PIE Tech

POLLACHI INSTITUTE OF ENGINEERING AND TECHNOLOGY

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

REGULATION 2021

III YEAR / V SEM

CBM 370 - WEARABLE DEVICES

CBM370 WEARABLE DEVICES

OBJECTIVES:

The student should be made to:

- To know the hardware requirement of wearable systems
- To understand the communication and security aspects in the wearable devices
- To know the applications of wearable devices in the field of medicine

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.

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.

UNIT III WIRELESS HEALTH SYSTEMS

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

UNIT IV SMART TEXTILE

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.

UNIT V APPLICATIONS OF WEARABLE SYSTEM

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

CBM370 **WEARABLE DEVICES**

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TOTAL PERIODS: 45

TEXT BOOKS

1. Annalisa Bonfiglo and Danilo De Rossi, Wearable Monitoring Systems, Springer, 2011
2. Zhang and Yuan-Ting, Wearable Medical Sensors and Systems,Springer, 2013
3. Edward Sazonov and Micheal R Neuman, Wearable Sensors: Fundamentals, Implementation and Applications, Elsevier, 2014
4. Mehmet R. Yuce and JamilY.Khan, Wireless Body Area Networks Technology, Implementation applications,Pan Stanford Publishing Pte.Ltd, Singapore, 2012

REFERENCES

1. Sandeep K.S, Gupta, Tridib Mukherjee and Krishna Kumar Venkatasubramanian, Body Area Networks Safety, Security, and Sustainability, Cambridge University Press, 2013.
2. Guang-Zhong Yang, Body Sensor Networks, Springer, 2006.

Wearable Devices.

UNIT-1

Introduction to Wearable Systems and Sensors.

Wearable System

- Wearable Technology is any kind of electronic devices 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 wearable can vary.

Examples:

1. Artificial Intelligence (AI) hearing aids.
2. Google Glass
3. Microsoft's hololens
4. Holographic Computer in the form of (VR)

Applications:-

1. Consumer Electronics, (Smart watches, fitness tracker)
2. IoT & AI
3. Health & fitness.
4. Sports
5. Entertainment and gaming
6. Health care & Medical
7. Fashion and Smart Clothing.
8. Military.

Types of wearable systems.

1. Smart Watches;

- A watch that does more than just telling time. It provides users notifications on their calls, Messages, emails, Social Media updates etc.

2. Fitness Tracker

Helps keep a track of the number of steps the user walks each day and continuously monitors the heart rate. Using this information, the devices are able to calculate the report accurate data on calorie burn and exercise done by the user

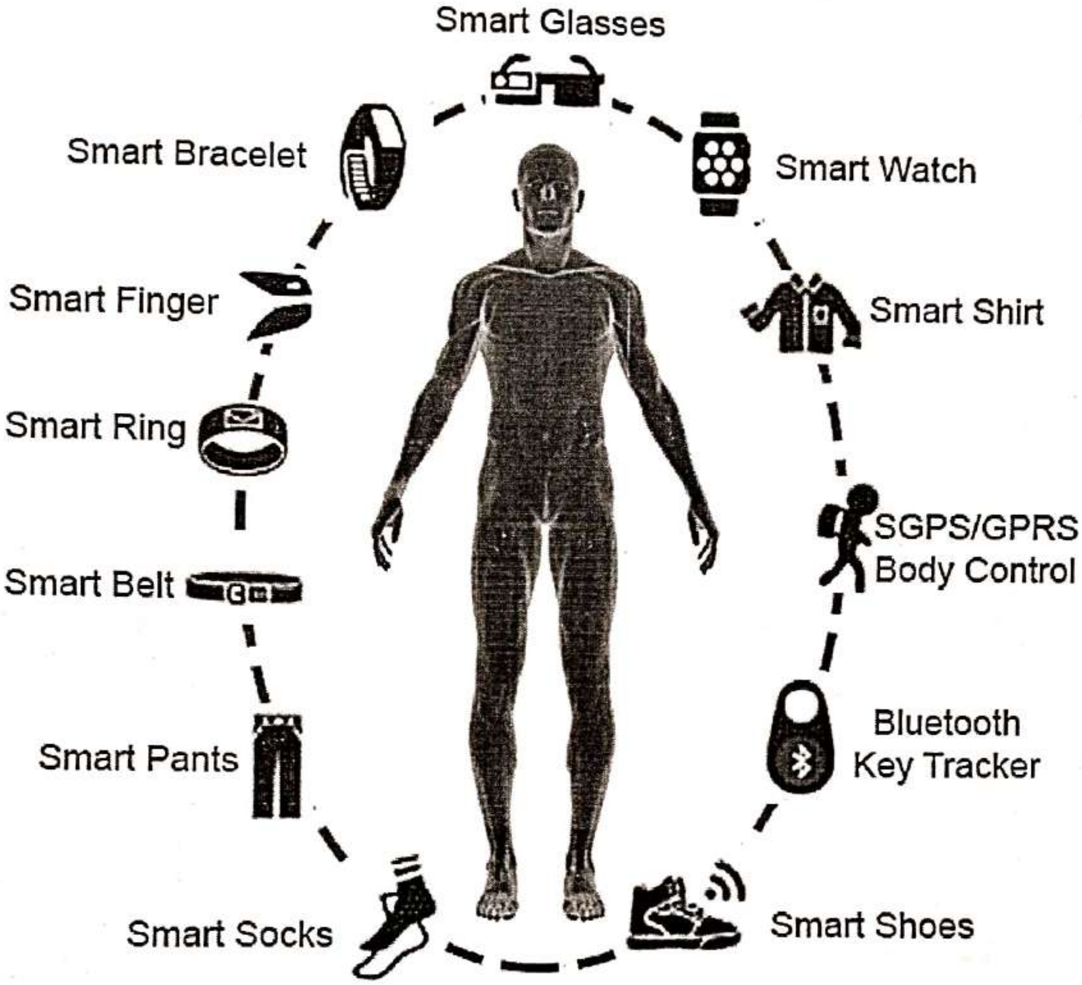


Fig: Types of wearable Technology.

3. Head Mounted display

- It takes us to the different world of virtual reality, It Provides virtual information directly to the human eyes.

4. Sports watches:

- Especially built for Sports Personnel who love running, cycling, Swimming, etc. also it may have GPS tracker, Heart rate Monitoring system.

5. Smart Jewellery

- Specially targetting women.
- Notify the users of their text msg, Calls, emails when their phone is out of reach.

6. Smart Clothing

- These kind of Smart electronic devices are incorporated into the wearable clothing to give an interesting and fashionable look.

7. Implantable:

These wearable devices are incorporated into the wearable electronic devices are Surgically implanted under the Skin. These are usually used for medical reasons like tracking.

Need for Wearable Systems

- Aims to influence the fields of health and medicine, fitness, aging, disability, education, transportation, Enterprise, finance, gaming, music etc.
- The goal is to Smoothly enter the daily lives of individuals and become a functional part of them.

- The hands-free nature of the wearable Computing devices makes it very useful for business.

- Tracking the emergency and rescue team becomes easy thus making the workplace more efficient and safe.

- Hands free access to important data and information through Smart glasses and Smart watches helps researcher, engineers, and technicians to be more efficient at their work

Drawbacks of Conventional Systems for wearable monitoring:

- Risks that brings on data Security and Privacy
- Companies should have very strong Policies and Procedures in place before introducing wearable technology for the Company usage.
- Batteries: Consume much Power.

- High Potential Cost:
- Capabilities are limited.
- Cyber issues.
- Technical issues.
- Data Interpretation.

Components of Wearable Systems:

1. Control

   ↳ Wearable specific file

2. Input / output
3. Conductive Textiles.
   - Silver or Stainless Steel
   - Thread for making Circuits
   - Fabric for Capacitive touch Sensors.
   - Hook-and-loop for Switches.

4. Sensors.

   - It gather information about the environment, the user, or both.

   Eg: light, Temperature, Motion, Location,

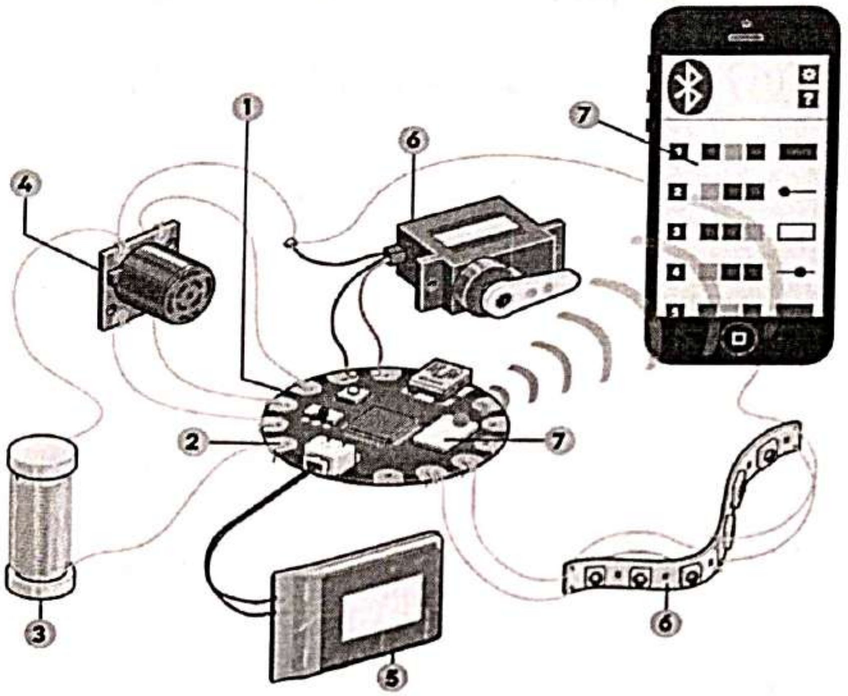


Fig: Illustration of wearable Components.

5. Power

↳ Lithium Coin Battery used for low Power Projects.

- To illuminate a few LED's
- To run Servo motor

6. Actuators

- LED's
- Buzzers
- Speakers
- Servomotors.

7. Networking:

- To Communicate with Smart devices, the internet, Need ~~to~~ wireless Connectivity.

Eg: Wifi, Bluetooth, Zigbee.

Sensors for Wearable Systems

- Used to monitor Physiological and bio mechanical parameters monitoring.

* Accelerometer

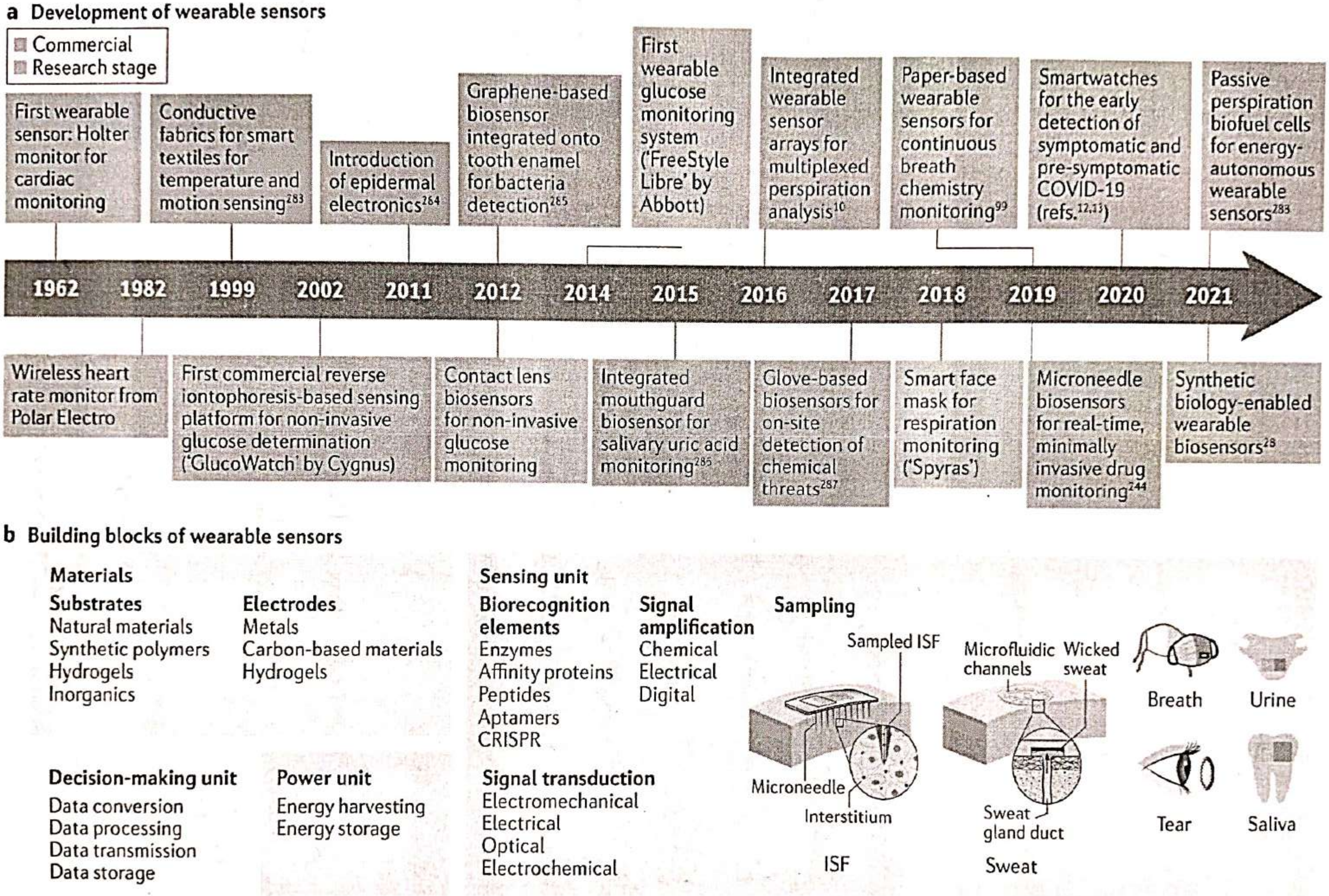
- Their brand of acceleration, Such as gravity, and linear, demonstrates their Sensing Capabilities.

* Gyroscopes.

- Used to Record only angular accelerations. also used to increase the Precision of the data.

* Magnetometers:-

- It Can be integrated to create an Inertial measurement Unit (IMU) with accelerometers and gyroscopes. It can have three axes. (Similar to Compass) to improve Balance.


a Development of wearable sensors
Commercial
Research stage
First wearable sensor: Holter monitor for cardiac monitoring
Conductive fabrics for smart textiles for temperature and motion sensing[283]
Introduction of epidermal electronics[264]
Graphene-based biosensor integrated onto tooth enamel for bacteria detection[285]
First wearable glucose monitoring system ('FreeStyle Libre' by Abbott)
Integrated wearable sensor arrays for multiplexed perspiration analysis[10]
Paper-based wearable sensors for continuous breath chemistry monitoring[99]
Smartwatches for the early detection of symptomatic and pre-symptomatic COVID-19 (refs.[12,13])
Passive perspiration biofuel cells for energy-autonomous wearable sensors[283]
1962
1982
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2021
Wireless heart rate monitor from Polar Electro
First commercial reverse iontophoresis-based sensing platform for non-invasive glucose determination ('GlucoWatch' by Cygnus)
Contact lens biosensors for non-invasive glucose monitoring
Integrated mouthguard biosensor for salivary uric acid monitoring[285]
Glove-based biosensors for on-site detection of chemical threats[287]
Smart face mask for respiration monitoring ('Spyras')
Microneedle biosensors for real-time, minimally invasive drug monitoring[244]
Synthetic biology-enabled wearable biosensors[28]
b Building blocks of wearable sensors
Materials
Substrates
Natural materials
Synthetic polymers
Hydrogels
Inorganics
Electrodes
Metals
Carbon-based materials
Hydrogels
Sensing unit
Biorecognition elements
Enzymes
Affinity proteins
Peptides
Aptamers
CRISPR
Signal amplification
Chemical
Electrical
Digital
Sampling
Sampled ISF
Microneedle
Interstitium
ISF
Microfluidic channels
Wicked sweat
Sweat gland duct
Sweat
Breath
Urine
Tear
Saliva
Decision-making unit
Data conversion
Data processing
Data transmission
Data storage
Power unit
Energy harvesting
Energy storage
Signal transduction
Electromechanical
Electrical
Optical
Electrochemical

GPS :-

- Scanning and informing users location.

- Information is sent to a satellite to quantify exact location and time.

Heart rate Sensors.

- To measure blood flow of the human body.

Photoplethysmography :- Technique that uses light to track blood flow volume changes.

Fitness Tracker :- There is a continuous green light transmitted to the skin of the ~~water~~ wearer, which measures the light absorption by the photodiode.

Pedometers

- Focused on physical health and can count the user's steps while running & walking.

Types :

1. Electrical
2. Mechanical

Pressure Sensors.

- Operate from Strain gauges.
- When Pressure is applied to the Sensors, the circuit causes a change in resistance - dependent electronic Measurements.

Inertia movement Sensors.

- Monitoring Parameters related to human movement has a wide range of applications.
- In medical field, motion analytics and analysis tools are widely used both in rehabilitation and in diagnostics.
- In multimedia field, motion tracking is used for the implementation of life-like videogame interfaces for computer animation.
- Inertial Sensors are composed of accelerometers and gyroscopes, which measure specific force and turn rate, respectively.

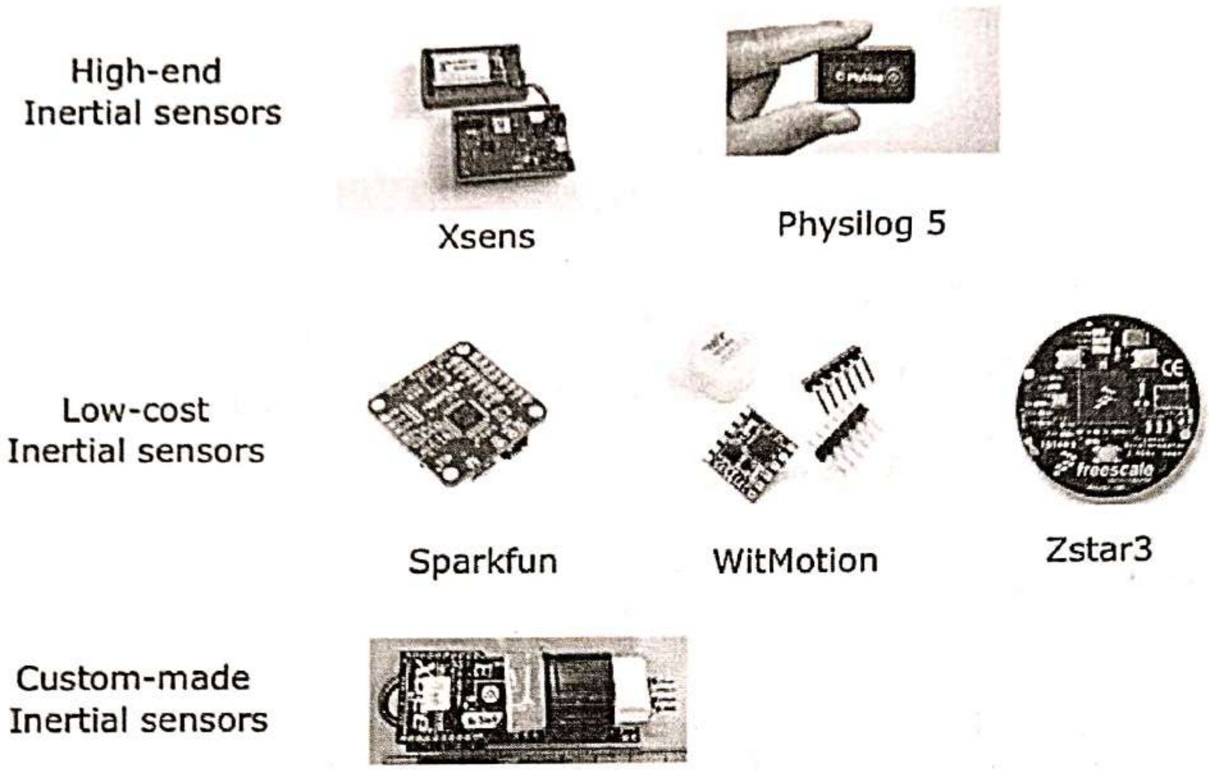


Fig: Different Inertial Sensors based on Cost

- These Sensors are directly applied on the body Segment to be monitored,

- These Sensors can be realized on a Single Chip (MEMS technology) with low cost & out standing miniaturization.

- Accelerometers are widely used for the automatic discrimination of Physical activity & the estimation of the body Segment inclination with respect to the absolute Vertical,

- Accelerometers alone are not indicated for estimation of the full orientation of body segments.

- It 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.

- Advantage of accelerometers:

- Motion analysis are very low encumbrance and the low cost.

Disadvantage of accelerometers:

- Possibility of obtaining only the inclination information in quasi-static situations (due to noise and double integration of acceleration to estimate the segment absolute position is unreliable

- Considering a Calibrated tri-axial accelerometer, the accelerometer signal (y) contains two factors:

1. Due to gravity (g)
2. Due to inertial acceleration (a)

$\therefore$ Accelerometer Reference frame expressed as

$$\boxed{Y = a - g \begin{pmatrix} Y_1 \\ Y_2 \\ Y_3 \end{pmatrix} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} - \begin{pmatrix} g_1 \\ g_2 \\ g_3 \end{pmatrix}} \quad (1.1)$$

Respiration Activity Sensor

- 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.

Types:

1. Inductive Plethysmography
2. Impedance plethysmography.

Inductive Plethysmography

- It is the method for breathing Monitoring Consists of two elastic Conductive wires placed around the throax and the abdomen to detect the Cross Sectional area changes of the rib Cage and the abdomen region during the respiratory cycles.

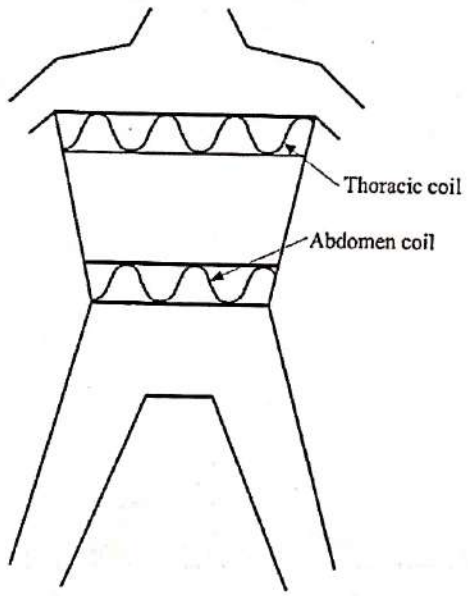


Fig: Respiratory inductive plethysmography.

- The Conductive wires are insulated and generally Sewn in a zigzag fashion onto each Separate Cloth band. They Can be Considered as a Coil and are used to modulate the o/p freq. of a Sinewave Current Produced by electric oscillator Circuit.

- The Sine wave Current generates a magnetic field, and the Cross-Sectional area changes due to the respiratory movements of the rib cage and of the abdomine determine a variation of the magnetic field flow through the coils.

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 Imp. changes.

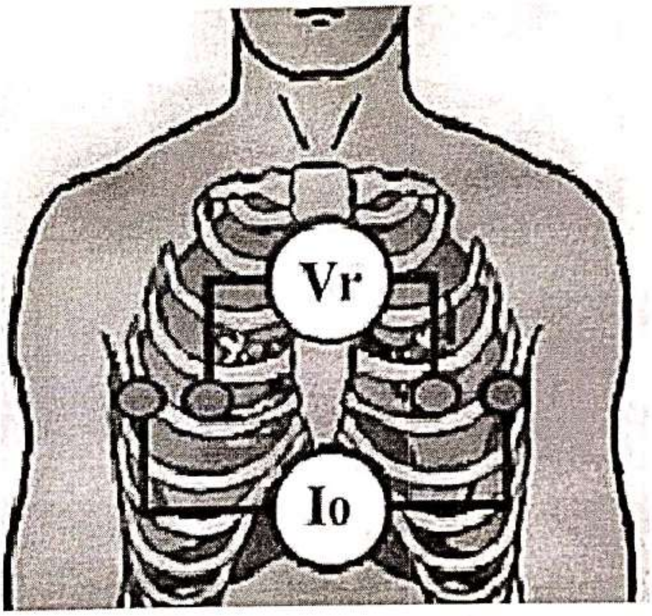


Fig: Principle scheme of impedance Plethysmography

- There is a relationship between the flow of air through the lungs and the impedance change of the thorax.

- The measurements of electrode can be made of fabric and integrated into a garment or even embedded into an undershirt.

Pneumography - Based on Piezoresistive Sensor

- It can be 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.

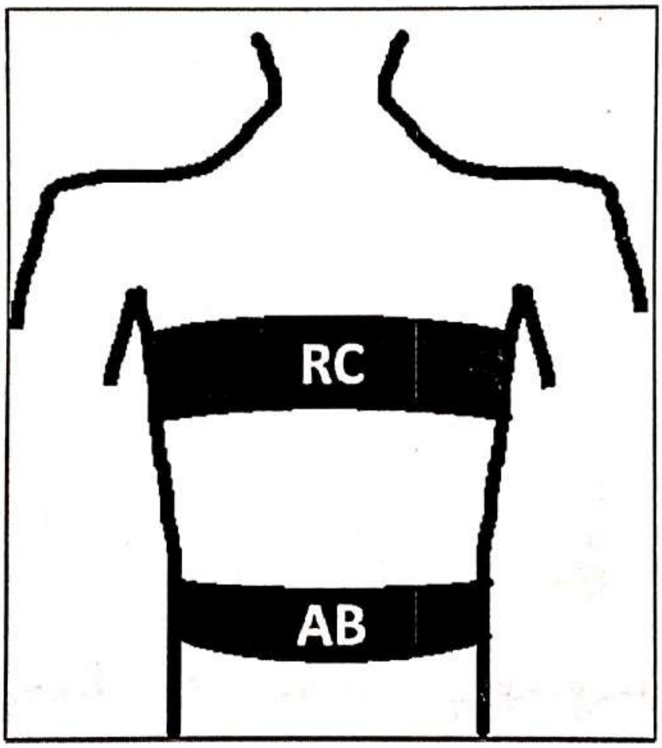


Fig: Pneumography - Two Piezoresistive belts.

- It 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.

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.

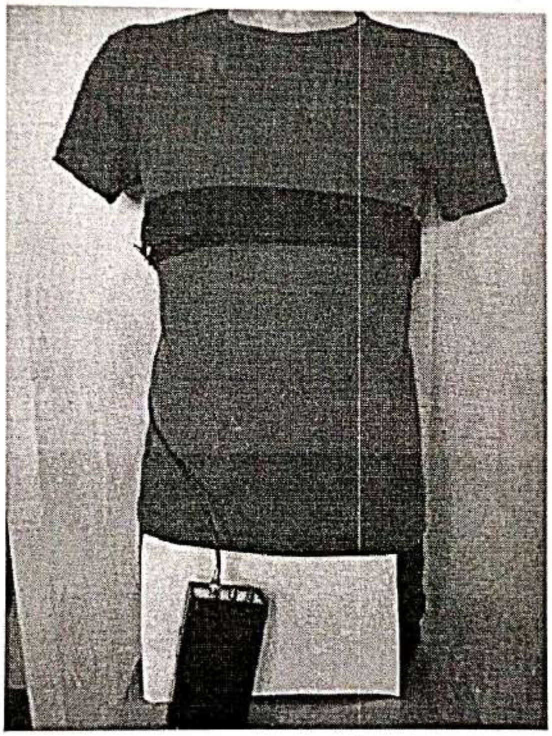


Fig: Plethysmography with a Piezoelectric band

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 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.

—x—x—x—

UNIT-II

Signal Processing and Energy harvesting for wearable devices.

Wearability Issues:-

1. Battery Technology
2. Excessive Air Traffic

   - So much Congestion → need to extend bandwidth.
3. Media device fatigue:

   - People will simply drop it for the multifunctionality of Smartphones.
4. Data Transmission

   - Wearable devices are useful and viable.
5. Potential health Problems.

   - Due to frequencies, high Radiations.
6. Fashion

   - The ability to adjust wearables into more fashionable pieces will be imperative for their long-term success.

7. Devices safety issues.

- Some wearables do so much as inject medication and Provide electrical Stimulation.

- It's crucial that these systems Perform Perfectly or else a human life could be Put at risk.

8. Data theft Incidents.

- Massive data leaks like location & health data.

9. Mobile Apps

↳ need to improve the quality & Accuracy of Apps

10. User distrust

- Bad experience could make the use of wearables questionable and diminish the impact its has had so far.

11. Slow Vendor Progress.

12. Negative user Experience

General issues:-

(1) Physical interference with movement
(2) Difficulty in removing and placing nodes.
(3) Social and fashion Concerns
(4) Frequency and difficulty of maintenance (Charging & Cleaning)

Technical Challenges:

1. Electrostatic Interference
2. Biopotential Electrodes.
3. Instrumentation Amplifier

Sensor design:

- Sensors are essential for all monitoring Applications.
- For Continuous monitoring, the most Prominent Sensors for activity recognition include accelerometers and gyroscopes.
- Additionally, Physiological Signals are important in Continuous monitoring.

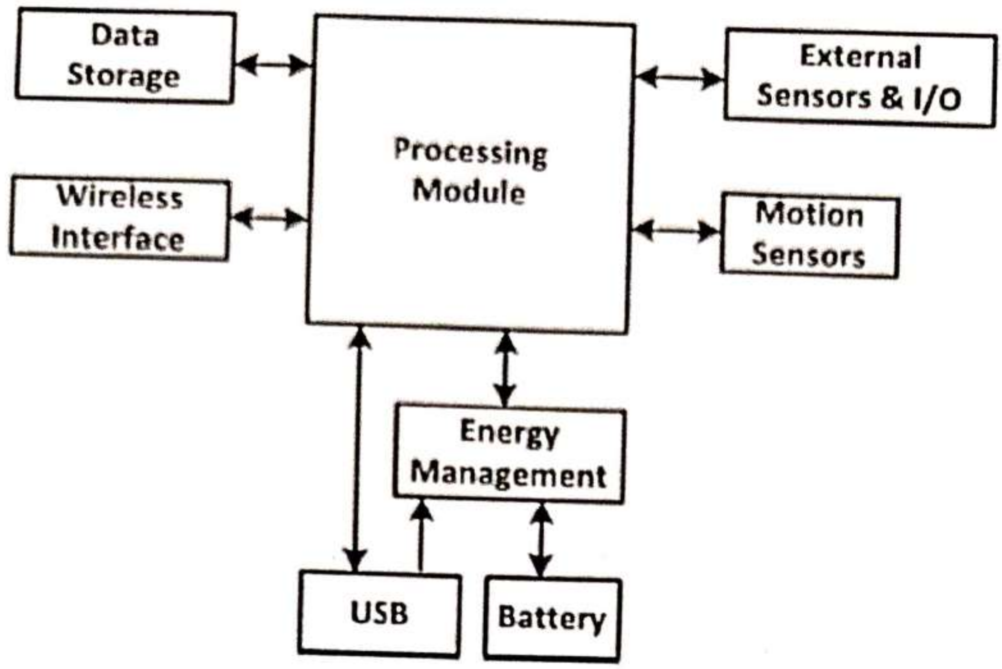


Fig: System architecture of Wireless health Platform for Continuous Monitoring.

- The above Module have Main Master class Processing Module.

- Typical Physiological Sensors include heart rate monitor, ECG/EMG Sensor, Pulse Oximeter, and respiratory Sensor.

- For Activity recognition, motion Sensors Can Provide accurate information and they Should be integrated into the main Printed Circuit board to reduce the overall Size of the Platform.

- External connectors for sensor board extension should be made available to accomodate additional sensors and provide flexibility for more specific applications.

Signal acquisition :-

- Analog signals from sensors must be acquired and preprocessed appropriately to obtain useful information.

- The preprocessing stage includes
  - * Amplification
  - * filtering.

- The type of the circuit necessary depends on the type of sensor used, dynamic range of signal output, and the sampling requirements.

$$\boxed{\text{Low Noise, high impedance amplifier}}$$
$$\Downarrow$$
$$\boxed{\text{Second anti-aliasing filter}}$$
$$\Downarrow \text{for}$$
$$\boxed{\text{Analog to digital conversion}}$$

Eg: ECG - Electro cardiogram (ECG)

- Certain Micro-electromechanical Systems (MEMS) Sensors provide digital outputs by embedding A/D Conversion on the Same MEMS Packages.

Sampling frequency for Reduced energy Consumption:-

- Sampling rate refers to the rate or frequency at which data are Collected per Second.

- For Continuous monitoring of the electrical activity of the heart and heart rate Variability (HRV) using the electro cardiogram (ECG), data are typically Sampled at 1000 HZ which requires approximately 192 KB/s of data Storage.

- One wearable Sensor that is used regularly in both Consumer and Clinical grade wearables is Photoplethysmography (PPG) a Cost-effective technique.

— used to measure blood volume changes.

Optimization frame work :-

— The following figure shows that sampling rate with 1000 Hz of frequency.

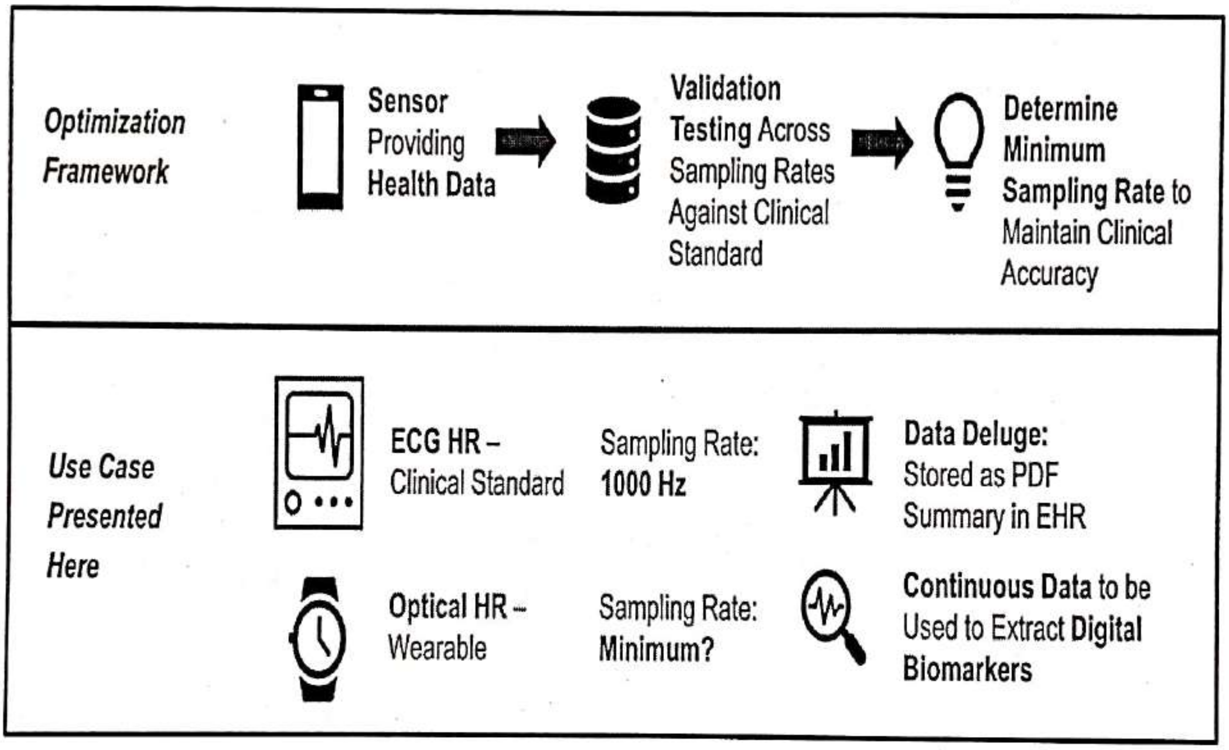


Fig: Sampling optimization method with frequency of 1000 HZ.

— The optimization frame work presented here examines a sensor providing health data and performs validation testing across sampling rates against the clinical standard in order to inform minimum sampling rate to maintain clinical accuracy.

Data Collection

- ECG and PPG signals were recorded simultaneously.

- PPG data were recorded at 64 Hz from the right wrist using Empatica E4 band.

- ECG data were recorded at 1000 HZ from the three leads using a biftium faros 180 ECG

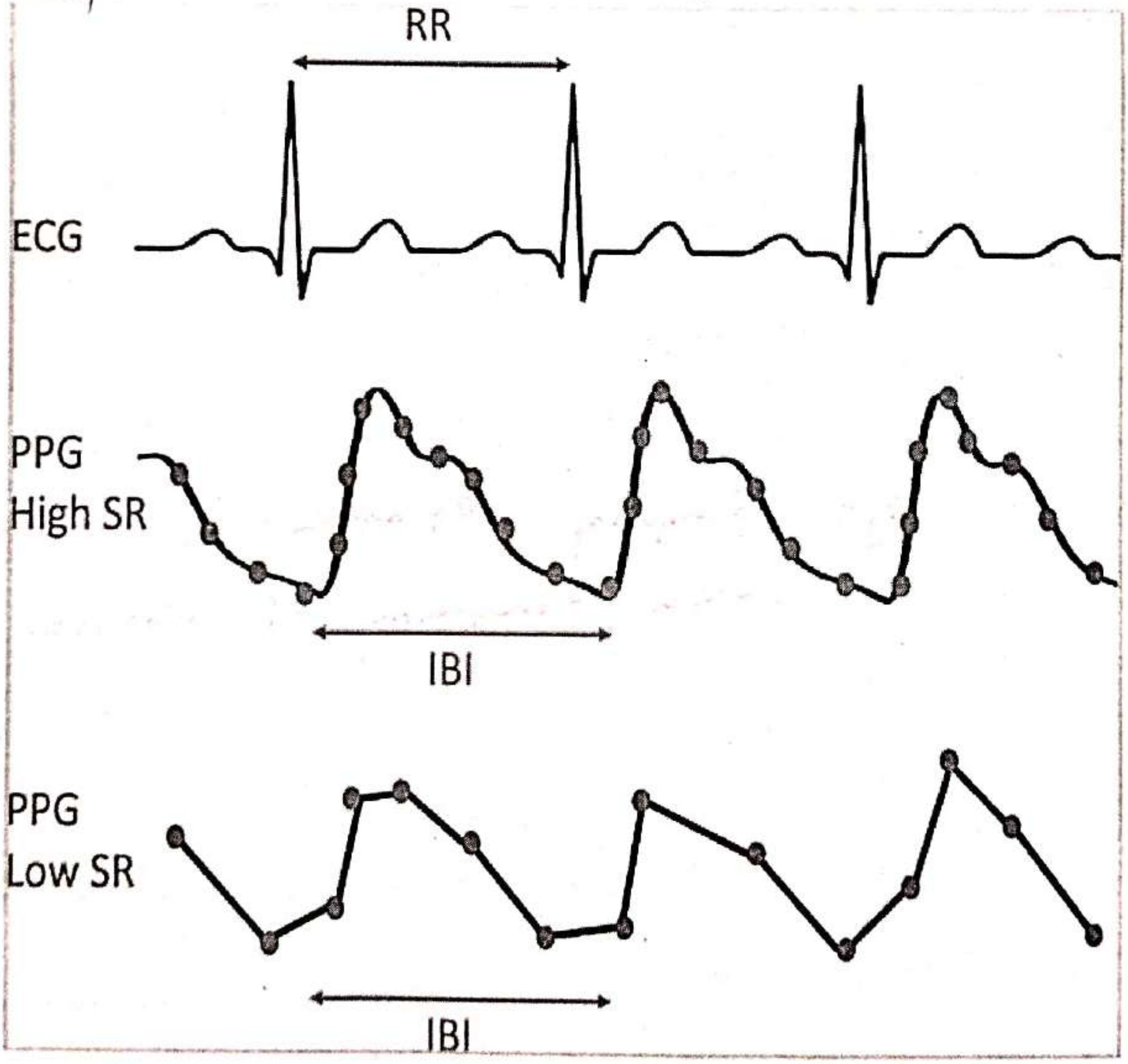


Fig: Data Collection at different samples.

Data Volumes with decreasing Sampling rates:

- Required data Storage was Computed from the file size of the raw Signals of the ECG and each of the down sampled PPG Signals.

$$\boxed{Cost_p(n) = Data_p(GB) \times 30.42 \text{ days} \times \frac{n(n-1)}{2} \times Cost}$$

Optimal Sampling rate of PPG for HR

- The mean and Standard deviation of HR metrices for each of the down Sampled Signals across the No. of Subjects may Varies.

- At all Sampling rates, maximum HR error between PPG and ECG increases as maximum HR increases.

- Our Linear regression Visualization Showed that mean HR error between ECG and PPG is not affected by lower or higher Values at 64 Hz.

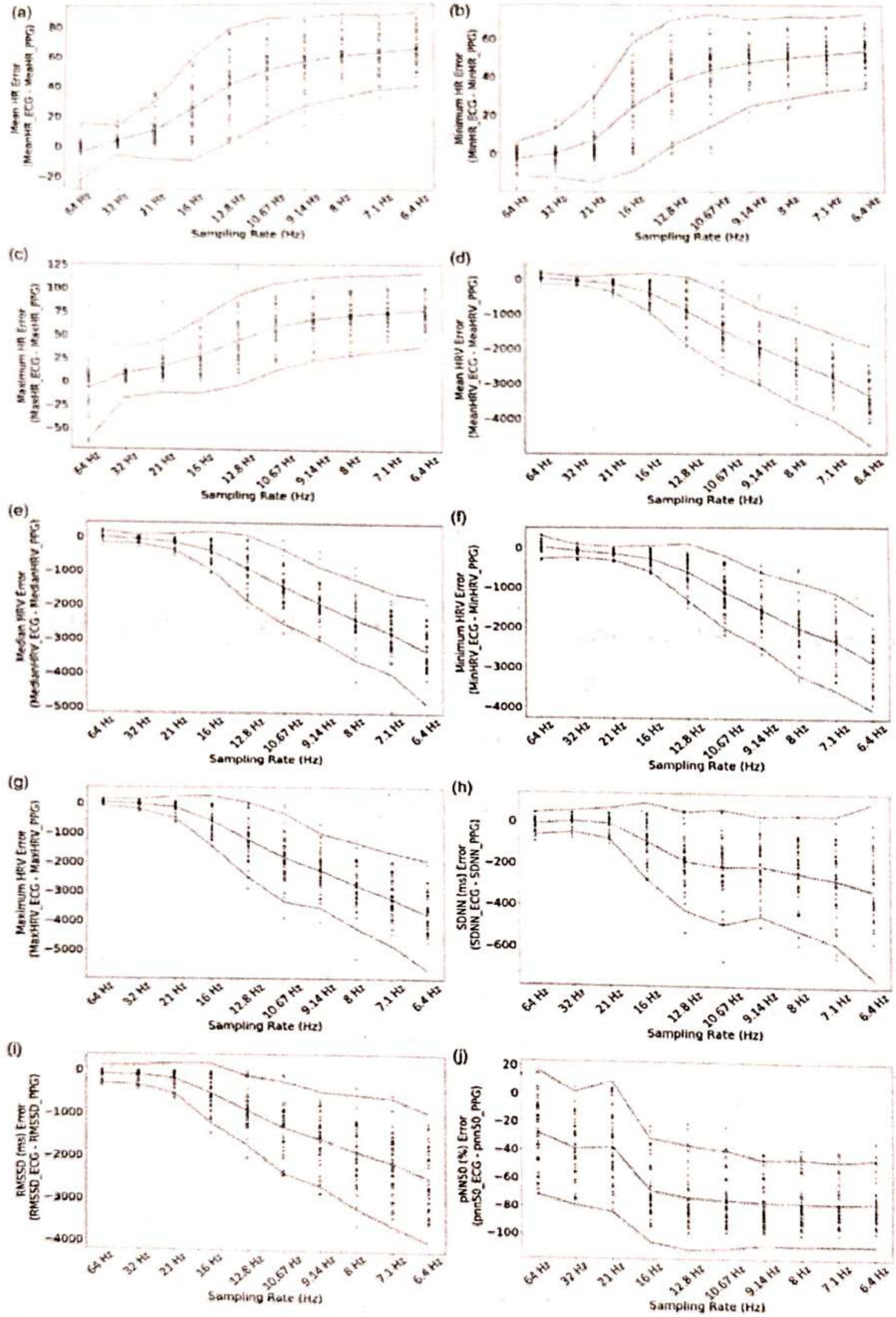


Fig: Bland–Altman analysis results between HR metrics and time domain HRV metrics according to sampling rate. (a) Mean HR, (b) minimum HR, (c) maximum HR, (d), mean HRV, (e) median HRV

Power Requirements:-

Solar Cell:-

- Solar cells are made of Semiconductor junctions that can convert sunlight energy into electric energy via Photovoltaic effect.

- Semiconductors have a characteristic energy level called a band gap.

- When the incident photons have higher energy than this band gap, the solar cell will generate an electrical current.

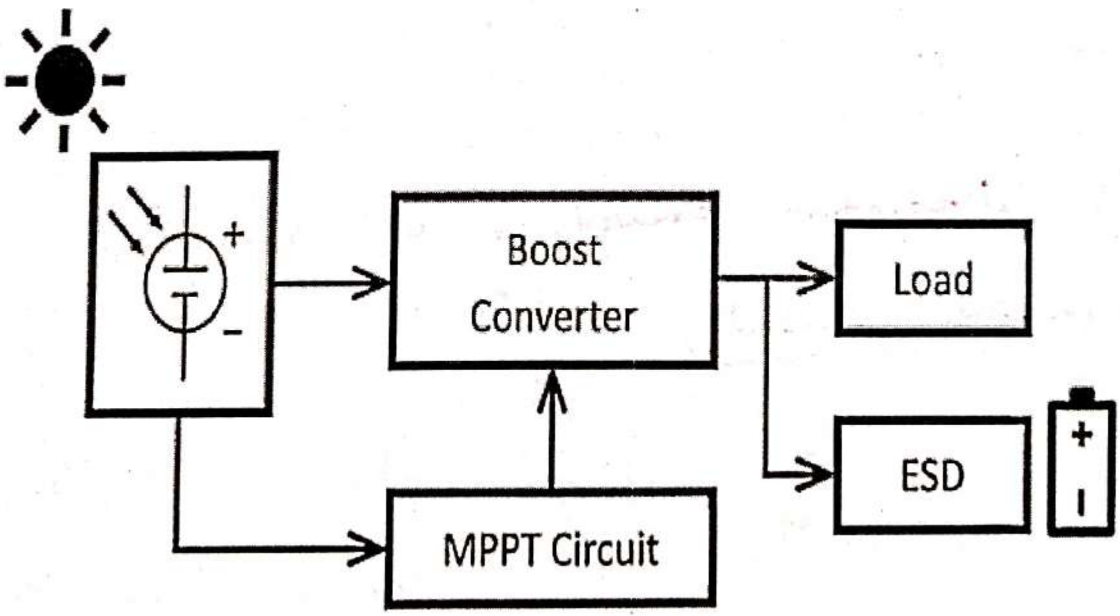
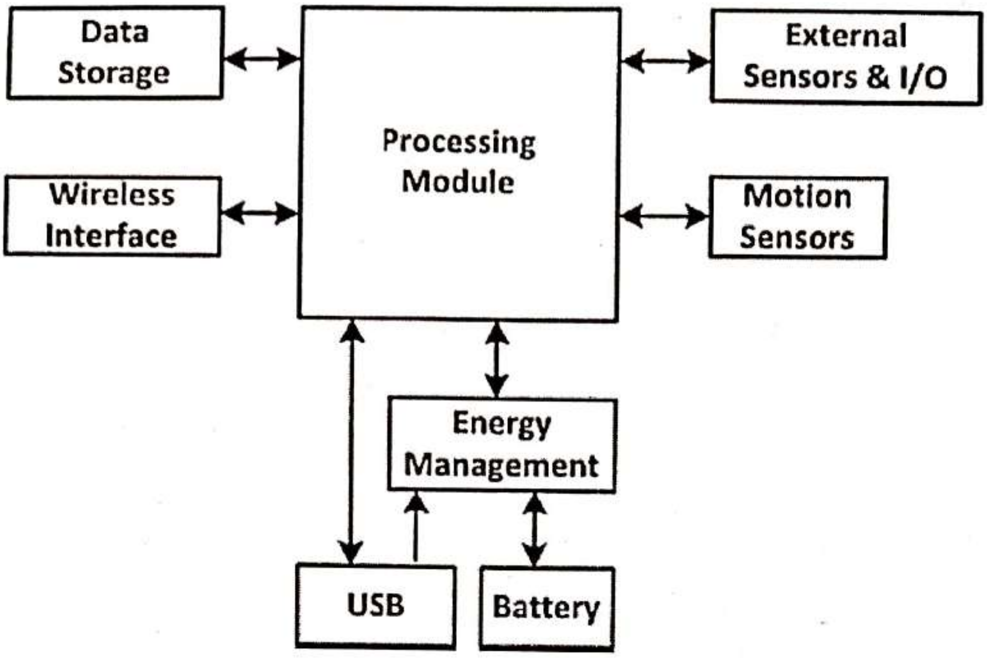


Fig: Schematic of a typical Solar Energy harvesting Circuit.



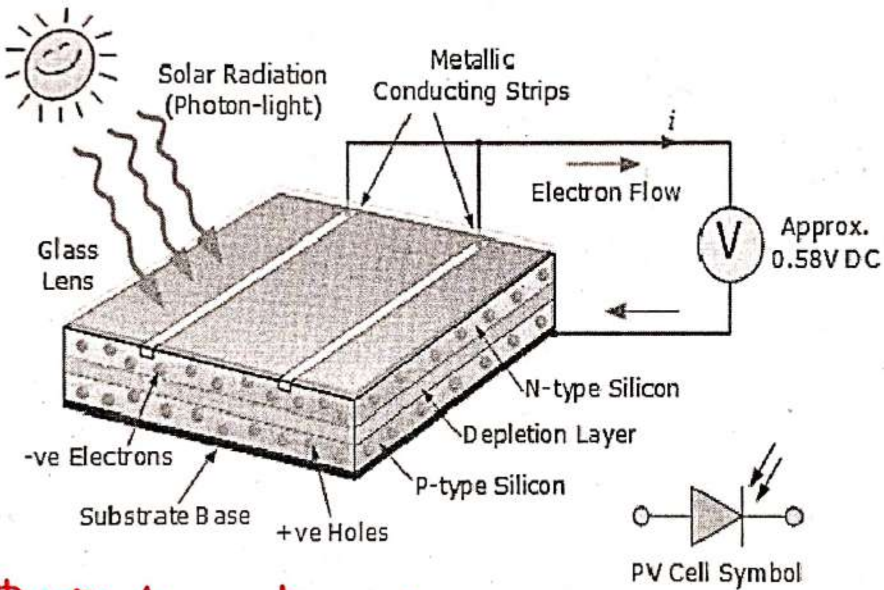


Fig: Depicting breakdown of solar cell.

Vibration Based :-

— There are two kinds of mechanical energy that can be scavenged from human body.

— The first is releated to continuous activity, such as breathing and heart beating.

- Another is releated to dis continuous 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 68 kg man is able to generate 67 W when walking at a speed of two steps per second.

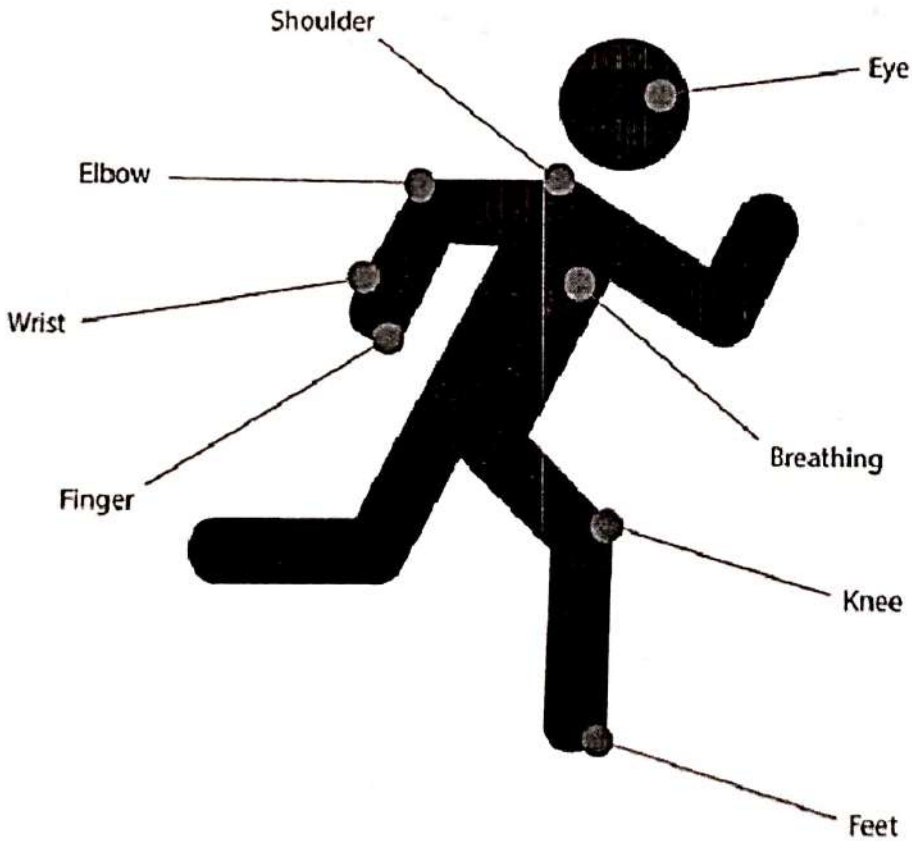


Fig: Different places of human body which produces energy with mechanical & vibration movements.

— The following schematics show that different Piezo electric materials which produce energy.

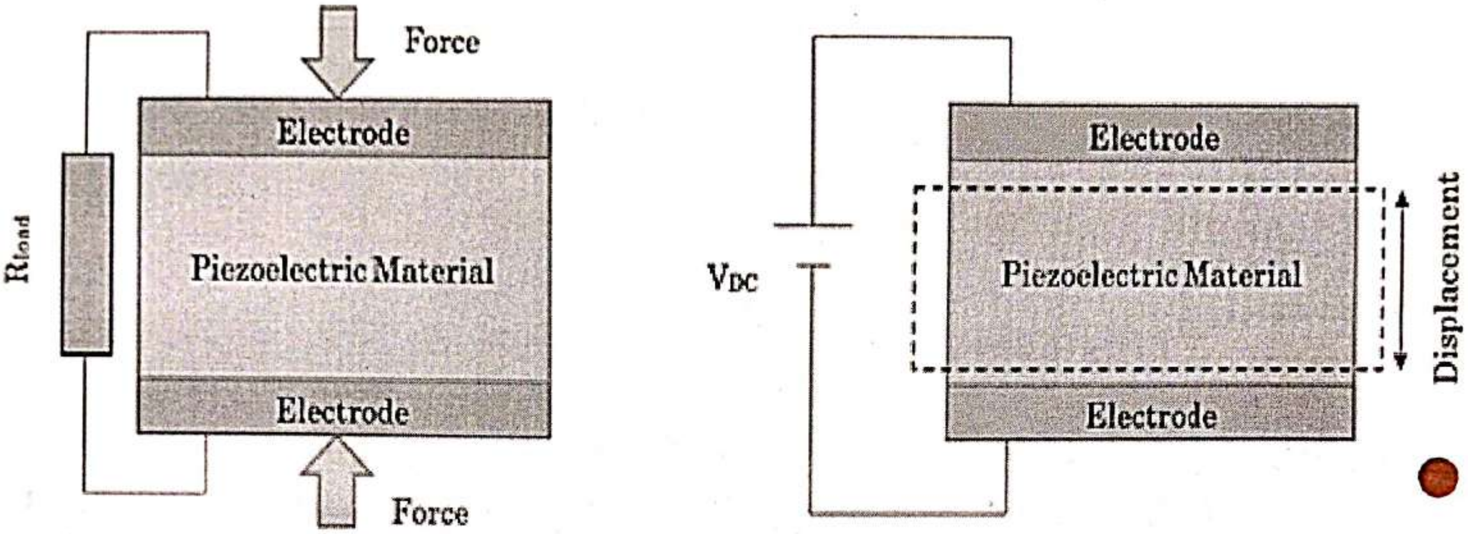


Fig: Direct and Inverse Piezo electric effects.

There are four different types of materials that can be used for Piezoelectric energy harvesting.

1. Ceramics
2. Single Crystals
3. Polymers.
4. Composites.

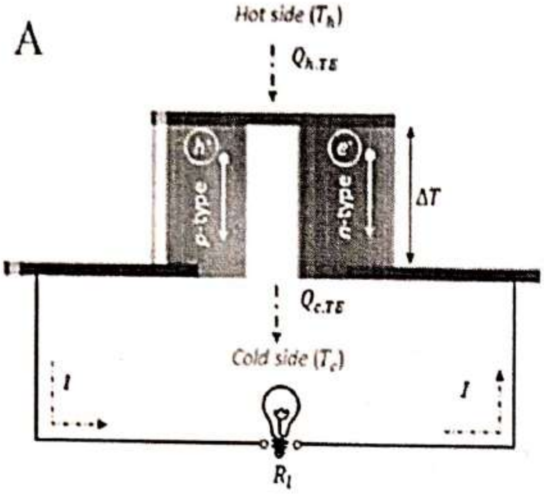
Applications:-

- A Piezo electric Pacemaker
- Foot Path lighting Powered by foot steps.
- A vehicle driver's Seat Monitoring heart beat of driver for Ventilation.
- Wearable devices that can be charged by walking, running (or) other Physical activity.

Thermal Based Power Requirements:-

- Wearable Thermo electric generators (WTEG) can convert body heat into electricity to Power electronics.
- However the low efficiency of Thermoelectric materials, tiny terminal temperature difference, rigidity, and neglecting optimization of lateral heat transfer Preclude WTEGs from broad utilization.
- It is fully based on Seeback effect with different metals.

– The following figures shows that Seeback effect and different TEG Module which produces Power.



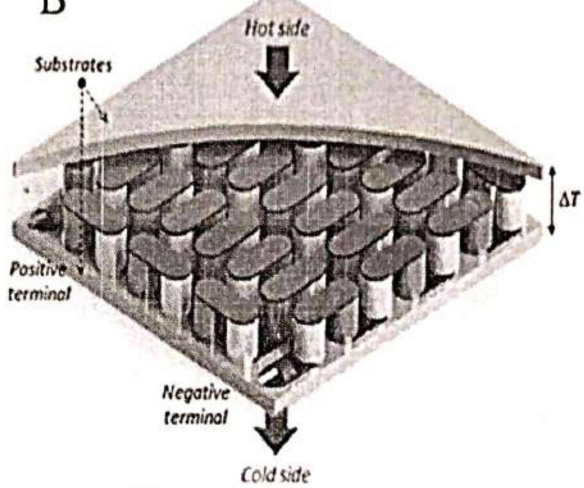


Fig: Seeback effect based on thermal Energy.

Fig: TEG Module

– Different metals have different free electron densities.

– When two different metals are in contact with each other, the electrons ~~can~~ on the contact surface will diffuse to eliminate the difference in electron density.

– A stable voltage is generated at the other end of metals and the diffusion rate of electrons is proportional to the temperature of the contact area.

$$\boxed{V = S \times \Delta T}$$

where S and ΔT are the Seeback Coefficient and Temperature difference.

The Practical TE Conversion efficiency of a TEG is given by the following equation

$$\boxed{\eta = \frac{P}{Q_n}}$$

P - Power output to the load

Q_n - Heat Energy absorbed at hot side.

Human body as a heat source for Power generation:-

- Our human body constantly generate heat as a useful side effect of metabolism.

- However only a Part of this heat is dissipated into the ambient as a heat flow and infrared radiation, the rest of it is rejected in a form of water vapour.

- The heat flow can be converted into electricity by using a thermoelectric generator (TEG).

- The human body is not a Perfect heat supply for a wearable TEG. The body has high thermal resistance, therefore the heat flow is quite limited.

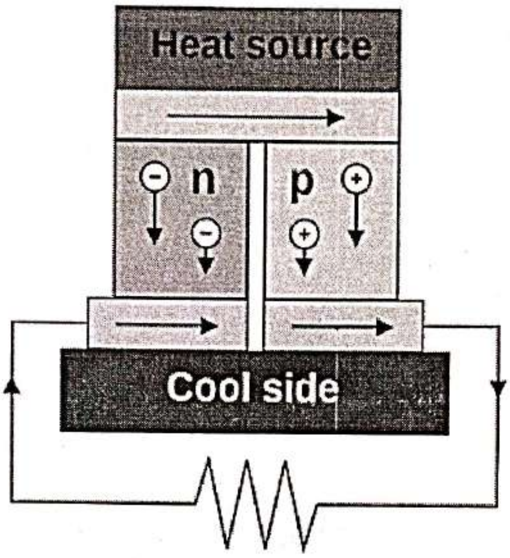


Fig: Schematic diagram of a thermoionic electricity generator to make power from human body.

- At typical indoor conditions, the heat flow in a Person depends on the location on the body and mainly stays within the 1-10 mW/cm².

- The corresponding thermal circuit is shown in the figure for two cases.

(1) A Naked human ~~body~~ being with no device

(2) with a TEG on the skin.

- The human body as a heat generator and the ambient air as a heat sink represent natural thermal generator, that is shunted on the skin at the interface b/w the body and air.

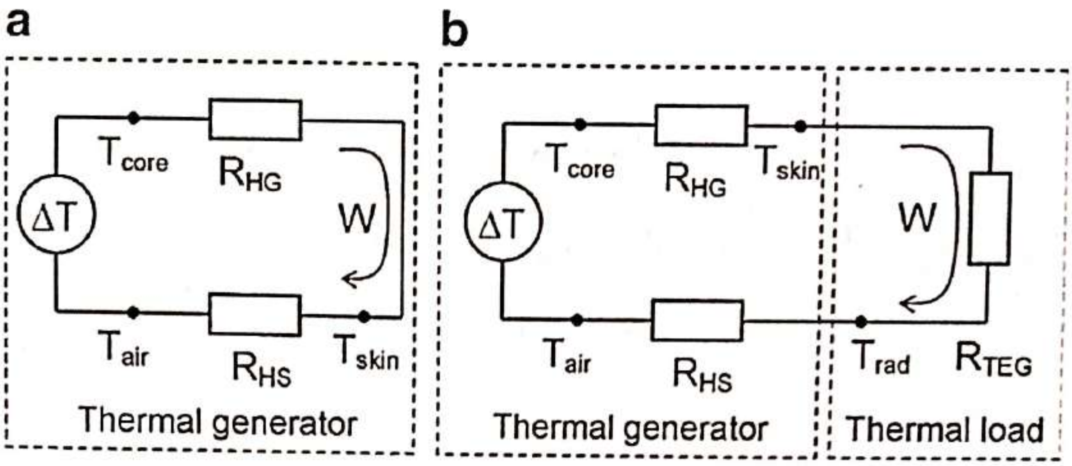


Fig: Equivalent thermal circuits of
(a) Short-circuit natural thermal generator
(b) Same circuit with thermal load.

- The skin involves the thermal resistance of the body, R_{HG}, and the ambient air R_{HS}.

-
$$\boxed{R_{tp} = \frac{R_{pp}\, R_{TEGopt}}{R_{pp} - R_{TEGopt}}}$$

- R_{tp} = Optimal thermal resistance of thermopile.

R_{pp} - Parasitic thermal resistance of TEG.

R_{TEGopt} - optimal thermal resistance of TEG.

- The optimal thermal resistance of a TEG can be obtained from the equation of its thermal matching with ambient

$$\boxed{R_{TEGopt} = \frac{(R_{HG} + R_{HS})\,R_{em}}{2\,(R_{HG} + R_{HS}) + R_{em}}}$$

R_{HG} - local thermal resistance of human body b/w body core and chosen location on the skin.

R_{HS} - Thermal resistance of a heat sink.

The thermal insulator factor N, defined as

$$\boxed{N = \frac{R_{em}}{(R_{HG} + R_{HS})}}$$

Hybrid thermoelectric Photovoltaic energy harvests:-

- Hybrid energy Scavengers have been fabricated for EEG systems to avoid sensation of cold induced by TEG in cold weather.

- The latter are mounted on the outer surface of radiators and serve as their external heat dissipating surface.

- The TEG and PV cells are connected in two parallel electrical circuits and charge one super capacitor.

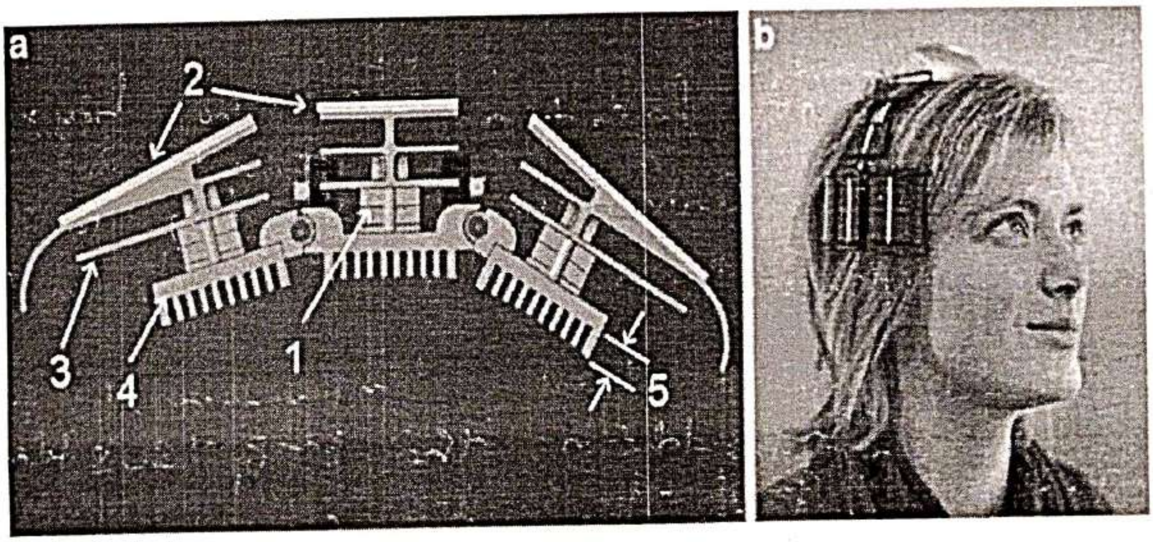


Fig: Cross section of the hybrid thermo-electric - Photovoltaic generator unit.

- As tested outdoors at a temperature of 7°c, the device is still very comfortable for the user.

- As a rule of thumb, at 10°c outdoors, PV cells generate eight times more power than the TEG while indoors the latter offers eight times more power than PV cells.

- By using a two-way power supply that exploits both the heat dissipated from person's temples and ambient light as energy sources, the dimensions and weight of the TEG are reduced.

The location of the hair is much more convenient, according to the user's response.

In addition, the EEG system works much more reliably at high ambient temperature like 28°c.

Thermopile :

A Thermopile is an electronic device that converts thermal energy into Electrical energy.

Thermocouples operate by measuring the temperature differential from their junction point to point in which the thermocouple output voltage is measured.

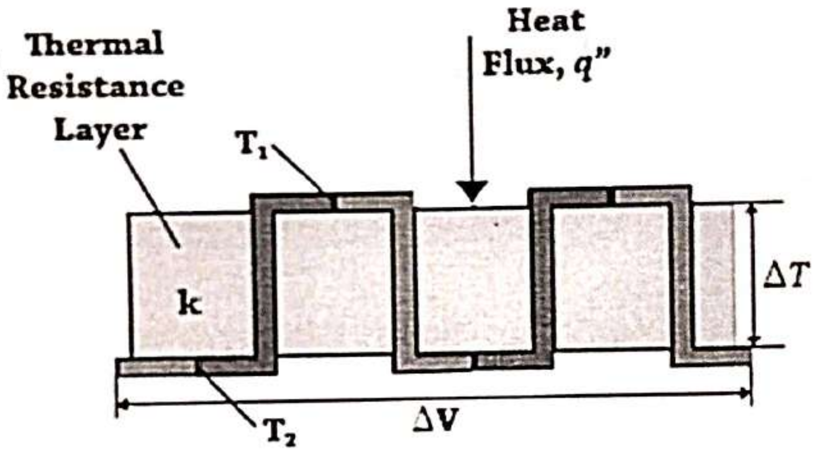


Fig: Thermopile with two sets of thermocouple pairs connected in series

- Thermopiles do not respond to absolute temperature, but generate an output voltage proportional to a local temperature difference or temperature gradient.

- The two top thermocouple junctions are at temperature T_1.

- The Two bottom thermo couple junctions are at temperature T_2.

- The output voltage from the thermopile is ΔV, is directly Proportional to the temperature differential ΔT or $T_1 - T_2$.

- The thermopile Voltage output is also directly Proportional to the heat flux 'q' through the thermal resistance Layer.

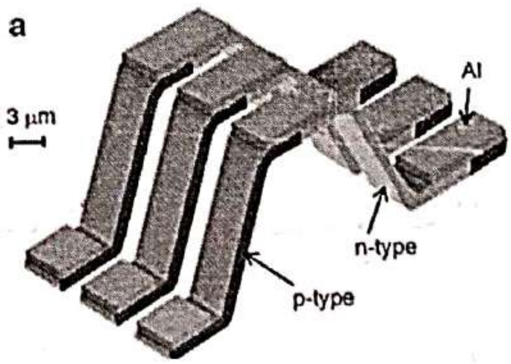


Fig: The Conceptual design of thermo Couple.

- Miniaturizing of thermopiles offers a Potential for essential reduction of the total fabrication Cost.

UNIT-III

WIRELESS HEALTH SYSTEMS

Need for wireless monitoring.

- Able to deliver health care services to patients not only in hospitals and medical centers, but also in their homes and workplaces.

- This kind of system may offering cost savings and improving the quality of life of patients.

- E-health services can be delivered anywhere at any time.

- Especially, when wireless devices are integrated with sensors, it is possible to acquire and monitor human signals at any kind of environment at any time.

Definition of Body area Network (BAN)

- It basically is a network containing Sensor nodes that are attached to the human body, used to measure the bio-signals (heart rate, blood Pressure, brain signals, etc) of humans.

It has majority of applications in medical Sector.

The Communication in body Sensor networks is of 2 types.

1. In-body Communication
2. On-body Communication

In-body Communication

- Communication between Sensor nodes that are implanted inside human body.

On-body Communication

- It occurs between wearable devices which Consist of Sensor nodes.

WBAN Requirements:-

- Low Power Consumption
- Interoperability
- Self-healing
- Security
- Low Latency.

Applications:-

1. Medical applications
   - Remote health care monitoring
   - Telemedicine
2. Non Medical Applications.
   - Sports
   - Military
   - Lifestyle and Entertainment
   - Global Positioning System.

Advantages of WBAN

1. Improved medical Care
2. Increased Portability
3. Enhanced Patient Solace - light weight, Small
4. Cost - Successful
5. Personalized Consideration.

Disadvantages of WBAN

1. Security and Protection Concerns
2. Interference
3. Limited territory
4. Battery Life
5. Standardization.

Technical Challenges :-

1. Range
2. Power Consumption
3. Security
4. Quality of Service
5. Placement

Ranges:

- WBAN has very small range. i.e few meters from the body, so dynamic communication management is done.

Power Consumption:

- Need for constant power to function properly and difficult to change power source especially if it's transplanted inside human body,

Security

- Due to low power and less processing, It's difficult to add sophisticated security mechanism to WBAN.

Quality of Service: (QoS)

- One of the major challenges in WBAN is to improve the quality of service.

Placement

- It is difficult to place many nodes in limited place

System Security and Reliability

Types of Techniques:

1. **Bilinear Pairing**

- It is one of the techniques used in WBAN Security to ensure data integrity.

- It uses Public and Private Key Cryptography. Publickey for session management and Private key for normal data encryption

2. **Biometric based Security approach for authentication:-**

- In this technique an individual is identified and its identity is Verified by its behavioral and Physiological Patterns.

This approach is uses an intrinsic Property of the human body for identification and authentication.

Heart Rate Variability

- In this method Variability in the heart rate is used for authentication of an individual as these signals are chaotic and have unique properties. So these technique considered one of the best ways to secure communication.

Hidden Markov Model - Based Authentication and Selection Encryption Approaches.

- It uses HMM to do authentication with help of body's intrinsic properties. For Eg, Blood circulation is taken as an example for body's intrinsic property used for secure communication specifically available for WBAN.

Authentication using HMM based Classification Approach:-

- It uses class 'c' and derive parameter 'p' to perform classification of various classes of signals, Here wavelet - domain HMM mentioned as eg. of this approach.

Realiability

- Reliable, Error free and robust information should be received from Sensors.

- A WBAN will use a wireless channel to transmit data, which is inherently unrealiable.

- Frequency bands that are immune to interference and thus increase the Co-existence of Sensor node devices with other network devices available at the Same location.

BAN- Architecture :

- Each Sensor in WBAN architecture is Considered as node and each node is either Placed on the human body in the form of wearable device (or) implanted inside the human body.

- Each of the nodes is a Sensor that stores and Sample ~~function~~ human's Physiological vitals in this network and Send Some data and Communicate with other nodes and mobile devices which work as gateway.

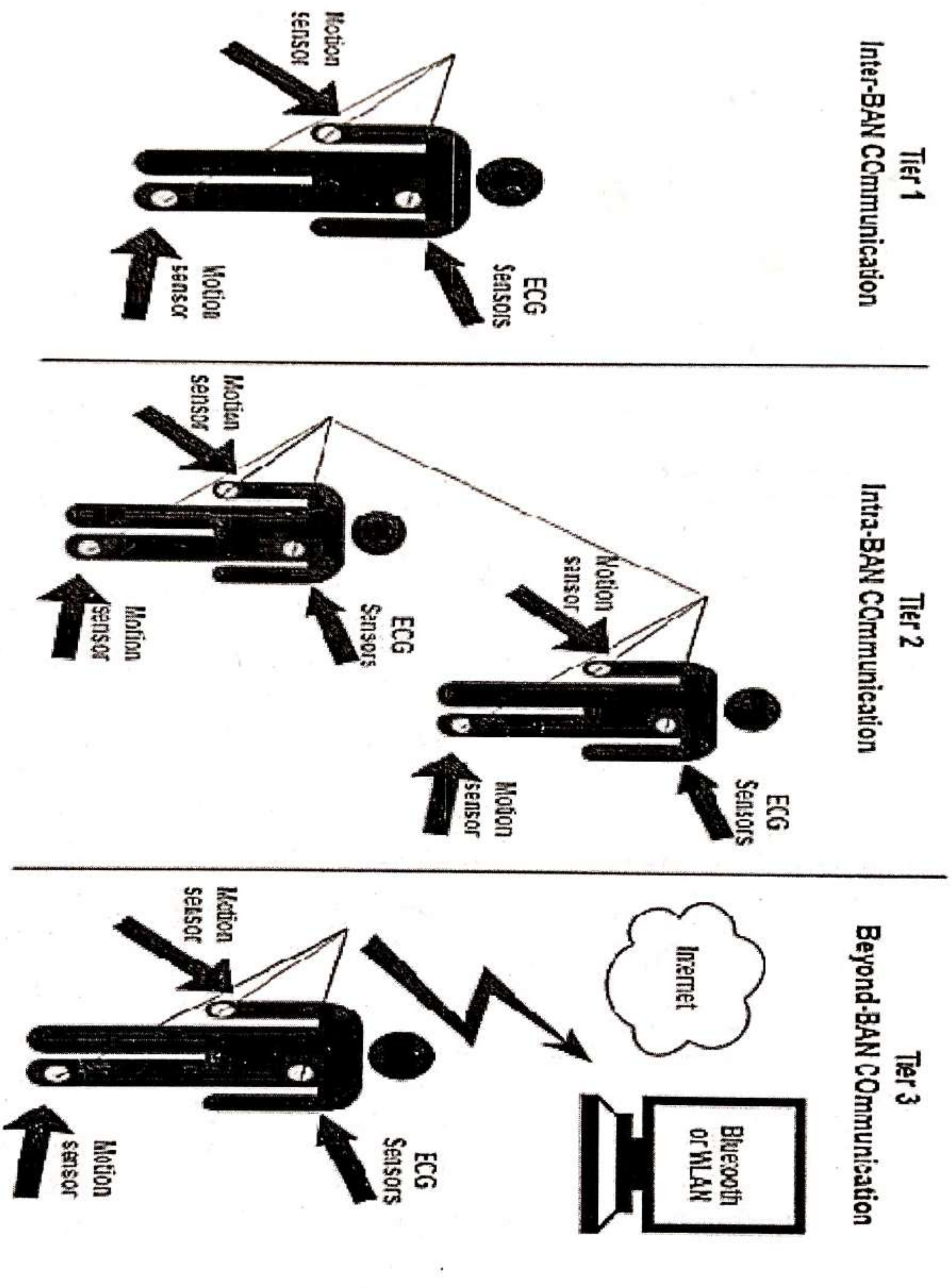


Fig: Architecture of WBAN

- There are three tiers of Communicate architecture for WBAN.
- This network architecture can hold up to more than a dozen of nodes.

Intra - BAN Communication

In a Single WBAN, there are more than one node. When we want to communicate between these nodes and not with any other BAN or outside the BAN, this type of communication takes place.

Inter - BAN Communication

- When want to communicate between multiple nodes (WBAN) this type of communication will be helpful namely Inter - BAN communication.

Beyond - BAN Communication

- There are Plenty of Network types such as local area network (LAN) and wide area network (WAN) when single WBAN is communicating outside its network with some other type of network is called Beyond - BAN communication. This is third and last tier of this architecture.

Wireless Communication Techniques:-

- This breakthrough technology (WBAN) is a result of advancement in various technologies such as BLE, Sensors, and Network Protocols.

The following technologies that enabled WBAN

1. Blutooth Low Energy (BLE)

- It is a technology that is extended from bluetooth Standard.

- It is considered more suitable for WBAN, because it consumes less power with the help of low duty cycle.

- It was designed to operate wirelessly with small mobile devices, these devices ale very small to bear power consumption of normal bluetooth technology.

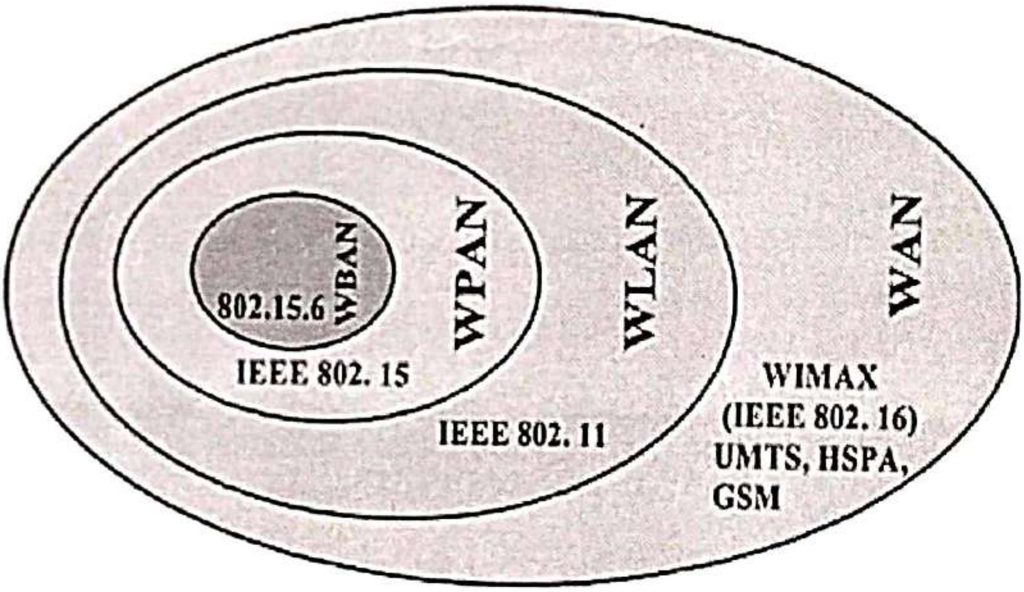
2. Bluetooth:

It is a short range wireless communication technology in which upto 8 devices can connect with each other. This n/w is also known as Piconet in which one device acts as the master while other device acts as the slaves.

Zigbee:

- This kind of technology mainly used in remote areas. and consumes less Power.

- Security in Zigbee is due to its 128-bit Security authentication System, using which it Provides guaranteed Privacy and integrity.



- With the help of Sleep mode Zigbee based devices can operate for several years without changing batteries.

- Zig bee network can be simulated using following Software technologies.

1. NS2
2. OPNET
3. Net Sim.

- Zig bee devices are of three types
  1. Zig bee Coordinator
  2. Zig bee Router
  3. Zig bee End device.

IEEE 802 :-

- IEEE 802 is a set of standards defined for wireless Local Area Networks (WLAN).

- IEEE 802.11 is a specification for Media access control (MAC) and a Physical Layer for wireless local area network.

- IEEE 802.15.6 serves for both medical and non-medical use of WBAN and also assists the Communication around and inside the body.

- The standard uses various communication bands such as
  1. Narrow Band
  2. Ultra-wide band
  3. Human Communication band.

This standard is specifically designed to support a wide range of data rates, minimum energy consumption, and no. of nodes.

Other Technologies:-

UWB Technology:-

- The Ultra Wide Band Technology is used for short-range communications providing high bandwidth.

ANT Protocol:-

- Health care and medical Applications
- Low speed and Low Power

Zarlink Technology

- Mainly for medical applications
- Low frequency and Low data rate.

—x—

UNIT IV

SMART TEXTILE

Introduction to Smart Textile

Smart textiles are one of the areas that provides added value to textile materials. It is a sector that has been developed with new technologies, new fibers, and textile materials. The production of smart or intelligent textiles cooperate with other branches of science like nanotechnology, materials science, design, electronics, and computer engineering, etc. Smart textiles are classified into three groups as passive smart textiles, active smart textiles and ultra smart textiles according to their performance characteristics. Passive smart textiles are the first generation of smart textiles and sense the external conditions; for instance, UV protecting clothing, conductive fibers, etc. As active smart textiles respond to external conditions, ultra smart textiles sense, react, and adopt themselves to conditions. Shape memory materials, chromic materials, heat storage, and thermo-regulated fabrics are the typical applications of active smart textiles.

Textiles, with the basic characteristics of clothing, protection, and esthetics, are the indispensable part of our lives, but in recent years with the development of technology and the variation of requirements, the demand to smart materials and intelligent textiles grows increasingly all over the world. In other words, technology has also taken control of textile industry. Smart textiles have superior performance and functionalities for the applications ranging from simple to more complicated uses such as military, healthcare, sportswear, etc. Smart or intelligent textiles can also be called as the next-generation textiles.

PASSIVE SMART TEXTILES:

When you hear the word smart, you probably think of items that are wifi-enabled. This might be a television or even a lightbulb. But smart technology doesn’t always need an internet connection.

Passive smart textiles are a good example of this. 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.

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.

FABRICATION TECHNIQUES:

DEFINITION

The selection of fabrics for the style or line of garments. The same style is frequently produced in more than one fabric.

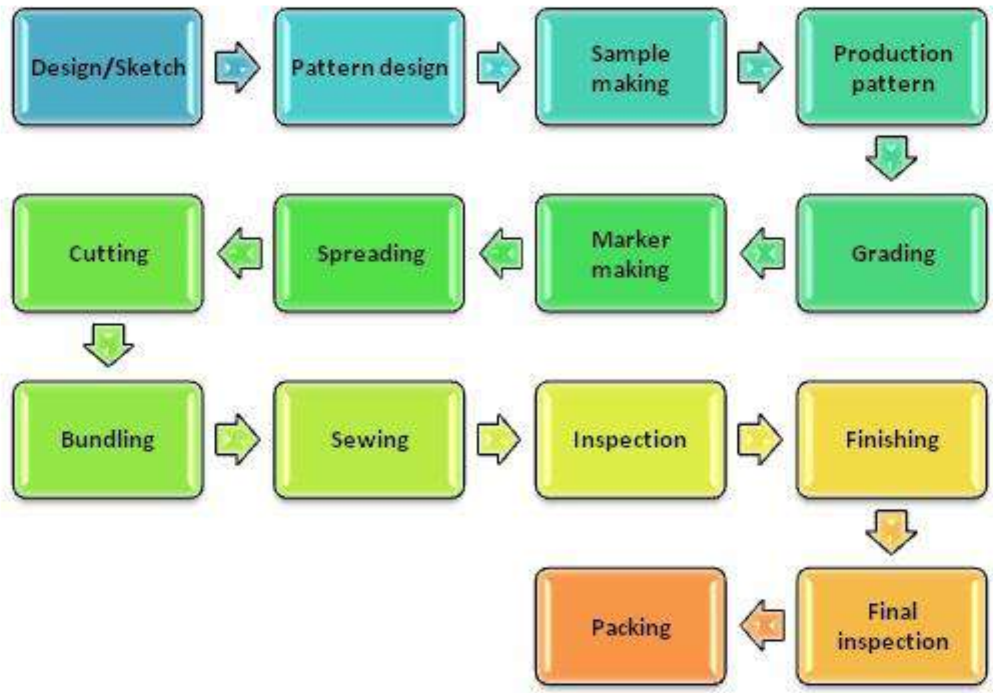


Figure 1 Fabrication process flowchart

Design / Sketch:

In the garment manufacturing the first step is designing the sketch for the dresses that have to be prepared. For this purpose the designer first draw several rough sketches in the sketch book. The designer also draws working drawings along with the sketch. Working drawings are flat drawing of the sketch and it help pattern maker in understanding the patterns involved in the construction.

Pattern Design:

The pattern maker now develop first pattern for the designing any one standard size. This is made by pattern drafting method and the purpose of making this pattern is to create the sample garment for test fit.

Sample Making:

The first patterns are sent to the sewing unit for assembling them into garment. This sample is constructed to analyze the pattern fit and design too. If any changes have to be made they are made at this time.

Production Pattern:

The pattern design is now taken for creating the production patterns. The production pattern is one which will be used for huge production of garments. The pattern maker makes the patterns on standard pattern making paper. Garment patterns can be constructed by two means: manual method, CAD/CAM method.

Grading:

The purpose of grading is to create patterns in different standard sizes. Grading a pattern is really scaling a pattern up or down in order to adjust it for multiple sizes. Pattern sizes can be large, medium and small or else there are standard patterns of size 10, 12, 14, 16 and so on for different figure and statures sizes. This is generally how we get S M L XL XXL sizing. Pattern grading by manual method is a cumbersome task because the grader has to alter the pattern on each and every point from armhole, to neckline, sleeve cap and wrist by using CAD it is much easier and faster.

Marker Making:

The measuring department determines the fabric yardage needed for each style and size of garment. Computer software helps the technicians create the optimum fabric layout to suggest so fabric can be used efficiently. Markers, made in accordance to the patterns are attached to the fabric with the help of adhesive stripping or staples. Markers are laid in such a way so that minimum possible fabric gets wasted during cutting operation. After marking the garment manufacturer will get the idea of how much fabric he has to order in advance for the construction of garments. Therefore careful execution is important in this step.

Spreading:

With the help of spreading machines, fabric is stacked on one another in reaches.

Cutting:

The fabric is then cut with the help of cloth cutting machines suitable for the type of the cloth.

Bundling:

This step requires much precision because making bundles of mismatched patterns can create severe problems. On each bundle there are specifications of the style size and the marker too is attached with it.

Sewing:

The sewing process is a sewing different parts of the cut pieces. In this workplace, there are many operators who perform a single operation. One operator may make only straight seams, while another may make sleeve insets. Yet another two operators can sew the waist seams, and make buttonholes. All these factors decide what parts of a garment can be sewn at that station. Finally, the sewn parts of the garment, such as sleeves or pant legs, are assembled together to give the final form to the clothing.

Inspection:

During this process of the quality control ,the section needs to check each prepared article against defects such as open seams, wrong stitching techniques, non- matching threads, and missing stitches.

Finishing:

The next operations are those of finishing. Molding may be done to change the finished surface of the garment by applying pressure, heat, moisture, or certain other combination. Pressing, pleating and creasing are the basic molding processes. Creasing is mostly done before other finishing processes like that of stitching a cuff.

Final Inspection:

For the textile and apparel industry, product quality is calculated in terms of quality and standard of fibers, yarns, fabric construction, color fastness, designs and the final finished garments. Quality control in terms of garment manufacturing, pre-sales and posts sales service, delivery, pricing, etc are essential for any garment manufacturer, trader or exporter.

Packing:

The finished garments are finally sorted on the basis of design and size and packed to send for distribution to the retail outlets.

CONCLUSION:

In this fabrication process, there are a lot of software used in order to easier the garment production. The software mainly use in large manufacture because they produce a mass production garment. Below is a list of software

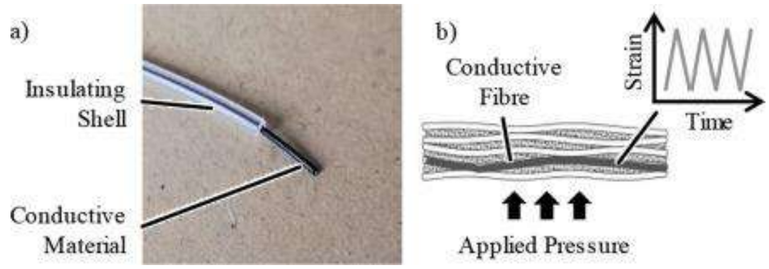
CAD System such as Textile Design Systems

- Digitizing System for apparel industry such as Lectra
- Grading System such as Gerber
- Marker making System such as OptiTex

CONDUCTIVE FIBRES:

Electrically conductive fibres can be divided into two main categories. These include intrinsically conductive fibres made from materials that are naturally conductive, and extrinsically conductive fibres that obtain electrical properties from the incorporation of conductive components to the base material. Intrinsically conductive fibres include those made from materials such as metals or carbon fibres. Intrinsically conductive polymers such as PANI or PPY are also suitable for fibre production. However, these are only available on the market in very small quantities and do not yet play a significant role due to their high price and simultaneously low or rapidly decreasing conductivity. Classical polymer fibres are electrical insulators. The category of extrinsically conductive fibres includes polymer fibres that are functionalised with conductive particles or coated with conductive materials. Silver-coated fibres such as Statex Shieldex have established themselves on the market and offer good electrical properties. The disadvantage of these coatings, however, is their proneness to abrasion and other wear phenomena typical for textiles). An alternative is the addition of conductive particles such as carbon nanotubes (CNTs), carbon blacks (CB), or graphene to the base polymer before it is spun into fibres. This approach promises higher resistance to mechanical wear, but yields only comparatively low conductivity.

Electrically conductive fibres can be integrated into various textile structures. Knitting, embroidery, and weaving are among the classic integration methods. To ensure a successful processing, particular design constraints and requirements are placed on the integration methods as well as on the conductive fibres. Depending on the application, the conductive yarns require special arrangements to provide sensing capabilities or maintain connectivity. The fibres to be integrated must meet process-specific requirements for bending radii, tensile strength, elongation, and surface resistance. In addition to the requirements for mechanical properties, the surface of the conductive fibres must also be coated with an insulating layer, depending on the application. The integration of electrically conductive fibres enables a variety of different applications in the field of smart textiles, whether as sensors for the monitoring of vital parameters, for the heating of outdoor clothing, or as control elements for external hardware.



A) Conductive biocomponent fibre with an insulating shell

B) Working principle of a sensor based on applied pressure

TREATED CONDUCTIVE FIBRES:

Various textile fibers in yarn forms were treated with aniline at different oxidative polymerization conditions to improve their electrical conductivities. In addition to the measurement of the electrical resistance, surface texture and fiber cross-sections were examined by an optical and a scanning electron microscope. Attenuated total reflection infra-red spectroscopy was used to detect the formation of polyaniline on the surface of fibers. An attempt was made to correlate the perceived colour of the treated samples via visible light reflection spectroscopy with electrical resistance. At proper condition of treatment, polyaniline formed on the surface of fibers improve the yarns conductivity. The decreases of electrical resistance in nylon. cotton and acrylics were found to be more than polyester and wool yarns. The changes in the mechanical properties of yarns after treatment were insignificant. The stability of different coating processes of polyaniline on the surface of cotton and acrylic yarns were compared.

CONDUCTIVE FABRICS:

Conductive fibres/yarns can be produced in filament or staple lengths and can be spun with traditional non-conductive fibres to create yarns that possess varying degrees of conductivity. Also, conductive yarns can be created by wrapping a non-conductive yarn with metallic copper, silver or gold foil and be used to produce electrically conductive textiles.

Conductive threads are typically finer and stronger than conductive yarns, with controlled conductivity through the placement of stitches. Conductive threads can be sewn to develop intelligent electronic textiles. Through processes such as electrodeless plating, evaporative deposition, sputtering, coating with a conductive polymer, filling or loading fibres and carbonising, a conductive coating can be applied to the surface of fibres, yarns or fabrics. Electrodeless plating produces a uniform conductive coating, but is expensive. Evaporative deposition can produce a wide range of thicknesses of coating for varying levels of conductivity. Sputtering can achieve a uniform coating with good adhesion. Textiles coated with a conductive polymer, such as PAn and PPy, are more conductive than metal and have good adhesion, but are difficult to process using conventional methods.

Adding metals to traditional printing inks creates conductive inks that can be printed onto various substrates to create electrically active patterns. The printed circuits on flexible textiles result in improvements in durability, reliability and circuit speeds and in a reduction in the size of the circuits. The inks withstand bending and laundering without losing conductivity. Currently, digital printing technologies promote the application of conductive inks on textiles.

CONDUCTIVE INK:

METALLIC PARTICLE INK:

Conductive ink is the most important component in printing of metallic structures. Several conductive materials could be considered for this purpose, such as conductive polymers, carbon, organic/metallic compounds, metal precursors and metal NPs. Most conductive inks are based on metal NPs. The reason for that is that their resistivity is close to that of bulk material (×2–3 times higher) as opposed to conductive polymers whose resistivity is higher. On the other hand, the use of organic/metallic compounds or metal precursors requires an additional heat treatment (>250°C) to reduce the precursors to metallic species. Fig. 3.5 shows the basic concept of preparation of metal NP. The particles (Fig. A) are inserted into a solvent at a certain loading ratio to provide the wanted viscosity. It results in a liquid solution, called the "the metal ink," with the nanoparticles in suspension (Fig. B). Fig. C shows an HR-SEM image of silver ink (from PVnanocell Ltd) after drying of the ink. Typical average size of the particle varies between 10 and 100 nm depending on the synthesis method.

Figure (A) Basic concept to explain metal ink preparation concept, (B) Silver NP ink in a small vial, and (C) HR-SEM of particle after evaporation of the solvent.

SILVER-BASED CONDUCTIVE INKS:

Silver-based conductive inks are mainly classified into two types: granular conductive inks and conductive inks without particles. For the granular conductive inks, the nozzle is often clogged when using inkjet printing, since the nanosilver particles are prone to agglomeration. In order to prevent agglomeration of the silver particles, it is necessary to add a polymer as the dispersion stabilizer. But it increases the content of the nonconductive substance in the silver conductive film, which is not advantageous to obtain a silver film with high conductivity. In addition, the addition of the dispersing agents cannot fundamentally solve nozzle clog. Therefore conductive inks without particles begin to draw attention. The conductive inks without particles are prepared through mixing a silver-containing precursor compound and some weak reductants. Some conditioning agent is then added to adjust the viscosity and surface tension. The aim is to finally obtain a conductive ink suitable for printing. In order to print on the flexible materials, it is required that the sintering temperature of the conductive ink should be as low as possible while having high conductivity. Silver citrate and silver carbonate are selected as the mixed metal precursor reactant to prepare conductive inks without particles. It allows the material to be printed and sintered on a flexible substrate which cannot bear high temperature to obtain a silver film with good conductivity.

CASE STUDY- SMART FABRIC FOR MONITORING BIOLOGICAL PARAMETERS:

ECG:

Smart clothing that can measure electrocardiogram (ECG) signals and monitor the health status of people meets the needs of our increasingly aging society. However, the conventional measurement of ECG signals is complicated and its electrodes can cause irritation to the skin, which makes the conventional measurement method unsuitable for applications in smart clothing.

As a wearable measurement device, a basic requirement is that the device should be put on a human body without affecting human activities such as working, exercise, and rest.

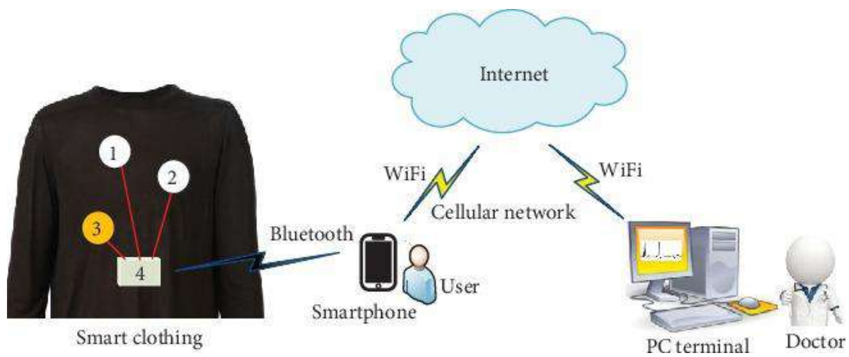
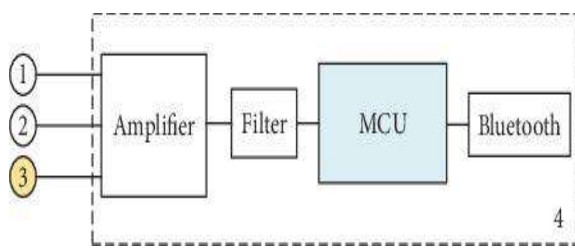


Fig 1 Wearable ECG measurement architecture based on smart clothing.

The system mainly consists of three subsystems: smart clothing, smartphone, and PC terminal. The three subsystems are connected together by some wireless communication technologies, such as WiFi, Bluetooth, cellular network, and Internet.

Some electrodes must be integrated with the smart clothing in order to measure ECG signals on the surface of the human body. These electrodes, made by conductive textile materials, should be soft and washable and should cause no irritation to the human skin, otherwise people will feel uncomfortable when wearing this kind of clothing and will not want to wear it again. Then, because the smart clothing is worn by a user in daily life to record the ECG signals for a long time, the numbers of the wearable electrodes on the smart clothing should be decreased in order that the electrodes have no effect on the users' daily life and work. And finally, the wearable electrodes should measure the ECG signals reliably.

Therefore only three ECG textile electrodes, made by silver-coated nylon yarns, shown as three circles and marked as numbers 1, 2, and 3 in Figure 1, are knitted into the fabric. The No. 1 and No. 2 electrodes are used to record the ECG signals on the body surface, while the No. 3 electrode fixed in the specific position on the user's body is used to obtain a reference potential that will help to reduce the common-mode interference between the two ECG signals. There is also a rectangle on the smart clothing marked as number 4 in Figure 1. It is a signal receiver that connects to the three ECG electrodes by conductive textile yarns, and it can transmit the ECG signals acquired to a smartphone. The block diagram of the signal receiver is described in Figure 2 .



Block diagram of signal receiver.

The signal receiver is designed based on an embedded system technology. Its components include a differential amplifier, a bandpass filter, a Microcontroller Unit (MCU), and a Bluetooth module. The differential amplifier can suppress the common-mode noise and amplify the ECG voltage from the textile electrodes. The bandpass filter has the frequency range of 0.04 Hz to 150 Hz and is aimed at removing baseline drifts and power line harmonics in the

ECG signals. And the MCU can reconstruct the ECG signals and then transmit the signals to a smartphone by Bluetooth. The signal receiver is powered by the minibutton battery.

The smartphone based on the IOS or Android operating systems will act as a portable device. When some special App programs designed for the processing of ECG signals are installed on the smartphone, the smartphone can display the ECG signals in real time for the user of the smart clothing, which allows the user to know his/her heart parameters anytime and anywhere. Moreover, the smartphone can immediately transmit the ECG signals received from the smart clothing to a remote PC terminal through WiFi or cellular network.

The PC terminal, however, can store large amounts of ECG signals transmitted from the smartphone for a long time. Some special programs are also designed and installed on the PC terminal in order for local or remote doctors to accurately diagnose the user's health status.

RESPIRATION:

The smart textile for monitoring several temporal respiratory parameters (ie, breath-by-breath respiratory period, breathing frequency, duration of inspiratory and expiratory phases), volume variations of the whole chest wall and of its compartments is performed on 8 healthy male volunteers. Values gathered by the textile are compared to the data obtained by a motion analysis system, used as the reference instrument. Good agreement between the 2 systems on both respiratory period (bias of 0.01 seconds), breathing frequency (bias of -0.02 breaths/min) and tidal volume (bias of 0.09 L) values is demonstrated. Smart textile shows good performance in the monitoring of thoraco-abdominal pattern and its variation, as well.

UNIT V

APPLICATIONS OF WEARABLE SYSTEMS

MEDICAL DIAGNOSTICS:

The diagnostic wearable medical devices market is the growing demand for early diagnosis and preventive medicine. Diagnostic wearable devices enable individuals to obtain real-time data, thus allowing them to track their health status. These devices include biosensing clothing, vital signs monitors, neuromonitoring devices, sensor-embedded equipment, wristband devices for sports and fitness, and sleep rate monitoring devices. Wearable devices help people monitor and track calorie intake, fitness level, and sleep patterns. Wearable devices also help individuals in the early diagnosis of any chronic diseases.

However, data privacy issues will be a major challenge for the diagnostic wearable medical devices market during the forecast period. The implications of giving up one's health data are huge. These devices share an enormous amount of data associated with personal health and fitness to an unquantifiable audience. Most of the wearable devices are small but they are capable of storing a large amount of data. The small size of these devices implies that the chance of losing or misplacing the data is high. Furthermore, wearable devices use a Global positioning system (GPS)do to retrieve location-based information. In some instances, people have to share their location to obtain certain information. This information can be saved and used by advertisers as well. Besides, the data of a subscriber's location is owned and controlled by the respective network operators, including mobile carriers and mobile content providers. With operators having such information, end-users are concerned about their privacy, despite legal frameworks to safeguard it.

DIAGNOSTIC WEARABLE MEDICAL DEVICES:

- **Device**
  - Vital Signs Monitors
  - Sleep And Activity Monitors
  - Fetal And Obstetric Monitoring Devices
  - Neuromonitoring Devices
  - ECG Monitors
- **Application**
  - Home Healthcare
  - Sports And Fitness

- Remote Patient Monitoring

MEDICAL MONITORING:

The combination of an ageing population and the increase in chronic disease has greatly escalated health costs. It has been estimated that up to 75% of healthcare spending is on chronic disease management (mainly cardiovascular disease, cancer, diabetes and obesity) (World Health Organization 2010). It is now widely recognized that there is a need to radically change the present Healthcare systems, historically based on costly hospital-centred acute care, and make them more appropriate for the continuous home-based management of chronic diseases. The goals of the new approach are the improved management of the chronic disease through encouraging lifestyle changes and the effective early detection and treatment of any problem before it necessitates costly emergency intervention.

The most recent European technology and innovation funding programme initiative using such an approach is termed Ambient Assisted Living (AAL). AAL aims to prolong the time people can live in a decent more independent way by increasing their autonomy and self-confidence by improved monitoring and care of the elderly or ill person while ultimately saving resources.

The main objective is to develop a wearable light device able to measure specific vital signs of the elder or ill person, to detect falls and to communicate autonomously in real time with his/her caregiver in case of an emergency, wherever they are. There is, therefore, an urgent need of novel monitoring systems, which include new sensor technologies, mobile technologies, embedded systems, wearable systems, ambient intelligence, etc., which are capable of conveniently, discreetly and robustly monitoring patients in their homes and while performing their daily activities without interfering significantly with their comfort or lifestyle

It is often vital to monitor in an ambulatory situation the following parameters: Heart activity (ECG, heart rate, blood pressure, pulse); Lung activity (respiration rate, respiration depth, tidal volume, oxygen saturation); Brain activity (EEG, vigilance, relaxation); Digestion (gastric emptying); Emotions and stress levels; Body characteristics (temperature, posture, position, activity), etc. Some of these parameters are already catered for to some degree, e.g. Holter systems for Cardiac activity have been widely used for many years and, as a result, have greatly increased understanding of heart disease and have led to significant improvements in patient care. Other important physiological functions have not benefited to the same degree due to the difficulties in obtaining accurate measurements outside of a laboratory, for example for assessing breathing or stress. One apparent area for application of this new technology is the monitoring of breathing patterns over extended periods in the study of respiratory disorders such as chronic obstructive pulmonary disease, pulmonary emphysema, restrictive lung disease, or asthma. Hitherto unexplored parameters should therefore not be ignored by scientists; however, the situation is something of a "catch 22." If the sensor systems do not as yet exist, there is often little clinical demand for them until they do and their relevance established by a pioneer. The design and relevance of wearable sensing systems will depend on, and will determine, the ambulatory monitoring applications.

"Holter-Type" Monitoring:

In many clinical areas, it is important to record measurements on patients over extended periods (generally for a maximum of a few days) as the patient goes about their every-day-life to accurately diagnose their condition. Again, the ECG Holter monitor would be the best known example. Often symptoms do not present themselves "on cue" in the doctor's surgery and hence the need for ambulatory monitoring, for example to detect periodic arrhythmias, to detect the location of an epileptic focus, or to study breathing difficulties. Such continuous recording furnishes clinicians with a much clearer picture than the occasional "snapshot" collected during a patient visit. Multi-parametric continuous ambulatory monitoring helps quantify the number of events, differentiate between several possible causes and helps identify any contributing factors such as stress, sleep, food, medications, activity, etc. For example, emotions and stress can affect a wide range of conditions and hence the concurrent monitoring of the former helps assess their contributions much more effectively than the usual patient diaries or retrospective reports. [An additional advantage of unobtrusive ambulatory monitoring systems is the avoidance of the well known "white coat" syndrome in which patients exhibit elevated blood pressures in clinical settings due to their increased anxiety in a clinic environment.] Multi-parametric monitoring which includes measures of posture and activity also help identify and possibly compensate for the effects of movement-induced artefacts on the other parametric traces. In "Holter-type" diagnostic recording applications, it is not always necessary to transmit the monitored data continuously to a remote monitoring station. Often the recorded data is accessed at the end of the recording period and/or transmitted periodically.

“Post-Intervention” Monitoring:

In post-intervention monitoring, such as that of a heart attack victim recovering in a coronary care unit, there is a role for “Holter-type” monitoring systems to progressively “un-tether” the patient from their bed and to encourage them to take part in some closely monitored movement and recreation for their physical and mental well-being. In such applications, the sensors will be accurately applied by clinical staff and the parameters monitored continuously. Such monitors are vital in assessing the efficacy of on-going treatment and in the planning of subsequent medication/treatment. As patients heal, there is a continued need for their monitoring as they gradually re-integrate into normal everyday life. As they do, the design of the monitoring systems, the sensors and positions used and the handling of the data will alter. As part of their rehabilitation, cardiac patients, for example, are encouraged to exercise while still in hospital or later on an out-patient basis. Patients are generally wary of doing so due to the fear of having a further heart attack. Apart from the use of stationary treadmills and exercise bikes, many exercise regimes do not lend themselves to the continuous monitoring of patients and there is therefore a need of ambulatory monitoring systems, if only to reassure the patient. The design of such systems would more optimally be in the form of a suitable wearable “smart garment” or “smart patch” (see next section). It would be preferable, given the vulnerability of the patient, that the measured data be monitored continuously; either remotely by a member of clinical staff or through onboard data processing coupled with the capability of alerting supervising staff.

“On-Demand” Monitoring:

As patients recover and return home, they may still require medical assessment of their condition from time to time. The same applies to those diagnosed with chronic diseases or perhaps to the “worried well” with a significant family history of a serious disease. In some cases, “continuous” measurement may be required, for example in the continuous measurement and control of glucose concentrations in diabetics, enabling the provision of better adjustment of insulin dosage. In this case, however, a clinician does not need to be involved, or at least only on an intermittent basis. Regular checks can be arranged with a patient’s general practitioner or, more conveniently, can be carried out remotely using home-based monitoring systems. In the next section, for example, a cancer detecting bra is presented which incorporates temperature sensors to detect cancer related changes in breast tissue. The question arises, however, does the patient really need to have such a system incorporated into an item of clothing or would it not be more appropriate to simply have some form of monitoring system housed, for example, in the patient’s bathroom.

There exists a significant need for “on-demand” (rather than continuous) “clinical support” for patients on the move. For example, a recovering heart attack victim may feel the occasional chest twinge and desire urgent medical feedback. “Smart garments” are generally not appropriate for such applications as the patient cannot be expected to wear such a system everyday if the need is only very occasional. However, a small, portable monitoring system, a sort of “professional-in-mypocket” would be more suitable and patient-compliant, especially if it is integrated into a standard accessory such as a wallet, watch or mobile phone. Depending on the condition, such an “on-demand” system could give direct feedback to the patient and/or send the information to a remote monitoring station. Some portable devices already exist, for example the Personal ECG monitor (PEM) from the European IST EPI-MEDICS project includes a reduced easy to place lead set that allows reconstruction of the standard 12-lead ECG and embeds intelligence that decides when and where to send the ECGs, when needed . A further example is SHL Telemedicine’s CardioSen’C™ personal cellular-digital 12-lead ECG monitor capable of transmitting to their Telemedicine monitoring centre via any type of phone connection, including regular fixed lines and cellular phones. The healthcare team at the SHL monitoring centre evaluates the transmitted data and provides immediate feedback and reassurance to the patient/subscriber. When necessary, they will instruct the patient on what action to take and/or contact emergency medical services, providing them with all the available medical data, thus saving critical time and ensuring rapid diagnosis and treatment. The success of such an approach obviously depends on the ability of the patient to apply the sensors in the correct anatomical positions. This will in turn depend on the design of the system and on the circumstances of the patient. From a design point of view, the accurate location of the sensors for the recording of many “vital sign” parameters is not trivial and warrants much research as misplaced sensors can give rise to misdiagnoses. Medical conditions which require the relatively straightforward application of sensors can enable the direct feedback to patients to reassure them or to encourage lifestyle changes. Such direct feedback to patients can be used to empower and motivate them, improve their awareness and potentially allow them to better control their condition.

MONITORING PATIENTS WITH CHRONIC DISEASE:

Stroke:

The scale of the requirement for patient monitoring in healthcare systems can only be appreciated once the magnitude of human disease processes requiring early diagnosis and treatment is considered. Several examples illustrate this need, but none as dramatically as cardiovascular related illnesses. Abnormalities of heart rhythm (arrhythmias) such as *atrial fibrillation* are commonly encountered in clinical practice, occurring in as many as 4% of the population over the age of 60, increasing with age to almost 9% in octogenarians. Early symptoms of atrial fibrillation include fatigue and palpitations, and often lead to the patient seeking medical advice. *Electrocardiography* (ECG) is eventually performed along with other investigations, and as soon as the diagnosis is made treatment is begun to try and prevent the longer-term complications of tachycardia (rapid heart rate), mediated cardiomyopathy (resulting in heart failure) and stroke. To prevent stroke, the patient is often placed on anticoagulant (blood thinning) medication placing them at risk of potential bleeding complications from this therapy. All of this results in a two-fold increase in mortality in this elderly patient group, independently of other risk factors. Apart from early detection of this condition using ECG so that prompt treatment can be initiated, regular monitoring is required to ensure control of the heart rate, which results in prevention of much of the associated morbidity and mortality. BSNs offer the chance to diagnose cardiac arrhythmias earlier than ever in “at risk” groups such as the elderly, as well as the ability to monitor disease progression and patient response to any treatment initiated.

HYPERTENSION:

High blood pressure (*hypertension*) is another cardiovascular disease thought to affect approximately 50 million individuals in the United States alone. The diagnosis of this disease is often made in an otherwise asymptomatic patient who has presented to their doctor for other reasons. This condition can, if untreated, result in end-organ failure and significant morbidity; ranging from visual impairment to coronary artery disease, heart failure, and stroke. *Heart failure* in turn affects nearly five million people every year in the United States, and is a contributory factor in approximately 300,000 deaths each year. Early diagnosis of high blood pressure is important for both controlling risk factors such as smoking and high cholesterol,
but also for early initiation of antihypertensive treatment. The diagnosis is confirmed using serial blood pressure measurements, and once treatment is commenced this is titrated to the required effect by monitoring the patient’s blood pressure over a period of weeks or months. Once a patient has been diagnosed with hypertension, they require regular blood pressure monitoring to ensure adequacy of therapy. Indeed over a patient’s life, the pharmacotherapy they receive may be altered many times. One can imagine how labour-intensive blood pressure monitoring in these patients can be, often requiring several visits to clinics. Although home blood pressure testing kits have been made available, the limitations of these devices are their dependence on the

operator and patient motivation. Recently, a new category termed "*prehypertension*" has been identified and may lead to even earlier initiation of treatment. BSNs would allow doctors to monitor patients with seemingly high blood pressure during their normal daily lives, correlating this to their other physiology in order to better understand not only the disease process but also to decide what therapy to start the patient on, and to monitor their response to this therapy.

Diabetes mellitus:

Diabetes mellitus is a well-known chronic progressive disease resulting in several end-organ complications. It is a significant independent risk factor for hypertension, peripheral vascular, coronary artery, and renal disease amongst others. In the United States, the prevalence of diabetes mellitus has increased dramatically over the past four decades, mainly due to the increase in prevalence of obesity. It is estimated that annually 24,000 cases of diabetes induced blindness are diagnosed, and 56,000 limbs are lost from peripheral vascular disease in the United States alone. The diagnosis is often made from measuring fasting blood glucose (which is abnormally raised) either during a routine clinical consultation, or as a result of complications of the condition. Once such acute complication is diabetic keto-acidosis which can be life threatening, and can occur not only in newly diagnosed diabetics, but also in those with poor blood sugar control due to reduce compliance with medication. Once diagnosed, these patients require the regular administration of insulin at several times during the day, with blood glucose "pinprick" testing used to closely monitor patients' blood sugar in between these injections. This need for repeated drawing of blood is invasive and therefore undesirable for many patients, yet there is at present no clear reliable alternative. As previously mentioned, variable treatment compliance rates (60-80% at best) in these patients are made worse the fact that they are on multiple medications. BSN technology used in the monitoring of this group would allow the networking of wireless implantable and attachable glucose sensors not only to monitor patient glucose levels but also to be used in "closed feedback loop" systems for drug (insulin) delivery, as described later on in this chapter. Although the three chronic conditions mentioned above illustrate the need for continuous physiological and biochemical monitoring, there other examples of disease processes that would also benefit from such monitoring.

Monitoring Hospital Patients:

In addition to monitoring patients with chronic diseases, there are two other specific areas where BSN applications offer benefit. The first of these is the hospital setting, where a large number of patients with various acute conditions are treated every year. At present, patients in hospital receive monitoring of various levels of intensity ranging from intermittent (four to six times a day in the case of those suffering with stable conditions), to intensive (every hour), and finally to continuous invasive and non-invasive monitoring such as that seen in the intensive care unit. This monitoring is normally in the form of vital signs measurement (blood pressure, heart rate, ECG, respiratory rate, and temperature), visual appearance (assessing their level of consciousness) and verbal response (asking them how much pain they are in). Patients undergoing surgery are a special group whose level of monitoring ranges from very high during and immediately after operation (under general anaesthesia), to intermittent during the post-operative recovery period. Aside from being restrictive and "wired", hospital ward-based patient vital signs monitoring systems tend to be very labour intensive, requiring manual measurement and documentation, and are prone to human error. Automation of this process along with the ability to pervasively monitor patients wherever they are in the hospital (not just at their bedside), is desirable not only to the healthcare provider, but also to the patient. In the post-operative setting, the use of implantable micro-machined wireless sensors to monitor the site of the operation has already begun, with a sensor being used to monitor pressure in the aneurysm sac following endovascular stenting. The next step for any "hospital of the future" would be to adopt a ubiquitous and pervasive in-patient monitoring system enabling carers to predict, diagnose, and react to adverse events earlier than ever before. Furthermore, in order to improve the efficiency of hospital systems, the movements of patients through its wards, clinics, emergency departments and operating theatres may be tracked to try and understand where workflow is being disrupted and may be streamlined. This would help, for example, to maintain optimal capacity to cater for elective (planned) admissions whilst having the ability to admit patients with acute illnesses.

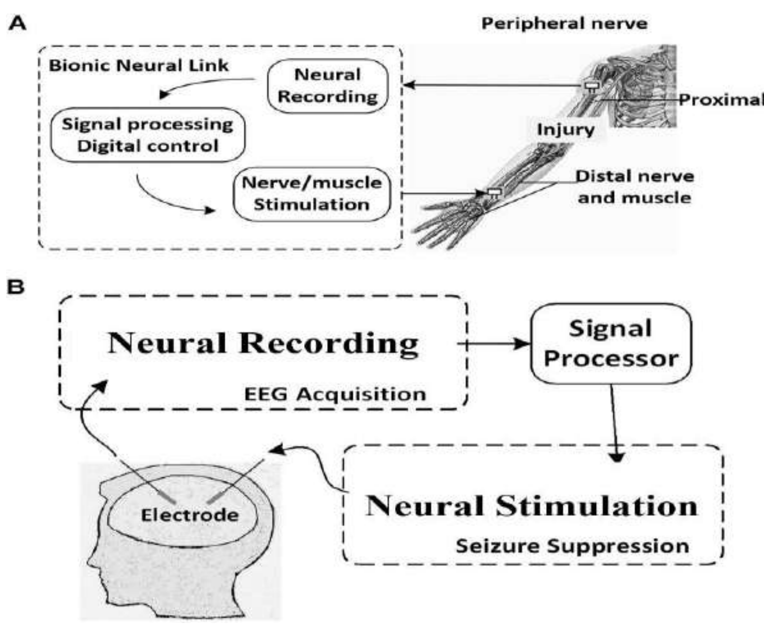
Table 1.2 Disease processes and the parameters commonly used to monitor these diseases. Suggested sensor types for measurement of these parameters are listed in brackets. All of these conditions currently place a heavy administrative and financial burden on healthcare systems, which may be reduced if they are reliably detected.

Disease Process	Physiological Parameter (BSN Sensor Type)	Biochemical Parameter (BSN Sensor Type)
Hypertension	Blood pressure (*implantable/ wearable mechanoreceptor*)	Adrenocorticosteroids (*implantable biosensor*)
Ischaemic Heart Disease	*Electrocardiogram* (ECG), cardiac output (*implantable/ wearable ECG sensor*)	Troponin, creatine kinase (*implantable biosensor*)
Cardiac Arrhythmias/ Heart Failure	Heart rate, blood pressure, ECG, cardiac output (*implantable/wearable mechanoreceptor and ECG sensor*)	Troponin, creatine kinase (*implantable biosensor*)
Cancer (Breast, Prostate, Lung, Colon)	Weight loss (body fat sensor) (*implantable/ wearable mechanoreceptor*)	Tumour markers, blood detection (urine, faces, sputum), nutritional albumin (*implantable biosensors*)
Asthma / COPD	Respiration, peak expiratory flow, oxygen saturation (*implantable/ wearable mechanoreceptor*)	Oxygen partial pressure (*implantable/wearable optical sensor, implantable biosensor*)
Parkinson's Disease	Gait, tremor, muscle tone, activity (*wearable EEG, accelerometer, gyroscope*)	Brain dopamine level (*implantable biosensor*)
Alzheimer's Disease	Activity, memory, orientation, cognition (*wearable accelerometer, gyroscope*)	Amyloid deposits (brain) (*implantable biosensor/EEG*)
Stroke	Gait, muscle tone, activity, impaired speech, memory (*wearable EEG, accelerometer, gyroscope*)	
Diabetes	Visual impairment, sensory disturbance (*wearable accelerometer, gyroscope*)	Blood glucose, glycated haemoglobin (HbA1c). (*implantable biosensor*)
Rheumatoid Arthritis	Joint stiffness, reduced function, temperature (*wearable accelerometer, gyroscope, thermistor*)	Rheumatoid factor, inflammatory and autoimmune markers (*implantable biosensor*)
Renal Failure	Urine output (*implantable bladder pressure/volume sensor*)	Urea, creatinine, potassium (*implantable biosensor*)
Vascular Disease (Peripheral vascular and Aneurisms)	Peripheral perfusion, blood pressure, aneurism sac pressure. (*wearable/implantable sensor*)	Haemoglobin level (*implantable biosensor*)
Infectious Diseases	Body temperature (*wearable thermistor*)	Inflammatory markers, white cell count, pathogen metabolites (*implantable biosensor*)
Post-Operative Monitoring	Heart rate, blood pressure, ECG, oxygen saturation, temperature (*implantable /wearable and ECG sensor*)	Haemoglobin, blood glucose, monitoring the operative site. (*implantable biosensor*)

Monitoring Elderly Patients:

The second scenario where BSNs may prove invaluable is for the regular and nonintrusive monitoring of “at risk” population groups such as the elderly. With people in industrialised nations living longer than ever before and an increase in average life expectancy of more than 25 years, the size of this group is set to increase, along with its potential demand upon healthcare resources. Identifying ways of monitoring this aging population in their home environment is therefore very important, with one key example of the usefulness of this approach being the vulnerable periods during months of non-temperate weather. There is evidence to suggest that at times of the year when weather conditions are at their extremes (either very cold or very hot), elderly patients are at increased risk of requiring hospital admission. They are at risk because they are not able to seek medical help early enough for simple and treatable conditions, which eventually may lead to significant morbidity. An example of this is an elderly individual who lives alone and acquires a chest infection, which he fails to identify and seek help for until the infection requires hospital admission, or even ventilatory support. This could all be potentially avoided if the infection, or change in patient habits as a result of this infection, was picked up early and antibiotic therapy initiated. Examples illustrating how people behave differently at the onset of illnesses include a decrease in appetite, a reduction in movement, and propensity to stay indoors. When correlated with physiological vital signs measurement, this system has the potential to clearly identify those most at risk. It is also demonstrates an instance in which a WSN (set up in the patient's home) and a BSN (on the patient's body) may overlap in their applications. It may be, therefore, that monitoring elderly patients in their home environment during non-temperate weather will allow earlier detection of any deterioration in their condition, for which prompt treatment may reduce the need for hospital admission, associated morbidity and even mortality. The concept of an unobtrusive "home sensor network" to monitor an elderly person's social health (giving feedback not only to that person's carers and family members, but also to the elderly individual themselves) is one that is being developed by several companies such as Intel. Whilst such a sensor network attempts to monitor well-being by identifying the individual and the level of activity they are undertaking, it is easy to see how this network could communicate with a body sensor network relaying physiological data about the individual. Combining these two networks would allow for a much better appreciation of the context in which the sensing is taking place.

Neural Recording:



(A) The Bionic Neural Link

(B) The epileptic seizure detection and suppression using neural recording and stimulation circuits.

The neural prosthesis chip for biomedical use includes the neural/muscular stimulators and neural recording circuits. In these circuits, the stimulator has been widely used in biomedical applications for decades, such as cardiac pacemaking, cochlear/retinal prosthesis, and cell activation. The neural recording circuit is also involved in these applications to sense the neural signal or assess stimulation efficacy and the tissue status to enable closed-loop control in simultaneous neural recording and stimulation. The circuits for simultaneous neural recording and stimulation are used in neural prostheses, such as the bionic neural link for limb function restoration.

The bionic neural link includes neural recording circuits, stimulation circuits, and action potential (AP) detection circuits . As shown in Figure, once the AP is detected in the circuit, the bionic neural link bypasses the injury and triggers the stimulator to stimulate the distal nerve/muscle and restore the limb function. The integrated circuit (IC) modules and the working theories will be illustrated in detail in the following sections.

SPORTS MEDICINE:

Sports medicine is a branch of medicine that deals with physical fitness and the treatment and prevention of injuries related to sports and exercise. Sports medicine is not just for professional athletes.

When you injure yourself during exercise or while playing a sport, you want to return to your routine and athletic pursuits as soon as possible. Sports medicine doctors have specialized training to help you do just that. They're also experienced with preventing illness and injury in active kids, adults, and people with physically demanding jobs.

A physician often leads a sports medicine team. Most sports medicine doctors are board-certified in a specialty such as family medicine, orthopedics or pediatrics, and then they pursue additional training in sports medicine.

There are other non-physician medical professionals who are critical to delivering care in sports medicine. They include physical therapists, certified athletic trainers and nutritionists. They each play an essential role in your care:

- **Physical therapists** help you rehabilitate and recover from injuries.
- **Certified athletic trainers** offer rehabilitative exercises to help you regain strength and develop programs to prevent future injury.
- **Registered dieticians** help you with needed weight loss or weight gain, and they offer dietary advice to help you improve how well your body is functioning.

Sports medicine doctors, physical therapists, certified athletic trainers and dieticians work together to help you get back to your physical activities as quickly as possible.

Common injuries treated in sports medicine

Being active and playing sports are so good for you physically and mentally. But there is an inherent risk of injury. Below are some of the common injuries we see in sports medicine:

- Ankle sprains
- Fractures
- Knee and shoulder injuries
- Tendonitis
- Exercise-induced asthma
- Heat illness
- Concussions
- Eating disorders
- Cartilage injuries