to better control fluid retention.

3. Remote Patient Monitoring Blood Glucose Meters

Diabetes is the 7th leading cause of death in the United States and the 4th most common cause of physician visits. If poorly managed, diabetes can cause kidney failure, heart attack, stroke, and blindness. By utilizing a blood glucose meter to remotely monitor blood sugar levels, clinicians can better assess whether a patient's treatment management plan is working and make adjustments to optimize care.

How to Use

Tenovi's Blood Glucose Meter is a top-line FDA-cleared RPM device. It includes a cell-enabled meter, lancet, and custom test strips that make measuring blood sugar very simple.

Gather all the materials and perform the following steps with clean hands:

1. Insert the test strip into the meter
2. Wipe your finger with an alcohol pad and let dry
3. Gently prick the side of the finger with the lancet
4. Place a drop of blood onto the test strip and wait for the reading

Most patients should aim for blood glucose levels between 80-130mg/dL before a meal or below 180 mg/dL in about 2 hours after a meal. If patients' blood glucose levels are too high, they may need to adjust their diet or medications.

4. Remote Patient Monitoring Peak Flow Monitors

Learning to use a peak flow meter for asthma care offers several advantages. One of the most significant benefits is the ability for physicians and patients to evaluate and pinpoint the causes of asthma flare-ups and determine the most effective treatment options for the specific lung condition. Remote monitoring of peak flow enables healthcare providers to identify if medication or treatment adjustments are required promptly.

How to Use

To begin using the Tenovi peak flow meter, relax for a few minutes before closely following these **3 easy steps.**

1. Turn it on. Press the power button for 3 seconds and wait for the Gateway to start flashing yellow.
2. Take a reading: Take a deep breath, then exhale quickly into the peak flow meter.
3. Data transfer: PEF and FEV1 data will automatically transfer to the Tenovi cloud or clinician portal.

PEF and FEV1 data will automatically transfer to the Tenovi cloud or clinician portal.

5. Remote Patient Monitoring Pulse Oximeters

Another remote patient monitoring device in healthcare that is useful for assessing lung disease is a pulse oximeter. A pulse oximeter measures heart rate and oxygen saturation in a patient’s red blood cells. Patients with conditions that affect blood oxygen levels, like heart attack, heart failure, COPD, anemia, lung cancer, asthma, and pneumonia, may benefit from regular pulse oximetry.

How to Use

Pulse oximetry is typically tested at the fingertips to measure how well oxygen is being sent to areas of your body furthest from the heart. This RPM is simple to use.

To use the Tenovi Pulse Oximeter, all the patient has to do is:

- Turn on the device. Place a finger inside the slit, and wait for the reading. A pulse oximeter uses light to measure the amount of oxygen in your blood at a given point.
- Pulse oximeters will show blood oxygen saturation level (SpO2) and pulse rate.
- Patients should seek medical attention if their reading indicates:
  -

- SpO2 under 90% (hypoxia)
- Low pulse rate
- High pulse rate

Most remote top remote patient monitoring devices will notify the healthcare provider immediately as well.

6. Remote Patient Monitoring Digital Thermometers

RPM cellular thermometers are used for body temperature monitoring for early infection detection where timely treatment is crucial. This is especially true in the case of sepsis. RPM digital thermometers are remote patient monitoring devices used in cancer care, to monitor COVID-19 and postoperative patients. Regular temperature monitoring reveals symptom patterns and serves as a warning signal when abnormalities arise.

How to Use

Patients should follow these 3 easy steps to use the Tenovi RPM thermometer.

1. Turn it on: Press the blue power button and wait for the Gateway to start flashing yellow.
2. Take a reading: Point the thermometer to the center of the forehead (1-3 cm away) and press the blue button.
3. Data transfer: The temperature measurement data will automatically transfer to the clinician portal.

Neural Recording:

In neuroscience, **single-unit recordings** (also, single-neuron recordings) provide a method of measuring the electro-physiological responses of a single neuron using a microelectrode system. When a neuron generates an action potential, the signal propagates down the neuron as a current which flows in and out of the cell through excitable membrane regions in the soma and axon. A microelectrode is inserted into the brain, where it can record the rate of change in voltage with respect to time. These microelectrodes must be fine-tipped, impedance matching; they are primarily glass micro-pipettes, metal microelectrodes made of platinum, tungsten, iridium or even iridium oxide. Microelectrodes can be carefully placed close to the cell membrane, allowing the ability to record extracellularly.

Single-unit recordings are widely used in cognitive science, where it permits the analysis of human cognition and cortical mapping. This information can then be applied to brain–machine interface (BMI) technologies for brain control of external devices.

There are many techniques available to record brain activity—including electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI)—but these do not allow for single-neuron resolution. Neurons are the basic functional units in the brain; they transmit information through the body using electrical signals called action potentials. Currently, single-unit recordings provide the most precise recordings from a single neuron. A single unit is defined as a single, firing neuron whose spike potentials are distinctly isolated by a recording microelectrode.

The ability to record signals from neurons is centered around the electric current flow through the neuron. As an action potential propagates through the cell, the electric current flows in and out of the soma and axons at excitable membrane regions. This current creates a measurable, changing voltage potential within (and outside) the cell. This allows for two basic types of single-unit recordings. Intracellular single-unit recordings occur within the neuron and measure the voltage change (with respect to time) across the membrane during action potentials. This outputs as a trace with information on membrane resting potential, postsynaptic potentials and spikes through the soma (or axon). Alternatively, when the microelectrode is close to the cell surface extracellular recordings measure the voltage change (with respect to time) outside the cell, giving only spike information. Different types of microelectrodes can be used for single-unit recordings; they are typically high-impedance, fine-tipped and conductive. Fine tips allow for easy penetration without extensive damage to the cell, but they also correlate with high impedance. Additionally, electrical and/or ionic conductivity allow for recordings from both non-polarizable and polarizable electrodes. The two primary classes of electrodes are glass micropipettes and metal electrodes. Electrolyte-filled glass micropipettes are mainly used for intracellular single-unit recordings; metal electrodes (commonly made of stainless steel, platinum, tungsten or iridium) and used for both types of recordings.

Single-unit recordings have provided tools to explore the brain and apply this knowledge to current technologies. Cognitive scientists have used single-unit recordings in the brains of animals and humans to study behaviors and functions. Electrodes can also be inserted into the brain of epileptic patients to determine the position of epileptic foci. More recently, single-unit recordings have been used in brain machine interfaces (BMI). BMIs record brain signals and decode an intended response, which then controls the movement of an external device (such as a computer cursor or prosthetic limb).

Electrophysiology

The basis of single-unit recordings relies on the ability to record electrical signals from neurons.

Neuronal potentials and electrodes

When a microelectrode is inserted into an aqueous ionic solution, there is a tendency for cations and anions to react with the electrode creating an electrode-electrolyte interface. The forming of this layer has been termed the Helmholtz layer. A charge distribution occurs across the electrode, which creates a potential which can be measured against a reference electrode. The method of neuronal potential recording is dependent on the type of electrode used. Non-polarizable electrodes are reversible (ions in the solution are charged and discharged). This creates a current flowing through the electrode, allowing for voltage measurement through the electrode with respect to time. Typically, non-polarizable electrodes are glass micropipettes filled with an ionic solution or metal. Alternatively, ideal polarized electrodes do not have the transformation of ions; these are typically metal electrodes. Instead, the ions and electrons at the surface of the metal become polarized with respect to the potential of the solution. The charges orient at the interface to create an electric double layer; the metal then acts like a capacitor. The change in capacitance with respect to time can be measured and converted to voltage using a bridge circuit. Using this technique, when neurons fire an action potential they create changes in potential fields that can be recorded using microelectrodes. Single unit recordings from the cortical regions of rodent models have been shown to dependent on the depth at which the microelectrode sites were located.

Intracellularly, the electrodes directly record the firing of action, resting and postsynaptic potentials. When a neuron fires, current flows in and out through excitable regions in the axons and cell body of the neuron. This creates potential fields around the neuron. An electrode near a neuron can detect these extracellular potential fields, creating a spike.

Experimental setup

The basic equipment needed to record single units is microelectrodes, amplifiers, micromanipulators and recording devices. The type of microelectrode used will depend on the application. The high resistance of these electrodes creates a problem during signal amplification. If it were connected to a conventional amplifier with low input resistance, there would be a large potential drop across the microelectrode and the amplifier would only measure a small portion of the true potential. To solve this problem, a cathode follower amplifier must be used as an impedance matching device to collect the voltage and feed it to a conventional amplifier. To record from a single neuron, micromanipulators must be used to precisely insert an electrode into the brain. This is especially important for intracellular single-unit recording.

Finally, the signals must be exported to a recording device. After amplification, signals are filtered with various techniques. They can be recorded by an oscilloscope and camera, but more modern techniques convert the signal with an analog-to-digital converter and output to a computer to be saved. Data-processing techniques can allow for separation and analysis of single units.

Types of microelectrodes

There are two main types of microelectrodes used for single-unit recordings: glass micropipettes and metal electrodes. Both are high-impedance electrodes, but glass micropipettes are highly resistive and metal electrodes have frequency-dependent impedance. Glass micropipettes are ideal for resting- and action-potential measurement, while metal electrodes are best used for extracellular spike measurements. Each type has different properties and limitations, which can be beneficial in specific applications.

Glass micropipettes

Glass micropipettes are filled with an ionic solution to make them conductive; a silver-silver chloride (Ag-AgCl) electrode is dipped into the filling solution as an electrical terminal. Ideally, the ionic solutions should have ions similar to ionic species around the electrode; the concentration inside the electrode and surrounding fluid should be the same. Additionally, the diffusive characteristics of the different ions within the electrode should be similar. The ion must also be able to "provide current carrying capacity adequate for the needs of the experiment". And importantly, it must not cause biological changes in the cell it is recording from. Ag-AgCl electrodes are primarily used with a potassium chloride (KCl) solution. With Ag-AgCl electrodes, ions react with it to produce electrical gradients at the interface, creating a voltage change with respect to time. Electrically, glass microelectrode tips have high resistance and high capacitance. They have a tip size of approximately 0.5-1.5 µm with a resistance of about 10-50 MΩ. The small tips make it easy to penetrate the cell membrane with minimal damage for intracellular recordings. Micropipettes are ideal for measurement of resting membrane potentials and with some adjustments can record action potentials. There are some issues to consider when using glass micropipettes. To offset high resistance in glass micropipettes, a cathode follower must be used as the first-stage amplifier. Additionally, high capacitance develops across the glass and conducting solution which can attenuate high-frequency responses. There is also electrical interference inherent in these electrodes and amplifiers.

Metal electrodes

Metal electrodes are made of various types of metals, typically silicon, platinum, and tungsten. They "resemble a leaky electrolytic capacitor, having a very high low-frequency impedance and low high-frequency impedance". They are more suitable for measurement of extracellular action potentials, although glass micropipettes can also be used. Metal electrodes are beneficial in some cases because they have high signal-to-noise due to lower impedance for the frequency range of spike signals. They also have better mechanical stiffness for puncturing through brain tissue. Lastly, they are more easily fabricated into different tip shapes and sizes at large quantities. Platinum electrodes are platinum black plated and insulated with glass. "They normally give stable recordings, a high signal-to-noise ratio, good isolation, and they are quite rugged in the usual tip sizes". The only limitation is that the tips are very fine and fragile. Silicon electrodes are alloy electrodes doped with silicon and an insulating glass cover layer. Silicon technology provides better mechanical stiffness and is a good supporting carrier to allow for multiple recording sites on a single electrode. Tungsten electrodes are very rugged and provide very stable recordings. This allows manufacturing of tungsten electrodes with very small tips to isolate high-frequencies. Tungsten, however, is very noisy at low frequencies. In mammalian nervous system where there are fast signals, noise can be removed with a high-pass filter. Slow signals are lost if filtered so tungsten is not a good choice for recording these signals.

Applications

Single-unit recordings have allowed the ability to monitor single-neuron activity. This has allowed researchers to discover the role of different parts of the brain in function and behavior. More recently, recording from single neurons can be used to engineer "mind-controlled" devices.

Cognitive science

Noninvasive tools to study the CNS have been developed to provide structural and functional information, but they do not provide very high resolution. To offset this problem invasive recording methods have been used. Single unit recording methods give high spatial and temporal resolution to allow for information assessing the relationship between brain structure, function, and behavior. By looking at brain activity at the neuron level, researchers can link brain activity to behavior and create neuronal maps describing flow of information through the brain. For example, Boraud et al. report the use of single unit recordings to determine the structural organization of the basal ganglia in patients with Parkinson's disease. Evoked potentials provide a method to couple behavior to brain function. By stimulating different responses, one can visualize what portion of the brain is activated. This method has been used to explore cognitive functions such as perception, memory, language, emotions, and motor control.

Brain–machine interfaces

Brain–machine interfaces (BMIs) have been developed within the last 20 years. By recording single unit potentials, these devices can decode signals through a computer and output this signal for control of an external device such as a computer cursor or prosthetic limb. BMIs have the potential to restore function in patients with paralysis or neurological disease. This technology has potential to reach a wide variety of patients but is not yet available clinically due to lack of reliability in recording signals over time.

Gait analysis:

Human gait depends on a complex interplay of major parts of the nervous, musculoskeletal and cardiorespiratory systems.

- The individual gait pattern is influenced by age, personality, mood and sociocultural factors.
- The preferred walking speed in older adults is a sensitive marker of general health and survival.
- Safe walking requires intact cognition and executive control.
- Gait disorders lead to a loss of personal freedom, falls and injuries and result in a marked reduction in the quality of life.

Definitions

- **Gait** - the manner or style of walking.

- **GaitAnalysis** -
  An analysis of each component of the three phases of ambulation is an es sential part of the diagnosis of various neurologic disorders and the asses sment of patient progress during rehabilitation and recovery from the effe cts of neurologic disease, a musculoskeletal injury or disease process, or amputation of a lower limb.

- **Gait speed**
  - The time it takes to walk a specified distance, usually 6 m or less. Slower speeds correlate with an increased risk of mortality in geriatric patients.[2]
  - Normal walking speed primarily involves the lower extremities, with the arms and trunk providing stability and balance.
  - Faster speeds - body depends on the upper extremities and trunk for propulsion, balance and stability with the lower limb joints producing greater ranges of motion.

- **Gait cycle** is a repetitive pattern involving steps and strides

- **Step** is one single step

- **Stride** is a whole gait cycle.

- **Step time -** time between heel strike of one leg and heel strike of the contralateral leg.

- **Step width -** the mediolateral space between the two feet.

The demarcation between walking and running occurs when periods of double support during the stance phase of the gait cycle (both feet are simultaneously in contact with the ground) give way to two periods of double float at the beginning and the end of the swing phase of gait (neither foot is touching the ground)

The Gait Cycle

The sequences for walking that occur may be summarized as follows:

1. Registration and activation of the gait command within the central nervous system.
2. Transmission of the gait systems to the peripheral nervous system.
3. Contraction of muscles.
4. Generation of several forces.
5. Regulation of joint forces and moments across synovial joints and skeletal segments.
6. Generation of ground reaction forces.

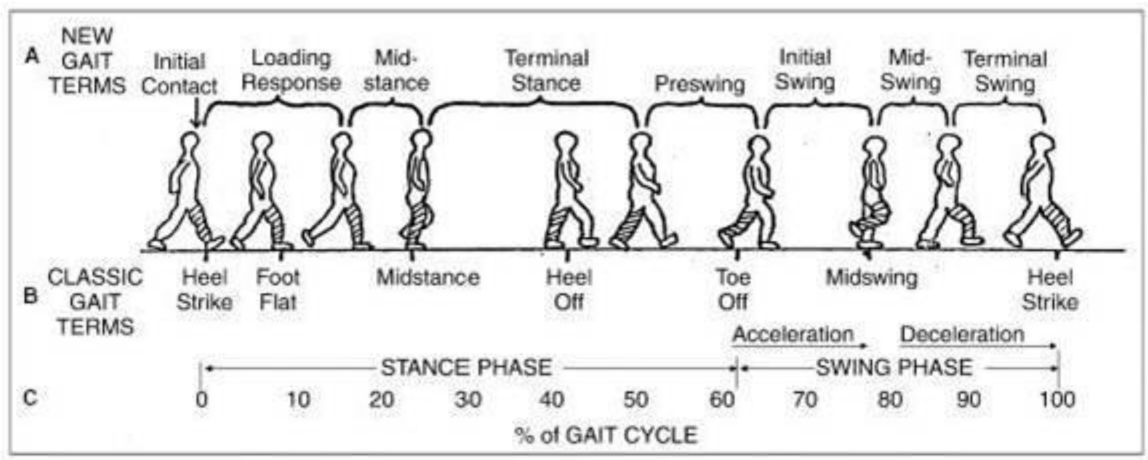
The normal forward step consists of two phases: stance phase; swing phase,

- The Stance phase occupies 60% of the gait cycle, during which one leg and foot are bearing most or all of the bodyweight
- The Swing phase occupies only 40% of it[4], during which the foot is not touching the walking surface and the bodyweight is borne by the other leg and foot.
- In a complete two-step cycle both feet are in contact with the floor at the same time for about 25 per cent of the time. This part of the cycle is called the double-support phase.Gait cycle phases: the stance phase and the swing phase and involves a combination of open and close chain activities.

Phases of the Gait Cycle (8 phase model):

1. Initial Contact
2. Loading Response
3. Midstance

4. Terminal Stance
5. Pre swing
6. Initial Swing
7. Mid Swing
8. Late Swing.



Heel Strike (or initial contact) -

Short period, begins the moment the foot touches the ground and is the first phase of double support.

Involves:

- 30° flexion of the hip: full extension in the knee: ankle moves from dorsiflexion to a neutral (supinated 5°) position then into plantar flexion.
- After this, knee flexion (5°) begins and increases, just as the plantar flexion of the heel increased.
- Plantar flexion is allowed by eccentric contraction of the tibialis anterior
- Extension of the knee is caused by a contraction of the quadriceps
- Flexion is caused by a contraction of the hamstrings,
- Flexion of the hip is caused by the contraction of the rectus femoris.

Foot Flat (or loading response phase)

- Body absorbs the impact of the foot by rolling in pronation.
- Hip moves slowly into extension, caused by a contraction of the adductor magnus and gluteus maximus muscles.
- Knee flexes to 15° to 20° of flexion.

- Ankle plantarflexion increases to 10-15°.

Midstance

- Hip moves from 10° of flexion to extension by contraction of the gluteus medius muscle.
- Knee reaches maximal flexion and then begins to extend.
- Ankle becomes supinated and dorsiflexed (5°), which is caused by some contraction of the triceps surae muscles.
- During this phase, the body is supported by one single leg.
- At this moment the body begins to move from force absorption at impact to force propulsion forward.

Heel Off

- Begins when the heel leaves the floor.
- Bodyweight is divided over the metatarsal heads.
- 10-13° of hip hyperextension, which then goes into flexion.
- Knee becomes flexed (0-5°)
- Ankle supinates and plantar flexes.

Toe Off/pre-swing

- Hip becomes less extended.
- Knee is flexed 35-40°
- Plantar flexion of the ankle increases to 20°.
- The toes leave the ground.

Early Swing

- Hip extends to 10° and then flexes due to contraction of the iliopsoas muscle 20° with lateral rotation.
- Knee flexes to 40-60°
- Ankle goes from 20° of plantar flexion to dorsiflexion, to end in a neutral position.

Mid Swing

- Hip flexes to 30° (by contraction of the adductors) and the ankle becomes dorsiflexed due to a contraction of the tibialis anterior muscle.
- Knee flexes 60° but then extends approximately 30° due to the contraction of the sartorius muscle. (caused by the quadriceps muscles).

Late Swing/declaration

- Hip flexion of 25-30°
- Locked extension of the knee
- Neutral position of the ankle.

Gait Cycle - Anatomical Considerations

- Pelvic region - anterior-posterior displacement, which alternates from left to right. Facilitates anterior movement of the leg (each side anterior-posterior displacement of 4-5°).
- Frontal plane - varus movement in the: foot between heel-strike and foot-flat and between heel-off and toe-off; hip, in lateral movements (when the abductors are too weak, aTrendelenburg gaitcan be observed). Valgus movement between foot-flat and heel off in the feet.
- A disorder in any segment of the body can have consequences on the individual's gait pattern.

Gait Disorders

Gait disorders - altered gait pattern due to deformities, weakness or other impairments eg loss of motor control or pain . Prevalence increases with age and the number of people affected will substantially increase in the coming decades due to the expected demographic changes.

- Lead to a loss of personal freedom and to reduced quality of life.
- Precursors of falls and therefore of potentially severe injuries in elderly person

Gait Descriptions

- Antalgic gait a limp adopted so as to avoid pain on weight-bearing structures, characterized by a very short stance phase.
- Ataxic gait an unsteady, uncoordinated walk, with a wide base and the feet thrown out, coming down first on the heel and then on the toes with a

double tap.This gait is associated with cerebellar disturbances and can be seen in patients with longstanding alcohol dependency. People with 'Sensory'Disturbances may present with a sensory ataxic gait. Presentation is a wide base of support, high steps, and slapping of feet on the floor in order to gain some sensory feedback. They may also need to rely on observation of foot placement and will often look at the floor during mobility due to a lack of proprioception.

- Equine gait a walk accomplished mainly by flexing the hip joint; seen in crossed leg palsy.
- Parkinsonian Gait (seen in parkinson's disease and other neurologic conditions that affect the basal ganglia). Rigidity of joints results in reduced arm swing for balance. A stooped posture and flexed knees are a common presentation. Bradykinesia causes small steps that are shuffling in presentation. There may be occurrences of freezing or short rapid bursts of steps known as 'festination' and turning can be difficult.
- Trendelenburg gait, the gait characteristic of paralysis of the gluteus medius muscle, marked by a listing of the trunk toward the affected side at each step.
- Hemiplegic gait a gait involving flexion of the hip because of foot-drop and circumduction of the leg.

- Steppage gait the gait in foot-drop in which the advancing leg is lifted high in order that the toes may clear the ground. It is due to paralysis of the anterior tibial and fibular muscles, and is seen in lesions of the lower motor neuron, such as multiple neuritis, lesions of the anterior motor horn cells, and lesions of the cauda equina.
- Stuttering gait a walking disorder characterized by hesitancy that resembles stuttering; seen in some hysterical or schizophrenic patients as well as in patients with neurologic damage.
- Tabetic gait an ataxic gait in which the feet slap the ground; in daylight the patient can avoid some unsteadiness by watching his feet.
- Waddling gait exaggerated alternation of lateral trunk movements with an exaggerated elevation of the hip, suggesting the gait of a duck; characteristic of muscular dystrophy.
- Diplegic Gait (Spastic gait). Spasticity is normally associated with both lower limbs. Contractures of the adductor muscles can create a 'scissor' type gait with a narrowed base of support. Spasticity in the lower half of the legs results in plantarflexed ankles presenting in 'tiptoe' walking and often toe dragging. Excessive hip and knee flexion is required to overcome this

- Neuropathic Gaits. High stepping gait to gain floor clearance often due to foot drop

Causes of gait disorders

They include neurological, orthopedic, medical and psychiatric conditions and multifactorial etiology becomes more common with advancing age, making classification and management more complex. Any gait disorder should be thoroughly investigated in order to improve patient mobility and independence, to prevent falls and to detect the underlying causes as early as possible. Thorough clinical observation of gait, careful history taking focussed on gait and falls and physical, neurological and orthopedic examinations are basic steps in the categorization of gait disorders and serve as a guide for ancillary investigations and therapeutic interventions.

Musculoskeletal Causes

Pathological gait patterns resulting from musculoskeletal are often caused by soft tissue imbalance, joint alignment or bony abnormalities affect the gait pattern as a result.

Hip Pathology

- **Arthritis** is a common cause of pathological gait. An arthritic hip has reduced range of movement during swing phase which causes an exaggeration of movement in the opposite limb ‘hip hiking[15][20].
- **Excessive Hip Flexion** can significantly alter gait pattern most commonly due to; • Hip flexion contractures • IT band contractures, • Hip flexor spasticity, • Compensation for excessive knee flexion and ankle DF, • Hip pain • Compensation for excess ankle plantar flexion in mid swing. The deviation of stance phase will occur mainly on the affected side. The result is forward tilt of the trunk and increased demand on the hip extensors or increased lordosis of the spine with anterior pelvic tilt. A person with reduced spinal mobility will adopt a forward flexion position in order to alter their centre of gravity permanently during gait.
- **Hip Abductor Weakness**. The abductor muscles stabilise the pelvis to allow the opposite leg to lift during the swing phase. Weak abductor muscles will cause the hip to drop towards the side of the leg swinging forward. This is also known as Trendelenburg gait[18]

- **Hip Adductor Contracture.** During swing phase the leg crosses midline due to the weak adductor muscles, this is known as 'scissor gait'[18]
- **Weak Hip Extensors** will cause a person to take a smaller step to lessen the hip flexion required for initial contact, resulting in a lesser force of contraction required from the extensors. Overall gait will be slower to allow time for limb stabilisation. Compensation is increased posterior trunk positioning to maintain alignment of the pelvis in relation to the trunk[18]
- **Hip Flexor Weakness** results in a smaller step length due to the weakness of the muscle to create the forward motion. Gait will likely be slower and may result in decreased floor clearance of the toes and create a drag

Knee Pathologies

- **Weak Quadriceps**. The quadriceps role is to eccentrically control the knee during flexion through the stance phase. If these muscles are weak the hip extensors will compensate by bringing the limb back into a more extended position, reducing the amount of flexion at the knee during stance phase. Alternatively heel strike will occur earlier increasing the ankle of plantar flexion at the ankle, preventing the forward movement of the tibia, to help stabilise the knee joint.
- **Severe Quadriceps Weakness** or instability at the knee joint will present in hyperextension during the initial contact to stance phase. The knee joint will 'snap' back into hyperextension as the bodyweight moves forwards over the limb
- **Knee Flexion Contraction** will cause a limping type gait pattern. The knee is restricted in extension, meaning heel strike is limited and step length reduced. To compensate the person is likely to 'toe walk' during stance phase. Knee flexion contractures of more than 30 degrees will be obvious during normal paced gait. Contractures less then this will be more evident with increased speeds.

Ankle Pathologies

- **Ankle Dorsiflexion Weakness** results in a lack of heel strike and decreased floor clearance. This leads to an increased step height and prolonged swing phase.
- **Calf Tightening or Contractures** due to a period of immobilisation or trauma will cause reduced heel strike due to restricted dorsiflexion. The compensated gait result will be 'toe walking' on stance phase, reduced step

length, and excessive knee and hip flexion during swing phase to ensure floor clearance.

Foot Pathologies

- **Hallux Rigidus** results in a lack of dorsiflexion of the great toe. The MPJ uses the windlass effect to raise the arch and stiffen the foot during dorsiflexion of the hallux. This stiffness increases the efficiency of the propulsion portion of the gait cycle. To be efficient in creating stiffness, the hallux should be able to dorsiflex at least 65 degrees.

Leg length discrepancy

Leg length discrepancy can be as a result of an asymmetrical pelvic, tibia, or femur length or for other reasons such as scoliosis or contractures. The gait pattern will present as a pelvic dip to the shortened side during the stance phase with possible ‘toe walking’ on that limb. The opposite leg is likely to increase its knee and hip flexion to reduce its length.

Antalgic Gait

- Antalgic gait due to **knee pain** presents with decreased weight bearing on the affected side. The knee remains in flexion and possible toe weight-bearing occurs during stance phase[15]
- Antalgic gait due to **ankle pain** may present with a reduced stride length and decreased weight bearing on the affected limb. If the problem is pain in the forefoot then toe-off will be avoided and heel weight-bearing used. If the pain is more in the heel, toe weight-bearing is more likely. General ankle pain may result in weight-bearing on the lateral border[15][18].
- Antalgic gait due to **hip pain** results in a reduced stance phase on that side. The trunk is propelled quickly forwards with the opposite shoulder lifted in an attempt to even the weight distribution over the limb and reduce weight-bearing. Swing phase is also reduced

Gait Analysis

- The analysis of the gait cycle is important in the biomechanical mobility examination to gain information about lower limb dysfunction in dynamic movement and loading.
- When analyzing the gait cycle, it is best to examine one joint at a time.

- Objective and subjective methods can be used.

Subjective

- Different gait patterns - We might ask the individual to walk normally, on insides and outsides of feet, in a straight line, running (all the time looking to compare sides and understanding of "normal").
- Ask/observe the type of footwear the patient uses (a systematic review suggests shoes affect velocity, step time, and step length in younger children's gait[32]).

An objective approach is quantitative and parameters like time, distance, and muscle activity will be measured. Other objective methods to assess the gait cycle that use equipment include:[33][31]

- Video Analysis and Treadmill
- Electronic and Computerized Apparatus
- Electronic Pedometers
- Satellite Positioning System

Qualitative methods to assess and analyse gait include:

- Rancho Los Amigos Hospital Rating List
- Ten Meter Walking Test
- 6 Minute Walk Test
- 2 Minute Walk Test
- Dynamic Gait Index
- Emory Functional Ambulation Profile
- Timed Up and Go Test. This test is statistically associated with falling in men, but not in women.
- Functional Ambulation Categories
- Tinetti-Test

Sports medicine
Sports medicine is a branch of healthcare. It deals with the diagnosis, treatment and prevention of Injuries related to participation in sports and/or exercise.

Scope of sports medicine
In the field of physical education and sports, the fields of various sub-disciplines of sports medicine are utilize. Without the knowledge of scope of sports medicine, it is

difficult to carry a sportsperson performance at apex level. There are following scope of sports medicine:

a) Sports and first aid

b) Human anatomy and physiology

c) Female and sports

d) Study of optimal load for different age groups

e) Scientific promotion of games and sports

f) Sports injury rehabilitation

g) Fitness for games and sports.

Aims of sports medicine

a) To provide information to athletes about injuries.

b) To provide knowledge about the causes of injuries.

c) To provide means or treatment for sports injuries and for rehabilitation of injuries.

d) To provide knowledge about the preventive measures of sports injuries.

e) To aware the sports person & athlete about the different kinds of injury in respect of different games.

f) To concentrate on the causes of injury

Concept of Sports medicine

- Bio-mechanics related to sports
- Effect of attitude on endurance performance
- Psychological aspect performance

- Nutrition & metabolism in relation to competition & performance
- Recommendations of FISM(the International Federation of Sports Medicine at world level)
- Cardio-respiratory function in relation to performance
- Exercise in Cardio-Vascular disease prevention & rehabilitation

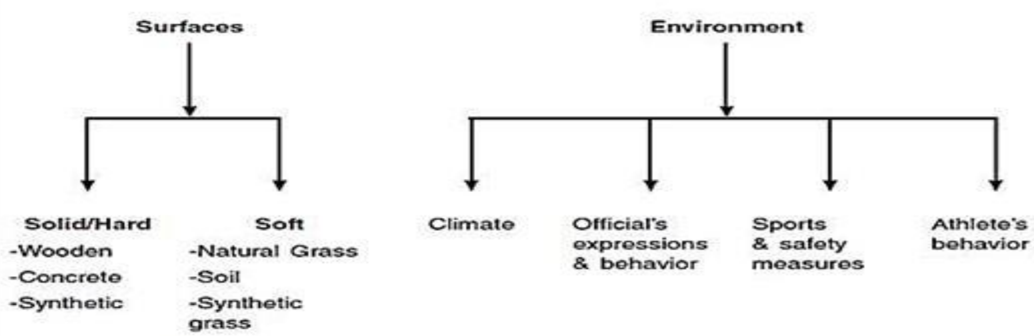
Prevention of Sports Injuries :

- Pre-participation of medical check up
- Proper conditioning
- Avoid dehydration
- Protective Sports equipment & Gears
- Adequate & effectively maintained facilities
- Sports person's psychological conditions & environment
- Adequate rehabilitation/Injury management
- Proper use of right techniques
- Balanced diet & adequate rest
- Use of proper skills
- Warming up & cooling down

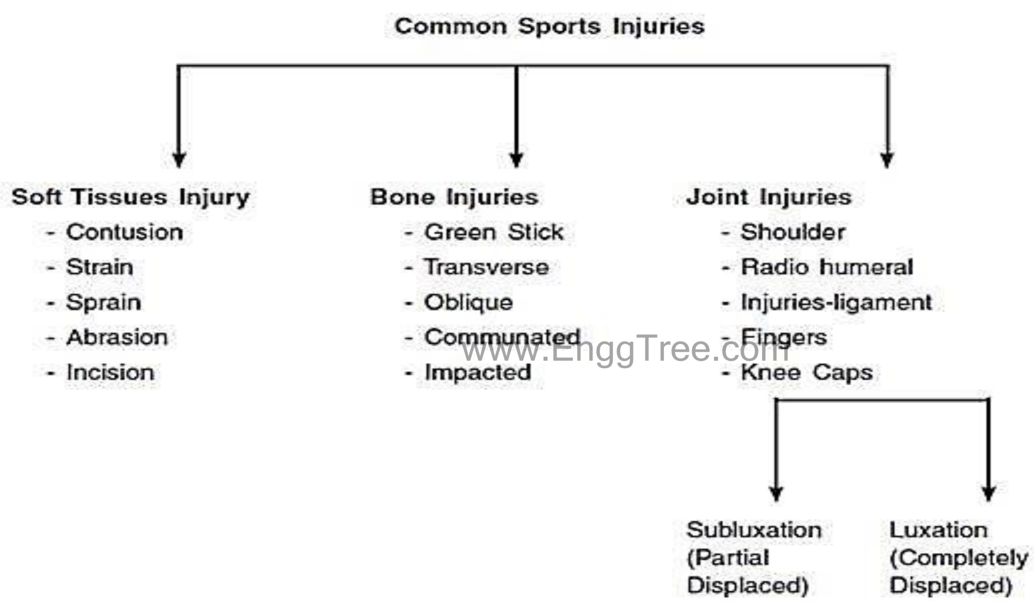
Impact of surface on athletes

There are two types of surfaces used in any indoor or outdoor games. These are natural and artificial surfaces. Natural surfaces is the surfaces that are prepared through proper combination of natural elements like soil and grass. On the other hand, artificial surfaces are more like carpets which are made from artificial components like rubber, synthetic fiber etc. These surfaces impact performance of athletes differently. In many contact games like football, cricket, running and Kabaddi natural surfaces are preferred because they provide more familiarity, grip and avoid severe injuries. On the other hand, artificial surfaces provide more opportunities for practice because their use need not be stopped for maintenance. Also, with innovation in technology, artificial surfaces are becoming more user friendly. Risks of injuries are reducing in artificial surfaces also nowadays.

Impact of Surfaces and Environment on Athletes



SportsInjury

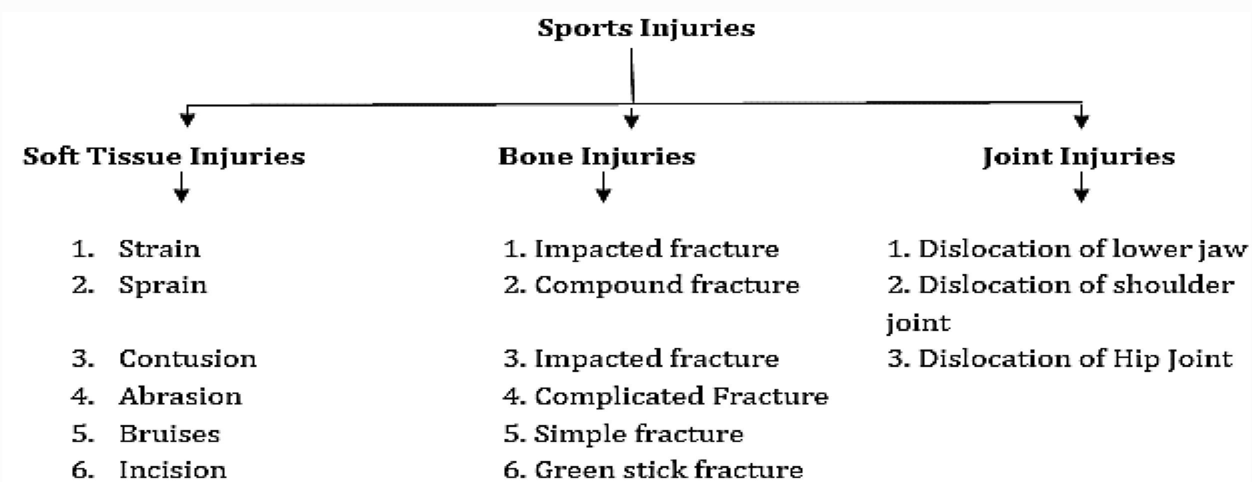


Intrinsic Risk Factor	Extrinsic Risk Factor	
Physical Preparation Lack of proper training Fitness label Improper warming up & cooling Down Over use of muscles Muscles imbalance **Individual variables:-** a. Gender and Age b. Nutrition c. Fatigue d. Posture deformities	**Coaching** a. Poor techniques b. Lack of knowledge • Skill • Rules & Regulations • Surrounding • Environment • Equipment • Facilities	**Environmental** Factors a. Climate b. Playing Surface c. Preventive surfaces d. Medical facilities

Climatic conditions affect the performance

Environmental conditions, such as excessively high or low temperatures, have the potential to have a negative impact on an athlete ‘s well-being. An athlete ‘ability to use a number of thermoregulation techniques helps in regulating body temperature.

Sports injuries are those which are common in the field of games and sports. During training, competition or practice, any player can be injured. Perhaps there will not be any player who has not been injured during his career.



Strain is also a muscle injury. A strain is caused by twisting or pulling a muscle or tendon. A sudden strain is caused by a recent injury, lifting heavy objects or rods in wrong way and over stressing the muscles. Chronic strain is usually caused by moving the muscles and tendons in repetition.

Sprain is a ligament injury. It may occur due to overstretching or tearing of ligaments. Many things can cause sprain. Falling, twisting, or getting hit can force a point out of its normal position. This can cause ligaments around the joints to tear. Generally, Sprain occurs at wrist and ankle joints.

Prevention of sprain and strain

a) Conditioning should be performed during the preparatory period.

b) Sports equipments must be of good quality.

c) Play courts should be smooth and clean.

d) The scientific knowledge of games should be must for preventing srain.

e) Player should discontinue during the condition of fatigue.

f) Good officiating is essential for preventing such injury.

g) Players should be careful and alert during practice, training and competition.

A**brasion** is a key injury generally occurs due to friction with certain equipments or a fall over the area where bone is very close to skin. It may be caused by a fall on hard surface. As someone falls or slides on the ground, friction causes layers of the skin to rub off.

Bruises are not clearly seen as upper skin remains undamaged and inner blood vessels are damaged and collect beneath the skin. A fresh bruise may actually be reddish and after a few hours it turns to blue or dark purple.

A **laceration** is a wound that is produced by tearing of soft body tissue.

Contusion is a muscle injury. A direct hit with or without any sports equipment can be the main cause of contusion. Contusion can also be due to minor accidents to the skin such as falling, bumping into something or being hit or kicked. In contusion blood vessels in muscles are broken and sometimes bleeding may occur in the muscles which may cause bruise. Stiffness and swelling are common features at the site of contusion.

Management:

- Cold compression should be used immediately. Ice or cold water should not be used for more than 40 minutes persistently.
- The cold compression should be performed 5 to 6 times daily.
- If there is more swelling at the sight of contusion, the anti-inflammatory medicine should be given.
- If the swelling persists, consult the Doctor immediately.
- For the purpose of rehabilitation, flexibility exercises should be performed.

Causes of sports injuries

To effectively diagnose, rehabilitate and ultimately prevent subsequent injuries, a sport therapist

- Anatomical Factors: These are related to make up of the body. Leg length differences a n d cause injury to ankle, hip and back.

- Age related causes as the body ages, it changes. It is less able to produce force, recovers slower and soft tissues lose the ability to stretch. Therefore, it is more prone to injury.
- Training related cause's Excessive repetitive loading of the tissues is needed for successive adaptation. However, without suitable recovery, tissues never have the chance to adapt and can fail.
- Equipment selection factors These are related to the suitability of equipment. An instance is incorrect footwear, which will not protect the foot and ankle adequately. It also will not distribute forces effectively. Thus it increases the risk of injury.
- Impact and contact causes Impact or contact can be with objects, surfaces or other people. These injuries are common in contact sports like football, rugby, hockey etc. Also they are common in more dangerous sports like motor racing, boxing and skiing.

Joint injuries & its types

A hard blow to a joint, a fall, a forceful throwing, lifting or hitting may cause dislocation. Infact it is dislocation of surface of bones.

Types of dislocation

a) Dislocation of lower jaw: it occurs when the chin strikes to any other object. It may occur if mouth is opened excessively.

b) Dislocation of shoulder joint: dislocation of shoulder joint may occur due to a sudden jerk or a fall over a hard surface. The end of the humerous comes out from the socket. In face when your shoulder dislocates, a strong force, such as a sudden blow to your shoulder. Pulls the bones in your shoulder out of place.

c) Dislocation of hip joint: By putting maximum strength spontaneously may cause dislocation of hip joint. The end of the femur is displaced from the socket.

d) Dislocation of wrist: A sportsperson who participates in a sports or game in which he may fall, runs the risk of getting a dislocated wrist. A miscalculated landing can also cause a dislocated wrist. Infact, it generally occurs to the person who use his hand to break his fall.

Preventions:
a) Adequate warming-up should be performed prior to any activity.

b) Proper conditioning should be performed during preparatory period.

c) Stretching exercises should be include in warm-up

d) Players should be careful during training and competition.

e) Protective equipment should be used

f) Players should have good anticipation and concentration power

g) Always obey the rules and regulations.

h) Perform regular exercise around your shoulder, hip, and wrist joints etc.

i) Avoid falls or hits as far as possible.

Causes of fracture
Fracture usually occurs due to a high impact on the bone. It can be causes by overuse. The most common causes of fracture are:

a) In such sports event where there is a high impact.

b) Traumatic, forceful and unnatural movements.

c) Prolonged long distance walking or running.

d) Sudden fall on hard surface.

e) Direct strike or hit with any solid sports equipment.

f) Osteoporosis.

Management of Fracture

a) Elevate the extremity and rest while bone heals itself.

b) Apply ice to the affected part for 24 to 48 hrs

c) If pain persists, give painkillers.

d) If there is any need of immobilization to the affected part, use a slint

e) After removal of swelling begin to put partial weight on the affected area.

f) Crutches or walking stick may be used in the beginning. After two weeks start putting normal weight.

g) For 6 to 8 weeks, avoid the activity that caused stress fracture. Then start doing the activity slowly.