Smart Sensors and Vital Parameters

UNIT I PART II

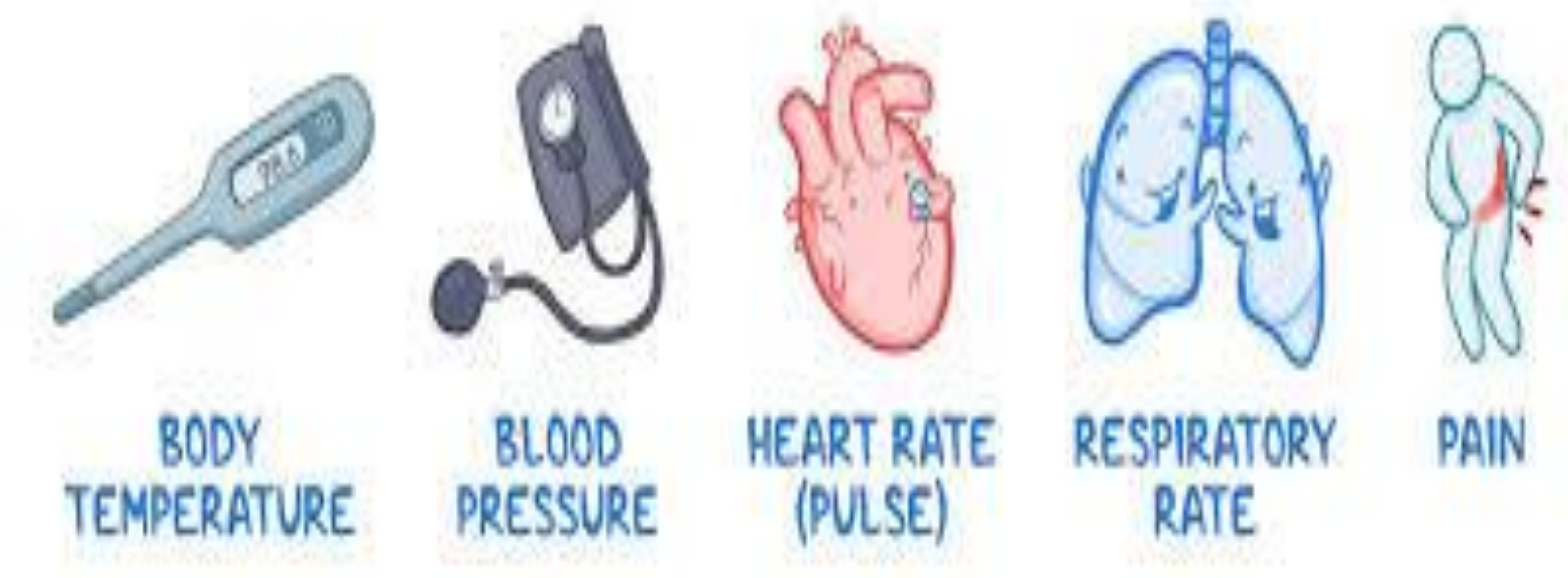
Smart Sensors

Sensors’ importance is constantly growing as a component of overall solutions for environment monitoring and assessment, eHealth (digital healthcare) and Internet of Things (IoT). Besides, there are plenty of appearing sensor applications to spread across large areas while retaining flexibility and comfortability. The sensor market will exceed trillion sensors per year soon. Therefore, for smart sensor development, the manufacturing should be low cost, high output and with short fabrication cycles

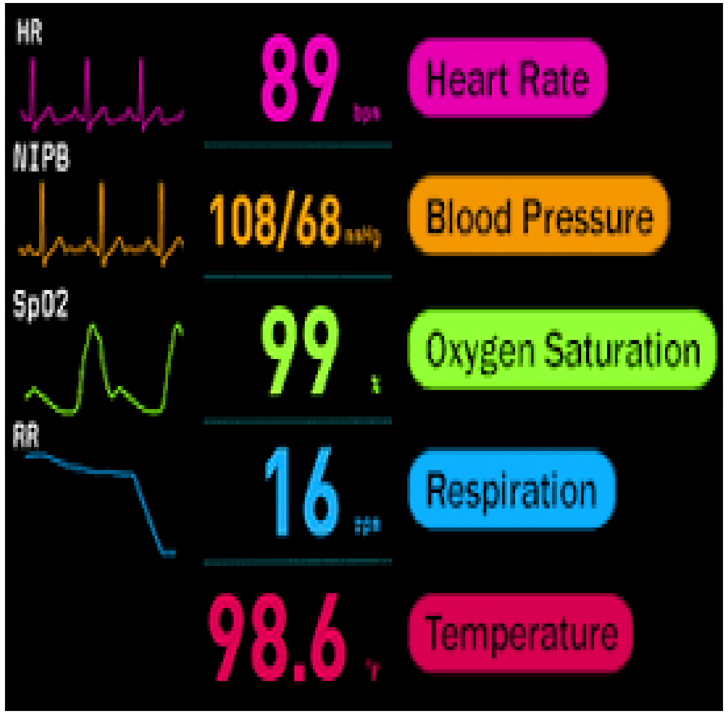
Smart sensor is a device that samples signals taken from the physical environment and processes them with its built-in computing resources before passing them to a centralized sensor hub. Smart sensors are key integral elements of the IoT notion. One implementation of smart sensors is as components of wireless sensor networks (WSNs) whose nodes can number in thousands, each of which is connected with other sensors and with the centralized hubs.

Smart sensors have numerous applications including scientific, military, civil, and home applications.

Vital Signs



BODY TEMPERATURE
BLOOD PRESSURE
HEART RATE (PULSE)
RESPIRATORY RATE
PAIN



HR
89
Heart Rate
NIPB
108/68
Blood Pressure
SpO2
99
Oxygen Saturation
RR
16
Respiration
98.6
Temperature

Why Vital Signs Monitoring Matters

Vital signs monitoring is **crucial for living a long and healthy life**. Vitals gives us a glimpse into our overall wellbeing. They signal early signs of an infection, prevent a misdiagnosis, detect symptom-less medical problems, and encourage us to make better choices.

1. Assess Your Wellbeing

2. Prevent Misdiagnosis

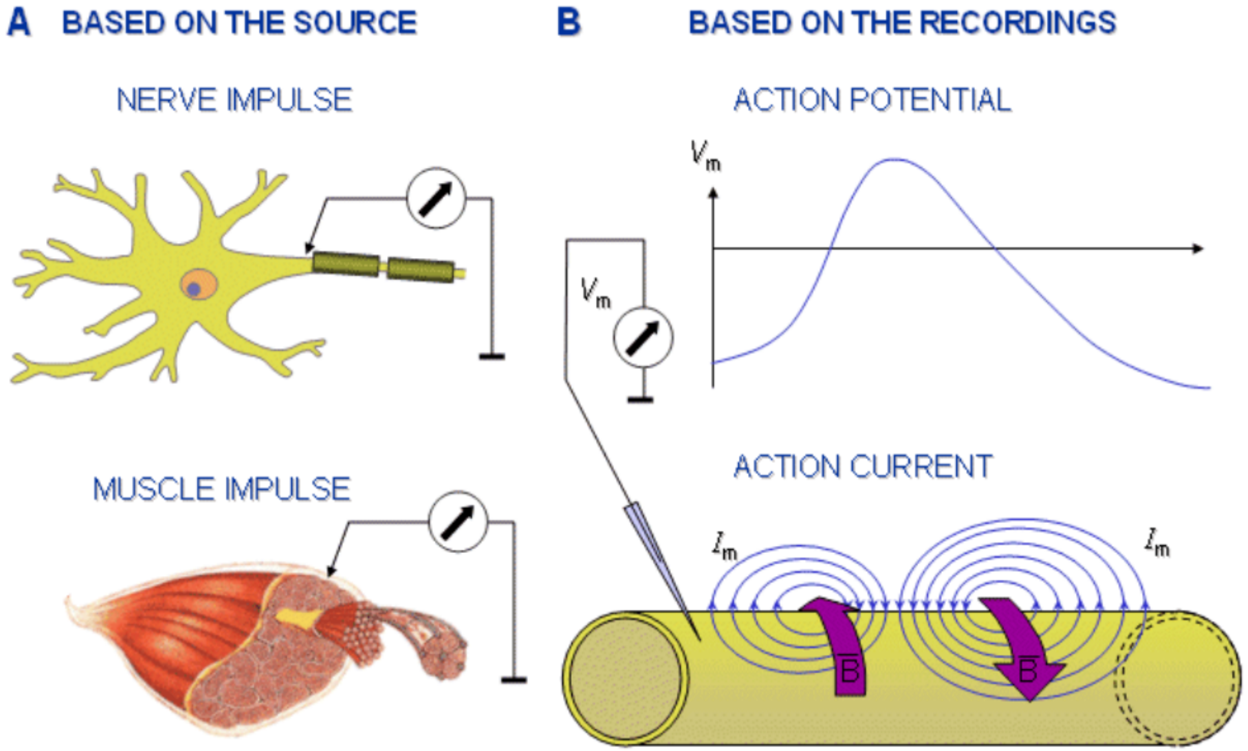
3. Detect Underlying Health Problems

4. Motivate Lifestyle Changes

What are Bio-potentials

Bio-potential: An electric potential that is measured between points in living cells, tissues, and organisms, and which accompanies all biochemical processes.

- Also describes the transfer of information between and within cells
- This book focuses strictly on the measurement of potentials



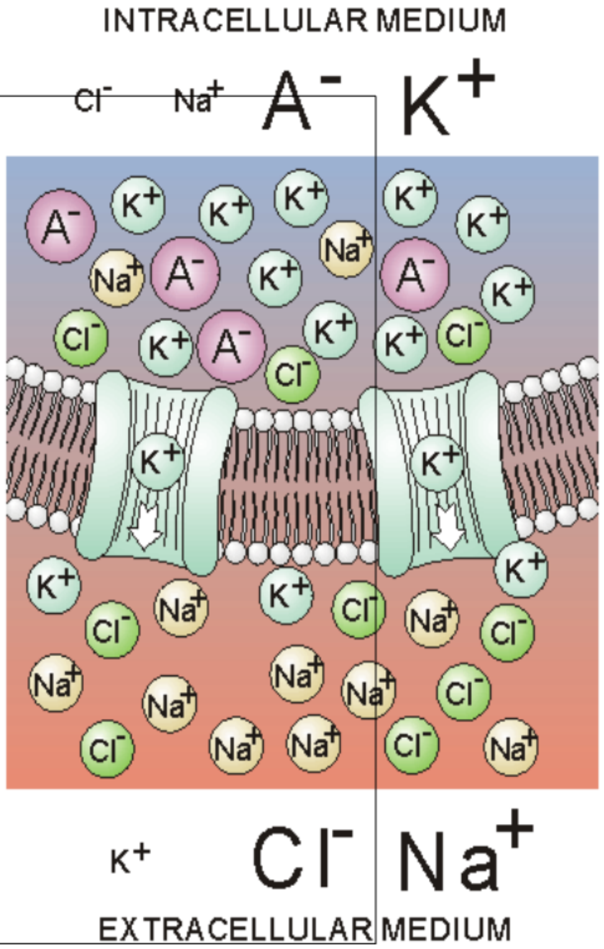
Mechanism Behind Bio-potentials

- Concentration of potassium (K^+) ions is 30-50 times higher inside as compared to outside
- Sodium ion (Na^+) concentration is 10 times higher outside the membrane than inside
- In resting state the member is permeable only for potassium ions
  - → Potassium flows outwards leaving an equal number of negative ions inside
  - → Electrostatic attraction pulls potassium and chloride ions close to the membrane
  - → Electric field directed inward forms
  - → Electrostatic force vs. diffusional force
- Nernst equation:

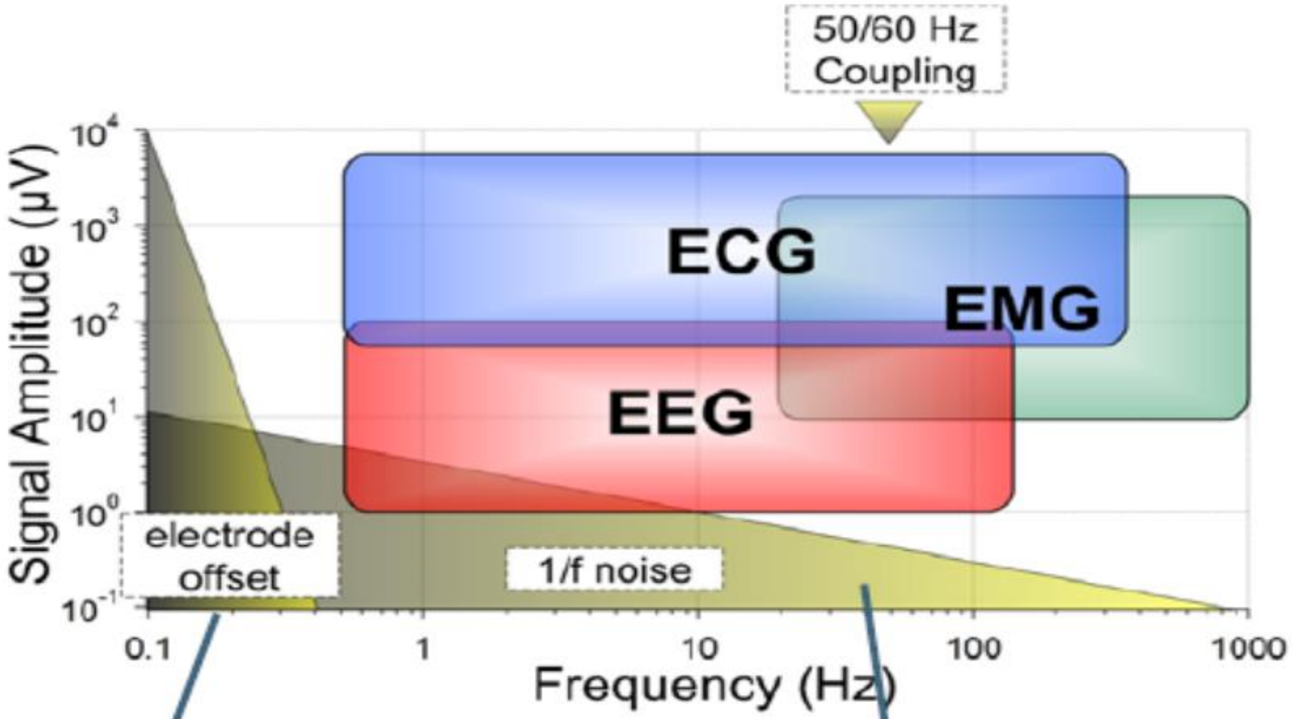
$$V_k = -\frac{RT}{z_k F} \ln \frac{c_{i,k}}{c_{o,k}}$$

- Goldman-Hodgkin-Katz equation:

$$V_m = -\frac{RT}{z_k F} \ln \frac{P_K c_{i,K} + P_{Na} c_{i,Na} + P_{Cl} c_{i,Cl}}{P_K c_{i,K} + P_{Na} c_{i,Na} + P_{Cl} c_{i,Cl}}$$



$$V_m \approx -70 \ldots -100\, mV$$



DC input to the readout due to Half-cell potential mismatch

1/f noise of the CMOS transistors

Application-specific requirements

- ECG amplifier
  - Lower corner frequency 0.05 Hz, upper 100Hz
  - Safety and protection: leakage current below safety standard limit of 10 uA
  - Electrical isolation from the power line and the earth ground
  - Protection against high defibrillation voltages
- EEG amplifier
  - Gain must deal with microvolt or lower levels of signals
  - Components must have low thermal and electronic noise @ the front end
  - Otherwise similar to ECG
- EMG amplifier
  - Slightly enhanced amplifier BW suffices
  - Post-processing circuits are almost always needed (e.g. rectifier + integrator)
- EOG amplifier
  - High gain with very good low frequency (or even DC) response
  - DC-drifting → electrodes should be selected with great care
  - Often active DC or drift cancellation or correction circuit may be necessary

Dry Electrodes

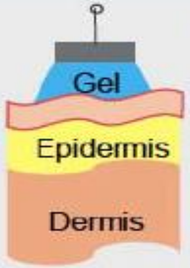
- What are Dry Electrode's
  - Does not require skin preparation
  - Skin Impedance is very high
  - Requires Good front-end amplifier design
  - Electrodes may require a active amplification
  - Comfortable
  - Long Duration Monitoring is Possible
  - No Skin rashes or irritations
  - No degradation of signal quality

	Conventional Wet-gel electrodes	Dry electrodes
preparation	• abrasive gel • cleaning by alcohol • use conductive gel	No need for preparation
Set-up	• expertise needed • time consuming	• easier • faster
Long-term usage	signal degradation due to gel drying	no signal degradation
User comfort	• irritation • discomfort when cleaning gel after use	depends on design and material

Types of Electrodes

Wet Contact

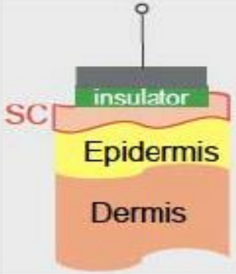
10-40 µm Stratum Corneum (SC) → high impedance



Gel: Reduce electrode-skin impedance and motion artifact

Dry Non-contact

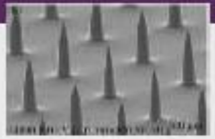
Capacitive

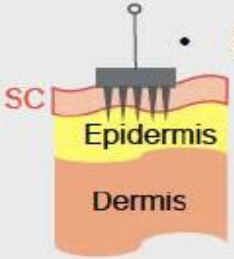


- Extremely sensitive to motion artifact
- signal very small → active electrodes (pre-amplification) and shielding needed
- safe

Dry Contact

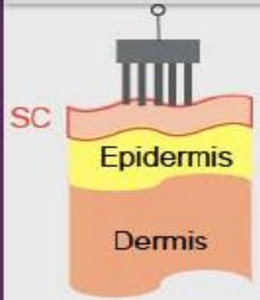
Invasive





- biomedical safety issue
  → biocompatible materials needed
  → more expensive fabrication

Non-invasive



- high impedance (electrode-SC layer)
- prone to motion artifact
- active electrodes needed for weaker biopotential signals

Dry Contact Electrodes

- **Flat foam electrodes**

  Conductive material or with conductive coating layer
  ➔ suitable for hairless position (forehead)

- **Metal electrodes**

  Hard ➔ uncomfortable

- **Metal electrodes + spring**

  Complex ➔ expensive

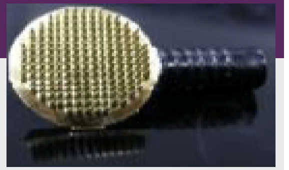
➔ polymer-based

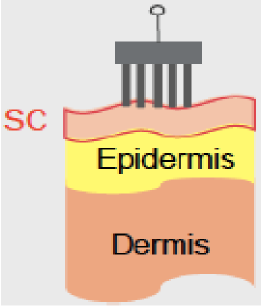
electrodes are presented

- ◇ **flexible**
- ◇ **comfortable**

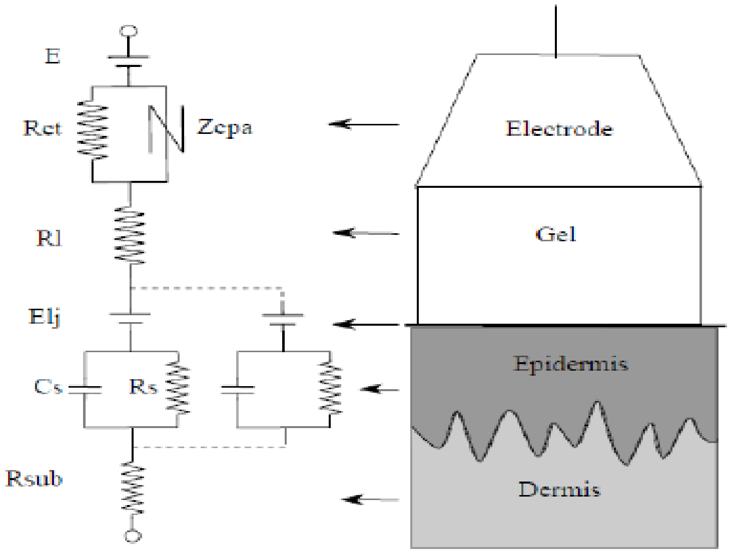
Dry Contact

Non-invasive



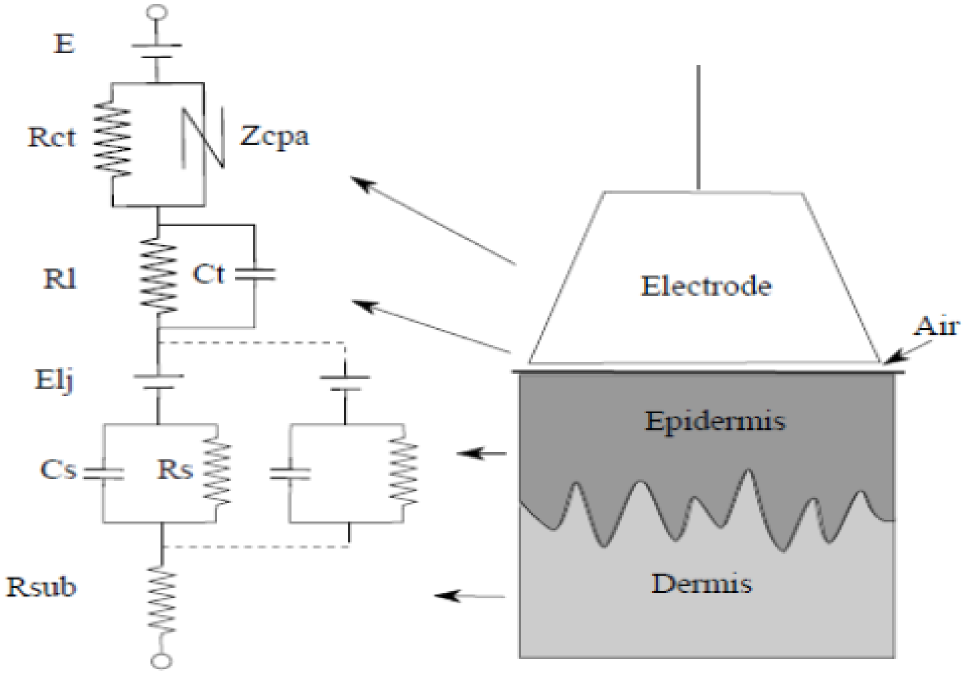


- high impedance
  (electrode-SC layer)
- prone to motion artifact
- active electrodes needed for weaker biopotential signals



Parameter	Description
R_{sub}	Internal body resistance, approximately constant ($\approx 100\Omega$)
R_s	Resistance of skin, depends on skin preparations, electrode gel and time after application.
C_s	Capacitance of skin, depends on skin preparation, electrolyte concentration and contact area.
E_{lj}	Liquid junction potential due to the concentration gradient of ions between body fluids and the electrolyte.
R_l	Resistance of electrolyte.
R_{ct}	Charge transfer resistance of the oxidation/reduction at the electrode/electrolyte interface.
Z_{cpa}	A constant phase angle impedance due to the double layer between electrolyte and electrode.
E	Half cell potential of the reaction at the electrode and electrolyte interface.

Electrical model of the interface from the body to the electrode



Electrical model of setup with a textile electrode.

Soft and Flexible Polymer-Based Dry Electrodes

- **Non-conductive polymer electrodes + coating: coating flakes off**
- **Conductive polymer electrodes: comfortable + stable**

Conductive polymer:

EPDM rubber + additives

For conductivity

For other properties

(mechanical, molding, de-molding...)

Various pin configurations are investigated.

Ethylene Propylene diene monomer (EPDM)

Dry Electrodes

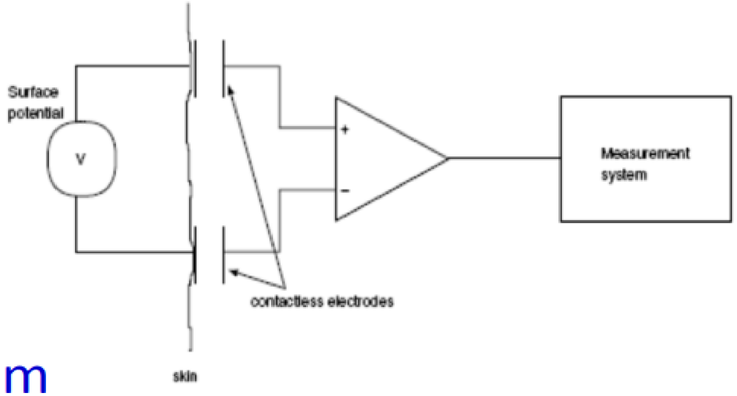
- No artificial electrolytic solution or gel is added
- They use the natural body fluids as an electrolytic coupling medium
- Sweat improves the skin contact impedance
- Extended monitoring of physiological signals

Contactless Capacitance Sensors

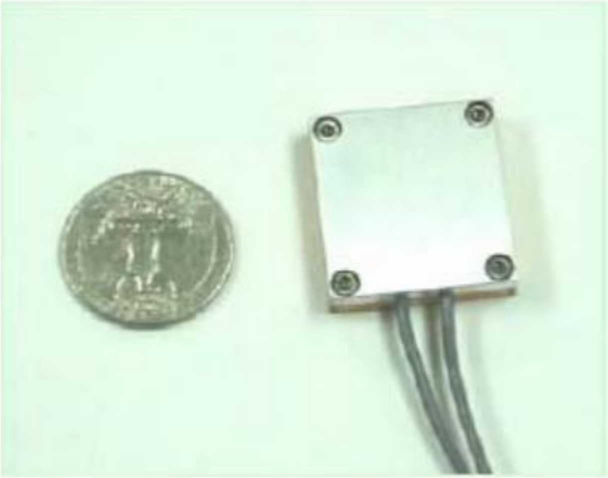
- Contactless Electrodes consists of a conducting plate covered by an layer, in this way forming a parallel plate capacitor with the skin.

- They couple capacitively to the body, hence, no direct electrical contact between the body and the electrode is required.

- Advantages
  - Long term monitoring
  - No skin preparation/gel application
  - Comfortable - no skin irritation
  - Easy to integrate in a wearable system



Non-contact electrodes for a wearable system

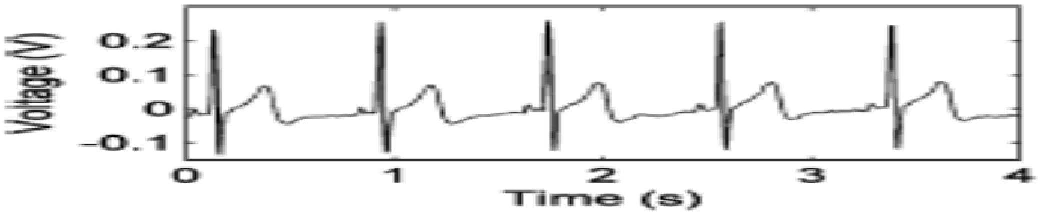


Electrode

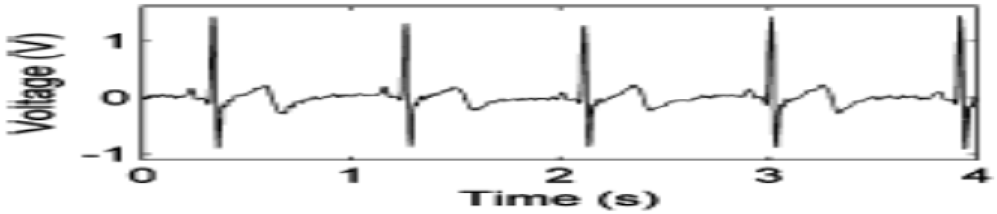
Arrangement of electrodes on a strap

A person wearing the strap over a T-shirt

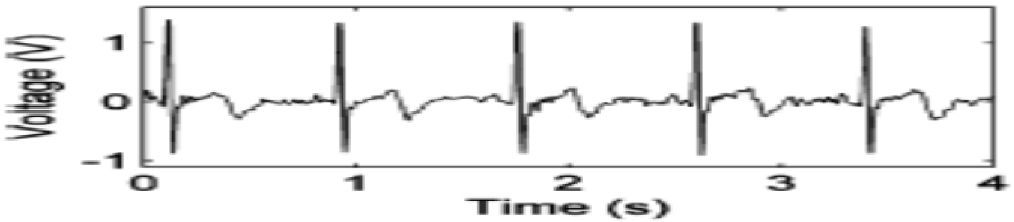
Comparison between obtained ECG signals with different textiles



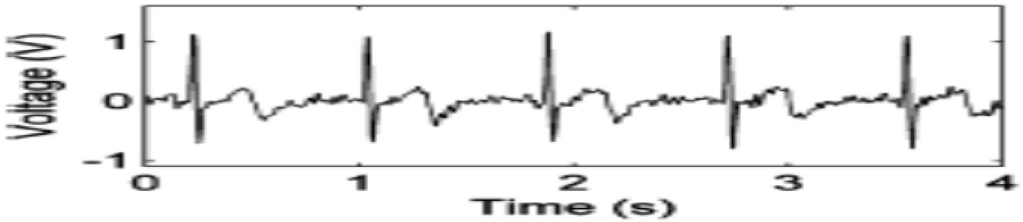
Conventional Ag–AgCl electrodes



Contactless electrodes-Cotton shirt (thickness 0.33mm)



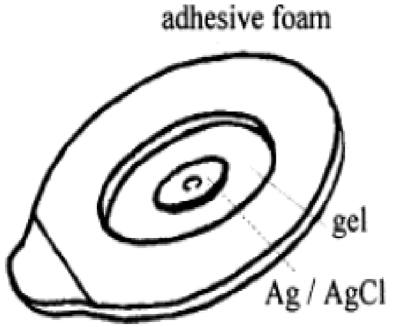
Contactless electrodes-Woolen business suit (thickness 0.37mm)

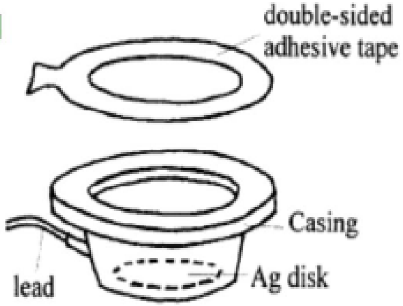


Contactless electrodes-Acrylic shirt (thickness 0.65mm)

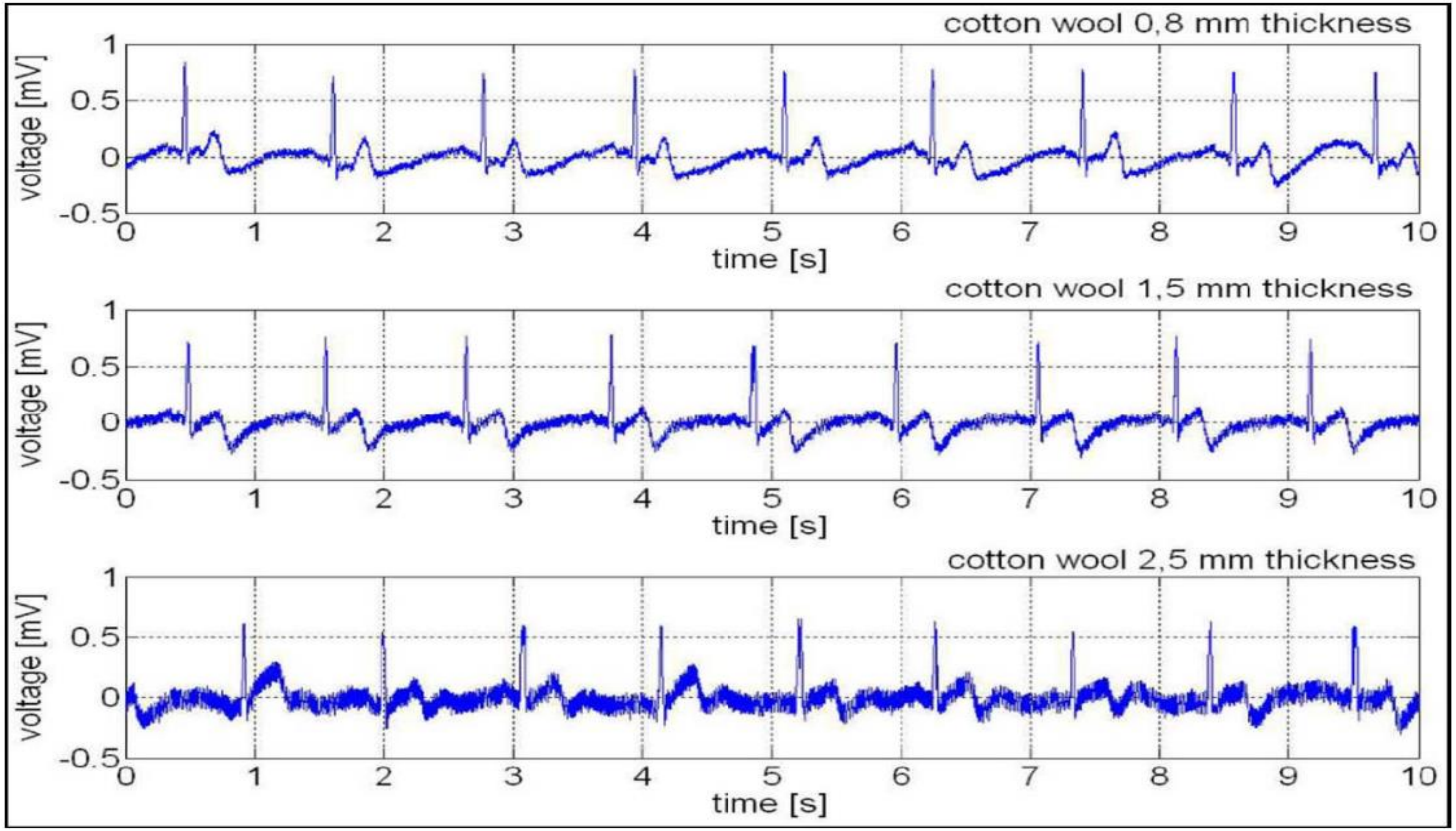
Ag-AgCl, Silver-Silver Chloride Electrodes

- The most commonly used electrode type
- Silver is interfaced with its salt silver-chloride
- Choice of materials helps to reduce junction potentials
  - Junction potentials are the result of the dissimilar electrolytic interfaces
- Electrolytic gel enhances conductivity and also reduces junctic potentials
  - Typically based on sodium or potassium chloride, concentration in the order of 0.1 M weak enough to not irritate the skin
- The gel is typically soaked into a foam pad or applied directly i pocket produced by electrode housing
- Relatively low-cost and general purpose electrode
- Particularly suited for ambulatory or long term use



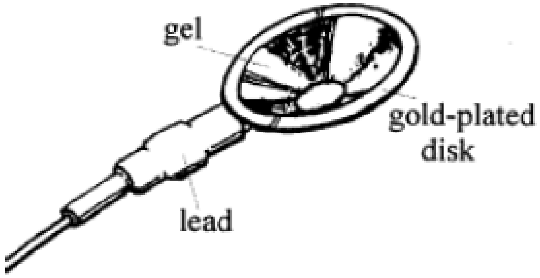


Comparison between obtained ECG signals with different thickness



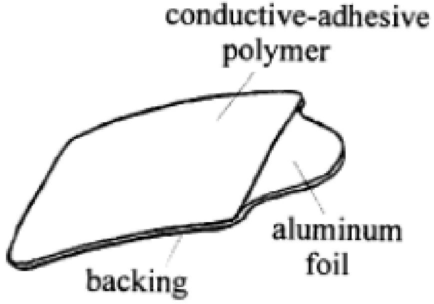
Gold Electrodes

- Very high conductivity → suitable for low-noise meas.
- Inertness → suitable for reusable electrodes
- Body forms cavity which is filled with electrolytic gel
- Compared to Ag-AgCL: greater expense, higher junction potentials and motion artifacts
- Often used in EEG, sometimes in EMG



Conductive polymer electrodes

- Made out of material that is simultaneously conductive and adhesive
- Polymer is made conductive by adding monovalent metallic ions
- Aluminum foil allows contact to external instrumentation
- No need for gel or other adhesive substance
- High resistivity makes unsuitable for low-noise meas.
- Not as good connection as with traditional electrodes

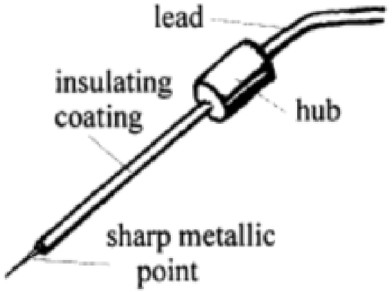


Metal or carbon electrodes

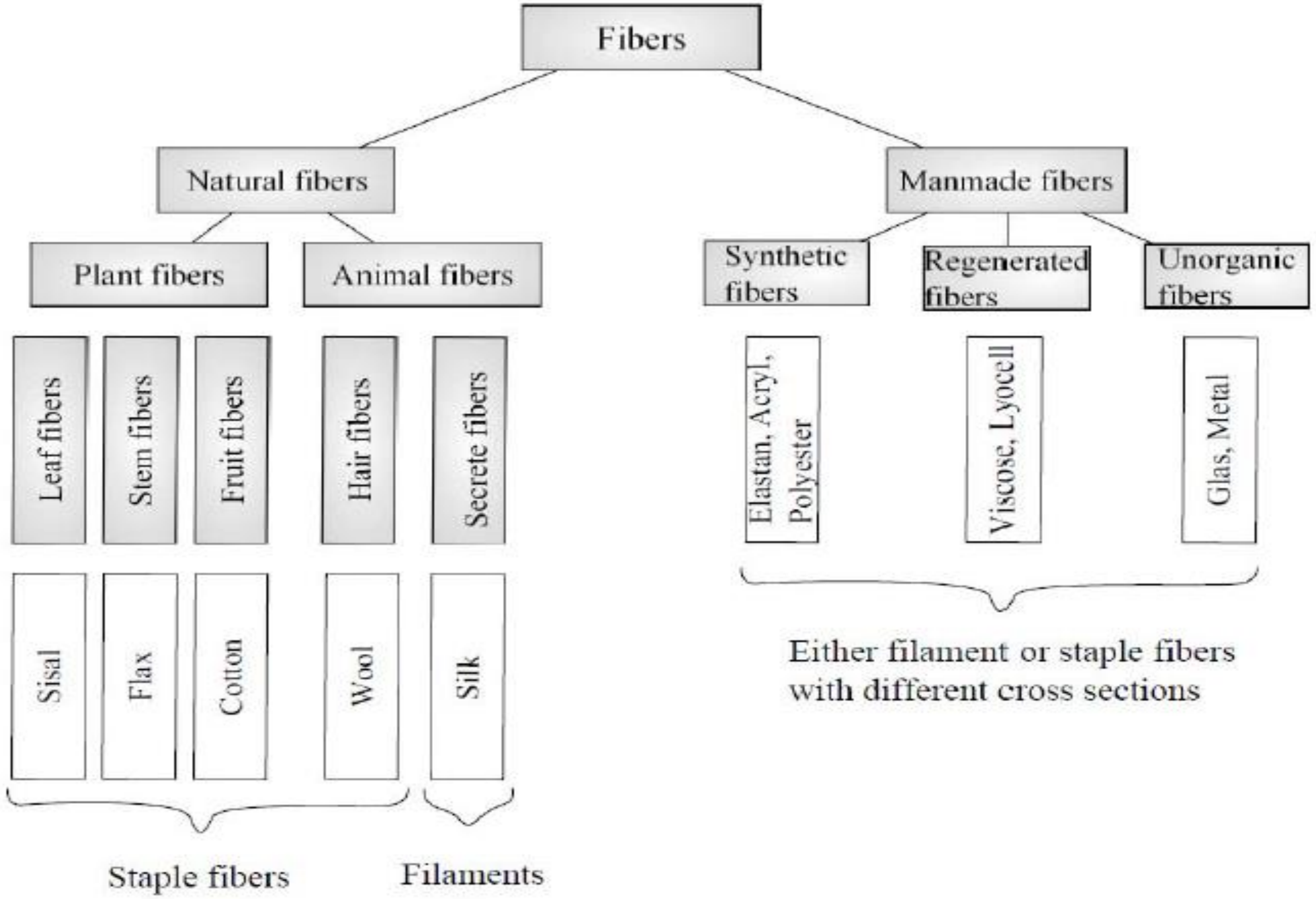
- Other metals are seldom used as high-quality noble metal electrodes or low-cost carbon or polymeric electrodes are so readily available
- Historical value. Bulky and awkward to use
- Carbon electrodes have high resistivity and are noisier but they are also flexibleand reusable
- Applications in electrical stimulation and impedance plethysmography

Needle electrodes

- Obviously invasive electrodes
- Used when measurements have to be taken from the organ itself
- Small signals such as motor unit potentials can be measured
- Needle is often a steel wire with hooked tip

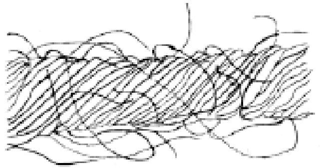


Textile Electrodes



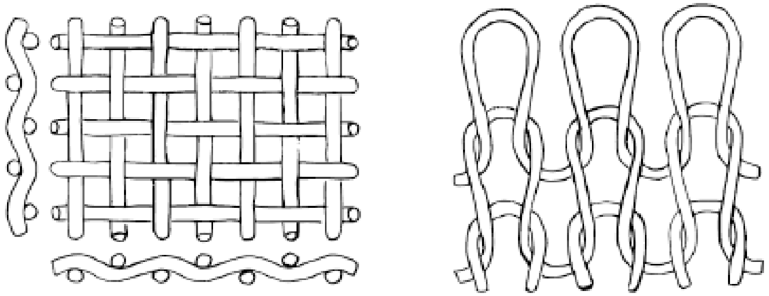
Overview of textile fiber categorization

(a) Twined yarn. The long strands are bundled together and the finish is smooth.



(b) Spun yarn. Staple fibers are parallelized and spun. The finish is hairy.

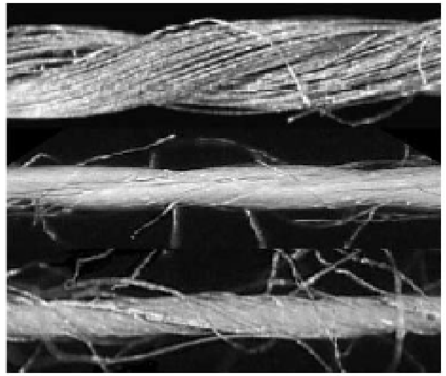
The two most common yarn modalities.



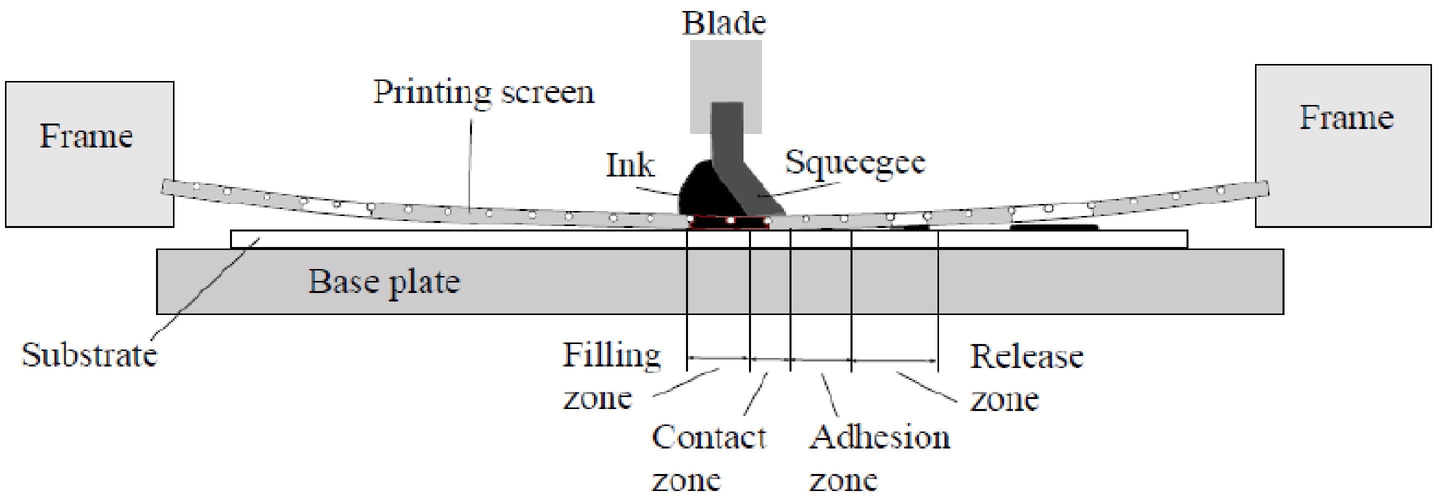
The two most common textile structures. On the left is a plain weave structure consisting of two sets of perpendicular strands. The horizontal set is the weft and the vertical is the warp. To the right is a weft knit.

Conductive Yarns

- 100% metal fibers/filaments or
- fibers/filaments coated with a conductive layer.

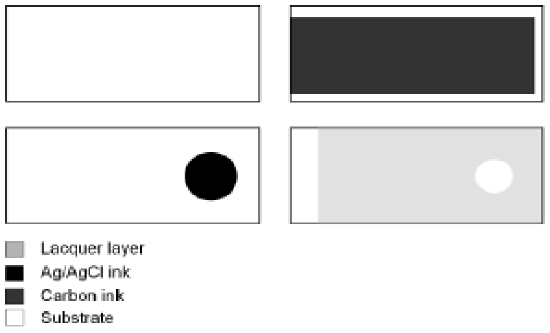


Screen Printed ECG Electrodes

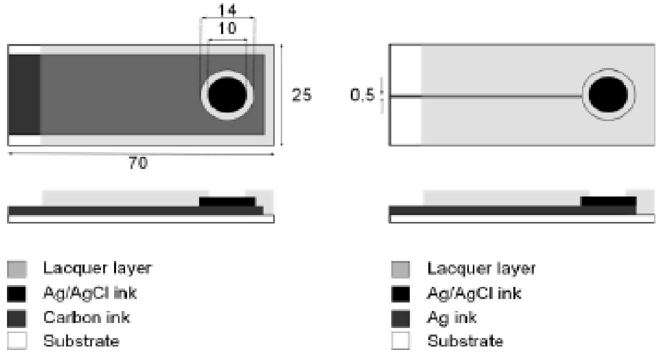


A setup for flatbed screen printing

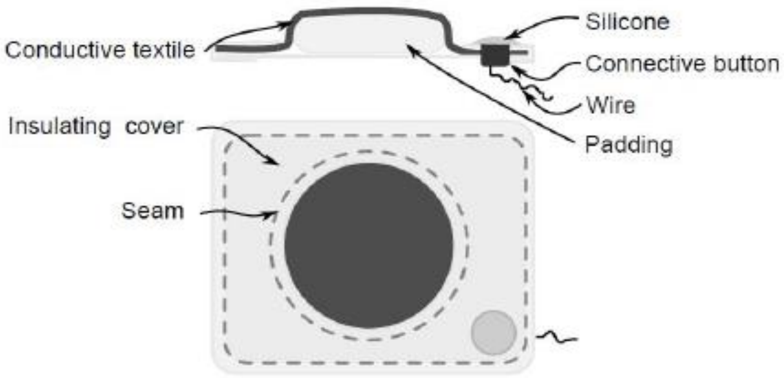
Screen printed electrode decomposition in different layers

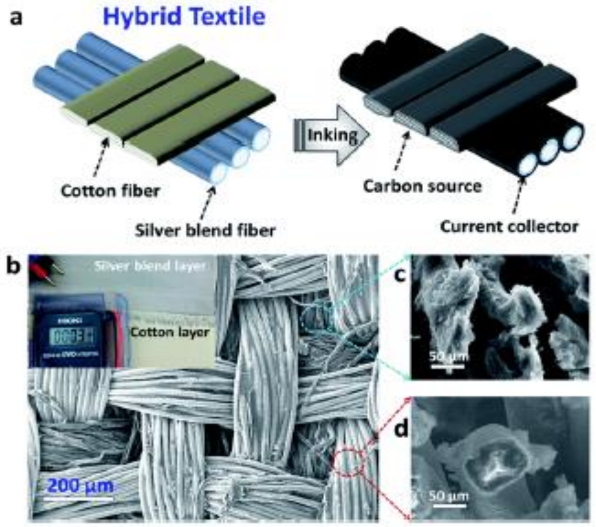


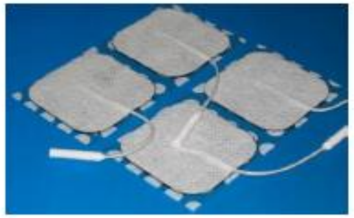
Screen printed electrodes

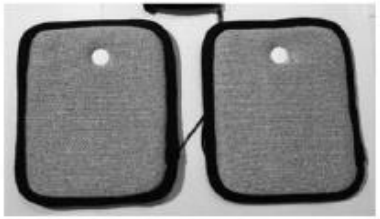


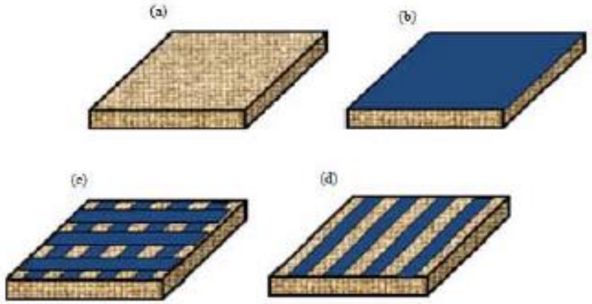
Textile Electrodes











100% Stainless Steel Electrodes

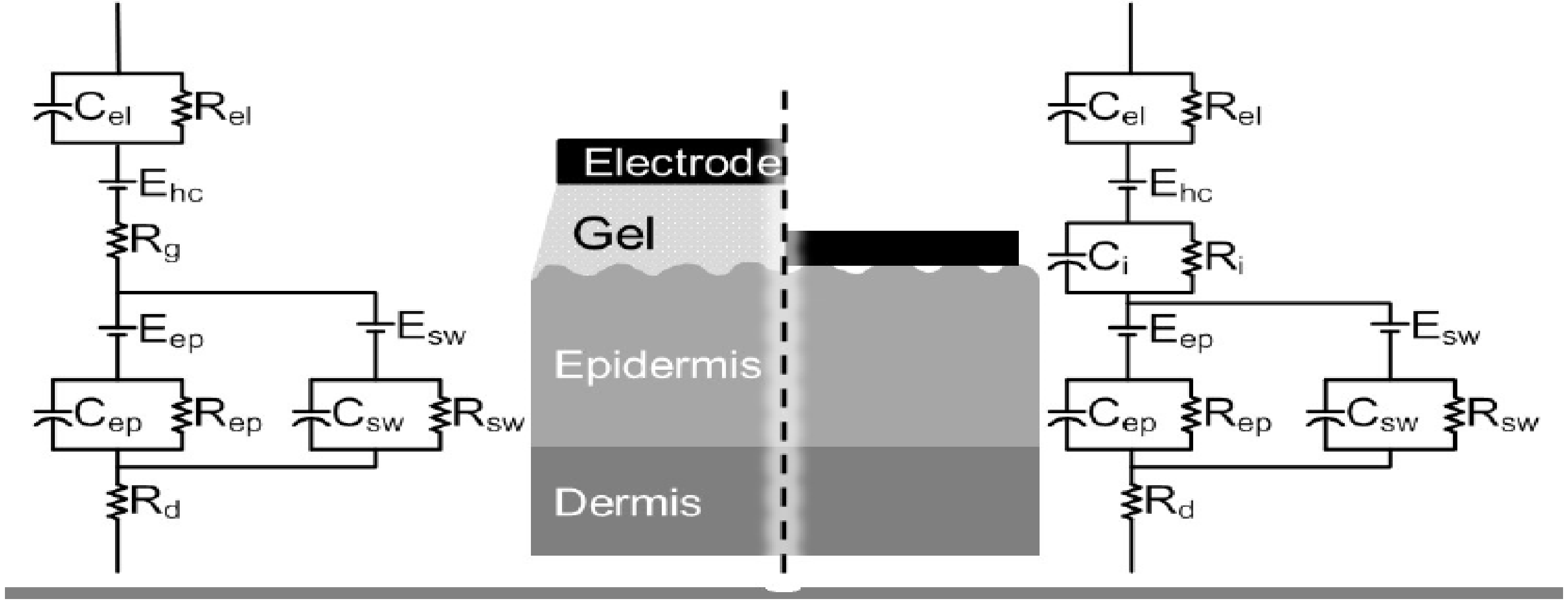








Equivalent Circuit



The electrode-skin interface model for gelled electrodes and dry electrodes

MedTex 130 Textile Material

- Surface Resistance: Average <5 Ohms/
- Plating: 99.9% pure silver
- Abrasion Resistance: 10,0000 cycles
- Temperature Range: -30c to +90c
- Total Thickness: 0.45mm
- Weight: 140 g /m²
- Stretch: Double stretch direction (wrap and weft)
- Roll Lengths: 50 LY average
- Roll Width: 135cm
- 78% Nylon + 22% elastormer

MedTex 180 Textile Material

- Silver plated knitted fabric
- Raw Material: 94% Silver plated Nylon+ 6% Elastomer
- Plating: 99.9% pure silver
- Surface Resistance: Average <100 Ohms/sq (front/visible side)
- Abrasion Resistance: 10,000 cycles Temperature Range: -30c to +90c
- Total Thickness: 0.55mm + 10% Weight: 210g /m2 +/- 10%
- Stretch: Single stretch direction (machine direction)
- Roll Width: 52“
- Roll Lengths: Average 30m

Sensors for Wearable Systems

When designing wearable systems to be used for physiological and biomechanical parameters monitoring, it is important to integrate sensors easy to use, comfortable to wear, and minimally obtrusive.

Wearable systems include sensors for detecting physiological signs placed on-body without discomfort, and possibly with capability of real-time and continuous recording.

The system should also be equipped with wireless communication to transmit signals, although sometimes it is opportune to extract locally relevant variables, which are transmitted when needed.

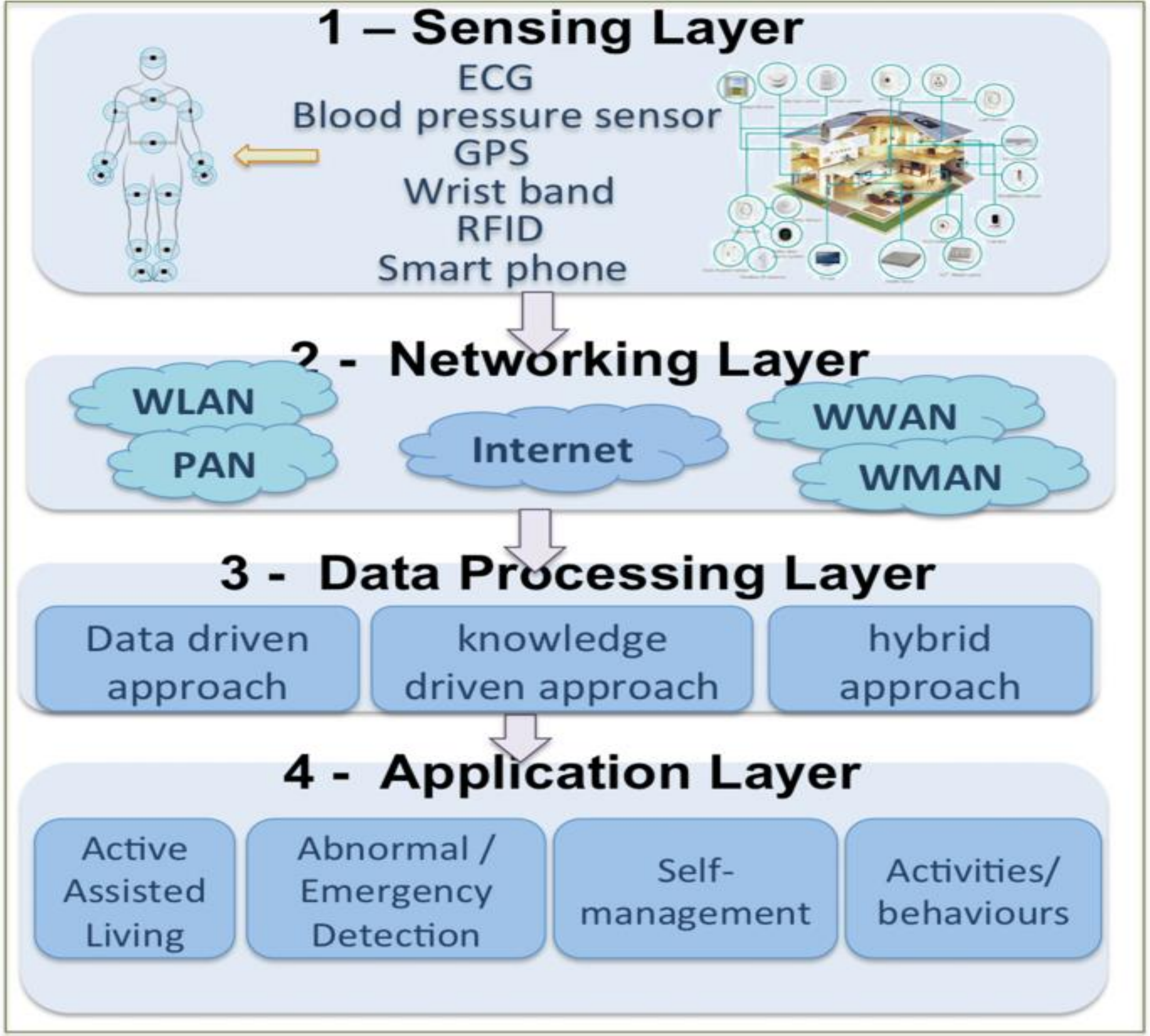
Sensors for Wearable Systems

Most sensors embedded into wearable systems need to be placed at specific body locations, e.g. motion sensors used to track the movements of body segments, often in direct contact with the skin, e.g. physiological sensors such as pulse meters or oximeters. However, it is reasonable to embed sensors within pieces of clothing to make the wearable system as less obtrusive as possible

Sensors for Wearable Systems

- A key technology for wearable systems is the possibility of implementing robust, cheap microsystems enabling the combination of all the above functionalities in a single device.
- This technology combines so-called micro-electro-mechanical systems (MEMS) with advanced electronic packaging technologies.
- The former allows complex electronic systems and mechanical structures (including sensors and even simple motors) to be jointly manufactured in a single semiconductor chip.

overall framework



Biomechanical Sensors

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

Biomechanical Sensors

A generic wearable system can be structured as a stack of different layers. The lowest layer is represented by the body, where the skin is the first interface with the sensor layer.

This latter is comprised of three sub-layers: garment and sensors, conditioning and filtering of the signals and local processing. The processing layer collects the different sensor signals, extracts specific features and classifies the signals to provide high-level outcomes for the application layer.

The application layer can provide the feedback to the user and/or to the professional, according to the specific applications and to the user needs. Recent developments embed signal processing in their systems, e.g. extraction of heart rate, respiration rate and activity level.

Biomechanical Sensors

- Monitoring of parameters related to human movement has a wide range of applications. In the medical field, motion analysis tools are widely used both in rehabilitation and in diagnostics.
- In the multimedia field, motion tracking is used for the implementation of life-like videogame interfaces and for computer animation.
- Standard techniques enabling motion analysis are based on stereophotogrammetric, magnetic and electromechanical systems. These devices are very accurate but they operate in a restricted area and/or they require the application of obtrusive parts on the subject body

Biomechanical Sensors

On the other hand, the recent advances in technology have led to the design and development of new tools in the field of motion detection which are comfortable for the user, portable and easily usable in non-structured environment

What are inertial sensors?

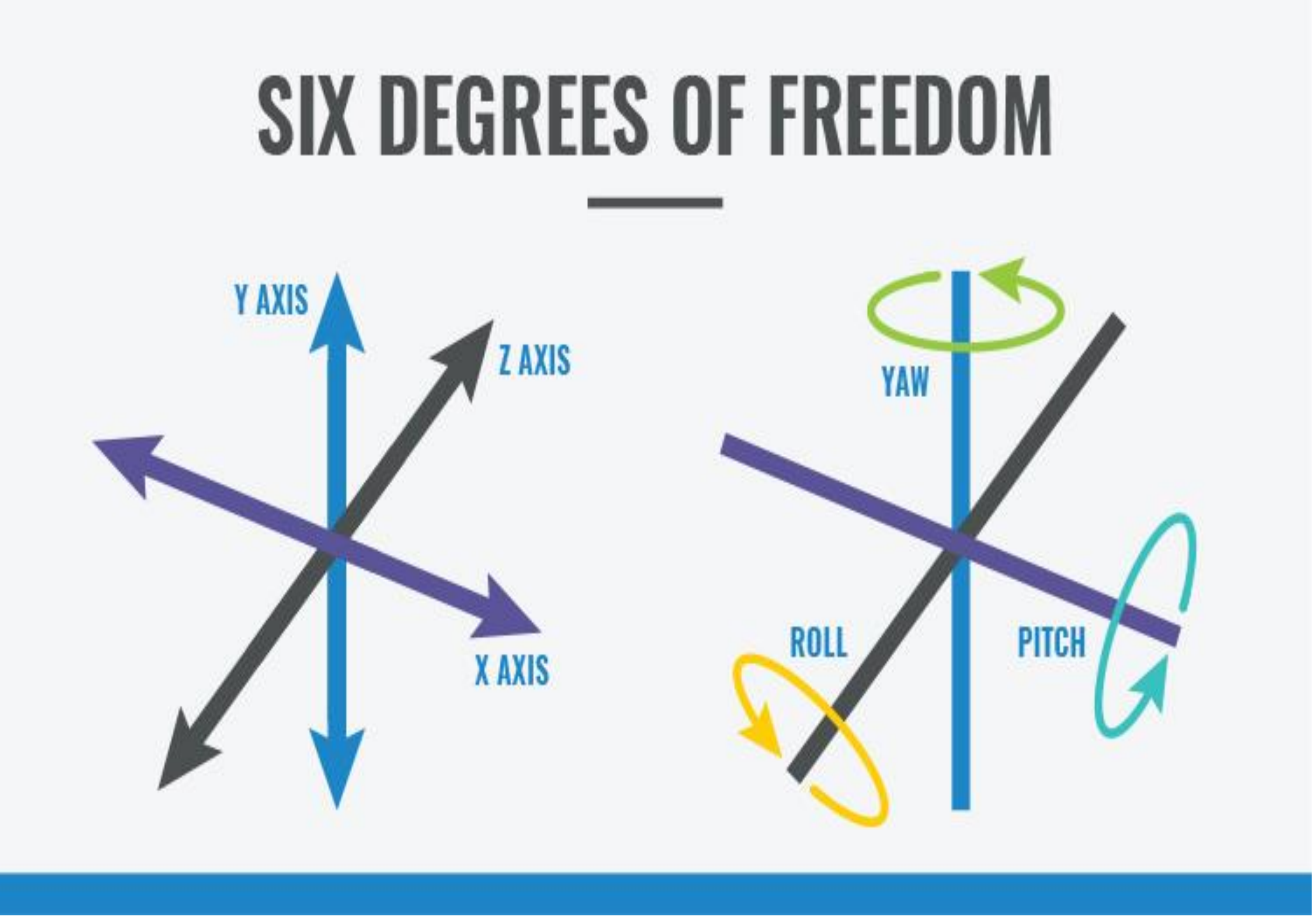
- Inertial sensors are used to transduce inertial force into measurable electrical signals to measure acceleration, inclination, and vibration of an object. Micromachining technology has made it possible to produce MEMS (Micro Electromechanical System) inertial sensors using single-crystal silicon sensor elements.

- These micron-sized sensors meet all major system design drivers like low-cost, high performance, high precision, and small form-factor. Based on the same principles as of macroscopic inertial sensors, MEMS inertial sensors can detect the slightest change in position, orientation, and acceleration of an object several metres long using a sensor unit as small as few micro-meters in dimensions.

What are inertial sensors?

There are mainly two types of MEMS inertial sensors – accelerometers that measure linear acceleration in one or more axis, and gyroscopes that measure angular motion. These sensors are manufactured for use in specific applications as each application requires inertial sensors having different bandwidth, resolution, and dynamic range

How does an IMU work?



An IMU provides 2 to 6 DOF (Degrees of Freedom), which refers to the number of different ways that an object is able to move throughout 3D space. The maximum possible is 6 DOF, which would include 3 degrees of translation (flat) movement across a straight plane/along each axis (front/back, right/left, up/down) and 3 degrees of rotational movement across the x, y and z axes/about each axis.

3 Main Types of Motion Sensor Devices

Accelerometer: The most commonly used type of motion sensor is the accelerometer. It measures acceleration (change of velocity) across a single axis, like when you step on the gas in your car or drop your phone. Accelerometers measure linear acceleration in a particular direction.

An accelerometer can also be used to measure gravity as a downward force. Integrating acceleration once reveals an estimate for velocity, and integrating again gives you an estimate for position.

Due to the double integration and the state of today’s technology, an accelerometer is not a recommended method of distance estimation.

Gyroscope: While accelerometers can measure linear acceleration, they can’t measure twisting or rotational movement. Gyroscopes, however, measure angular velocity about three axes: pitch (x axis), roll (y axis) and yaw (z axis).

When integrated with sensor fusion software, a gyro can be used to determine an object’s orientation within 3D space. While a gyroscope has no initial frame of reference (like gravity), you can combine its data with data from an accelerometer to measure angular position

Magnetometer: A magnetometer, as the name suggests, measures magnetic fields. It can detect fluctuations in Earth’s magnetic field, by measuring the air’s magnetic flux density at the sensor’s point in space. Through those fluctuations, it finds the vector towards Earth’s magnetic North. This can be fused in conjunction with accelerometer and gyroscope data to determine absolute heading

Physiological Sign Sensors

- ✓Wearable systems are generally thought to be used for health care, therefore necessarily including sensors to monitor physiological signs.
- ✓Occasionally, it is possible to adapt commercial devices to be integrated into a wearable system, but mostly dedicated and customized sensors should be designed and embedded.
- ✓Here sensors for respiration activity, pulse monitoring, galvanic skin response, thermal and cardiopulmonary radiant sensors, gas sensors and sensors for detecting biochemical markers are envisaged

Respiration Activity

The most challenging vital sign to accurately record during continuous monitoring is the respiratory activity due to the fact that the signals are affected by movement artifacts and filtering or feature recognition algorithms are not very effective. Monitoring of respiratory activity involves the collection of data on the amount and the rate at which air passes into and out of the lungs over a given period of time.

Directly, by measuring the amount of air exchanged during the respiration activity, and Indirectly, by measuring parameters physically correlated to breathing, such as changes in thorax circumference and/or cross section, or trans-thoracic impedance.

Direct methods are based on a spyrometer that measures directly the airflow in the lung exchanged during inspiration and expiration, but of course it cannot be integrated into a wearable system because it employs a mouthpiece, which could interfere with the freedom of movements, disrupting the normal breathing pattern during measurement, thus causing discomfort for the user.

Indirect methods exploit displacements of the lung that are transmitted to the thorax wall and vice versa, and therefore measurements of chest-abdominal surface movements can be used to estimate lung volume variation.

number of devices have been used to measure rib cage and abdominal motion including mercury in rubber strain gauges [33], linear differential transducers [34], magnetometers [35], and optical techniques [36], but almost all cannot be comfortably integrated into a wearable system.

For reference only, it is worthwhile citing a more sophisticated technique, called stereophotogrammetry, which makes it possible to estimate the three-dimensional coordinates of points of the thorax, estimating therefore volume variations.

Nevertheless, this system presents a considerable drawback in that it is cumbersome, extremely expensive, and can only be used in research environments or in laboratory applications

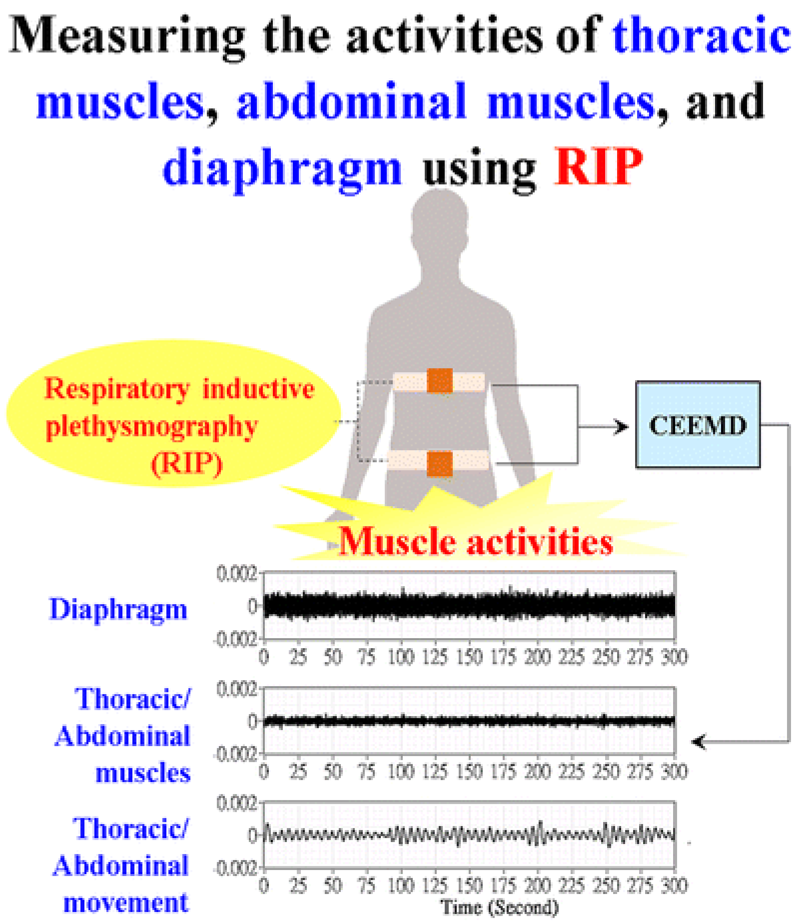
Indirect techniques that can be implemented in wearable systems are respiratory inductive plethysmography (RIP) [37], impedance plethysmography [38], piezoresistive [39] and/or piezoelectric pneumography.

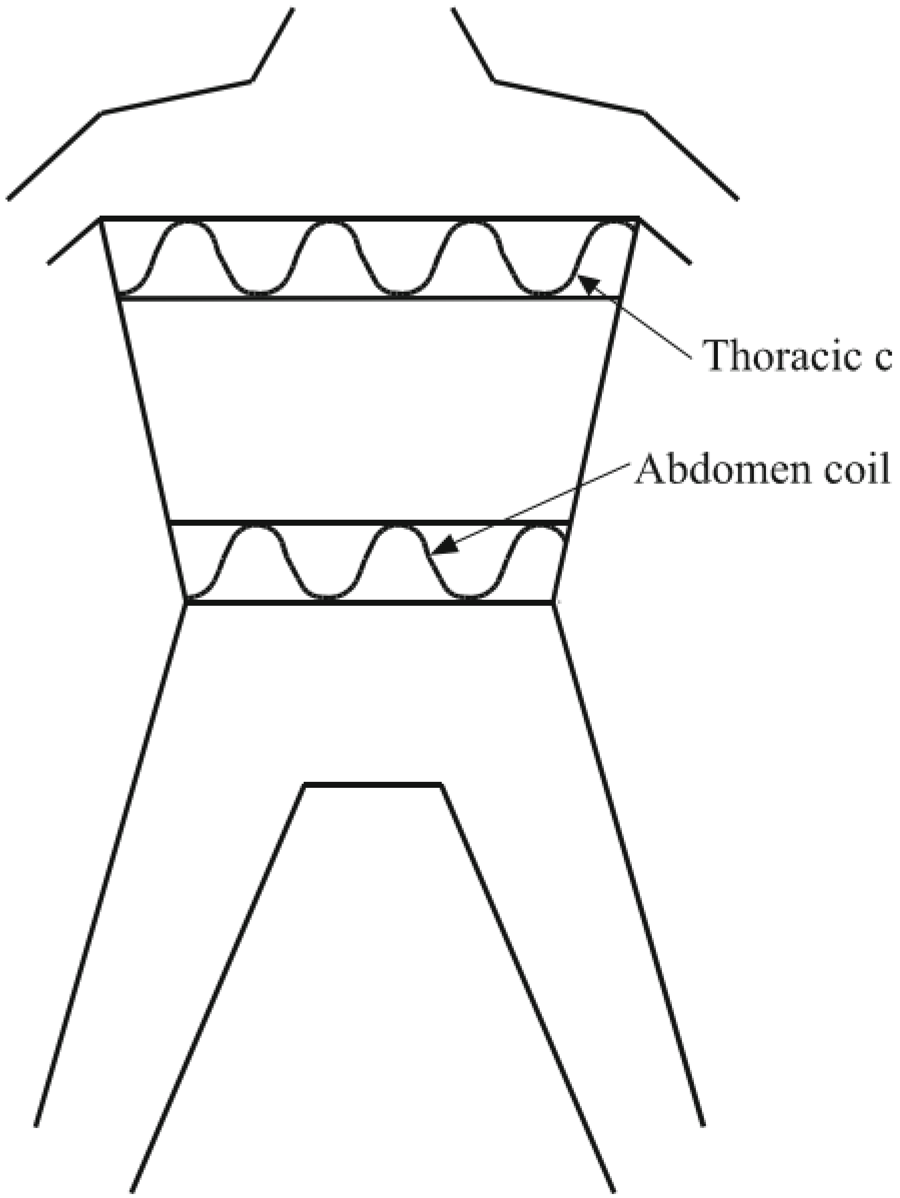
These systems are minimally invasive and do not interfere with physical activity

Inductive Plethysmography

The inductive plethysmography method for breathing monitoring consists of two elastic conductive wires placed around the thorax and the abdomen to detect the cross sectional area changes of the rib cage and the abdomen region during the respiratory cycles. The conductive wires are insulated and generally sewn in a zigzag fashion onto each separate cloth band (see Fig. 1.1). They can be considered as a coil and are used to modulate the output frequency of a sinewave current produced by an electric oscillator circuit.

Fig. 1.1 The respiratory inductive plethysmography system including the rib cage and abdominal sensor bands



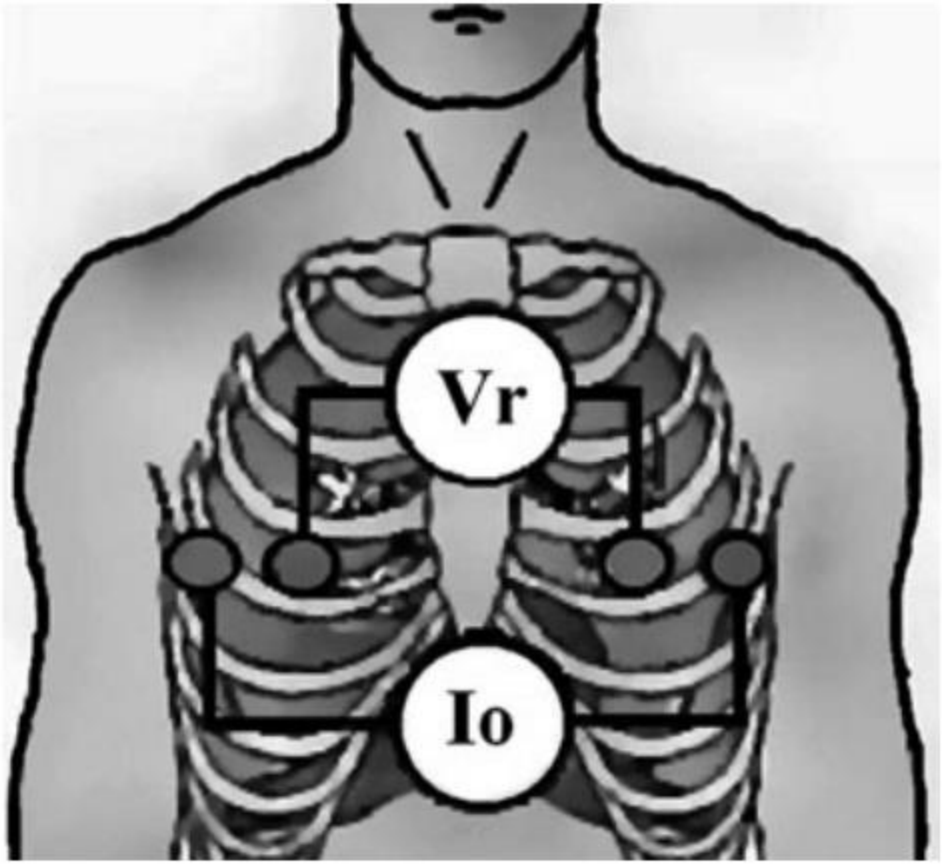


Impedance plethysmography

Impedance plethysmography is used to measure changes in volume associated with changes in electrical impedance. Combined with the venous occlusion method, this technique can be used to measure blood flow in a limb or digit

This technique consists of injecting a high frequency and low amplitude current through a pair of electrodes placed on the thorax and measuring the trans-thoracic electrical impedance changes [40]. As a matter of fact, there is a relationship between the flow of air through the lungs and the impedance change of the thorax. The measurements can be carried out by using either two or four electrode configurations. Electrodes can be made of fabric and integrated into a garment or, even, embedded into an undershirt

Fig. 1.2 Principle scheme of impedance plethysmography system which can be integrated into a wearable system

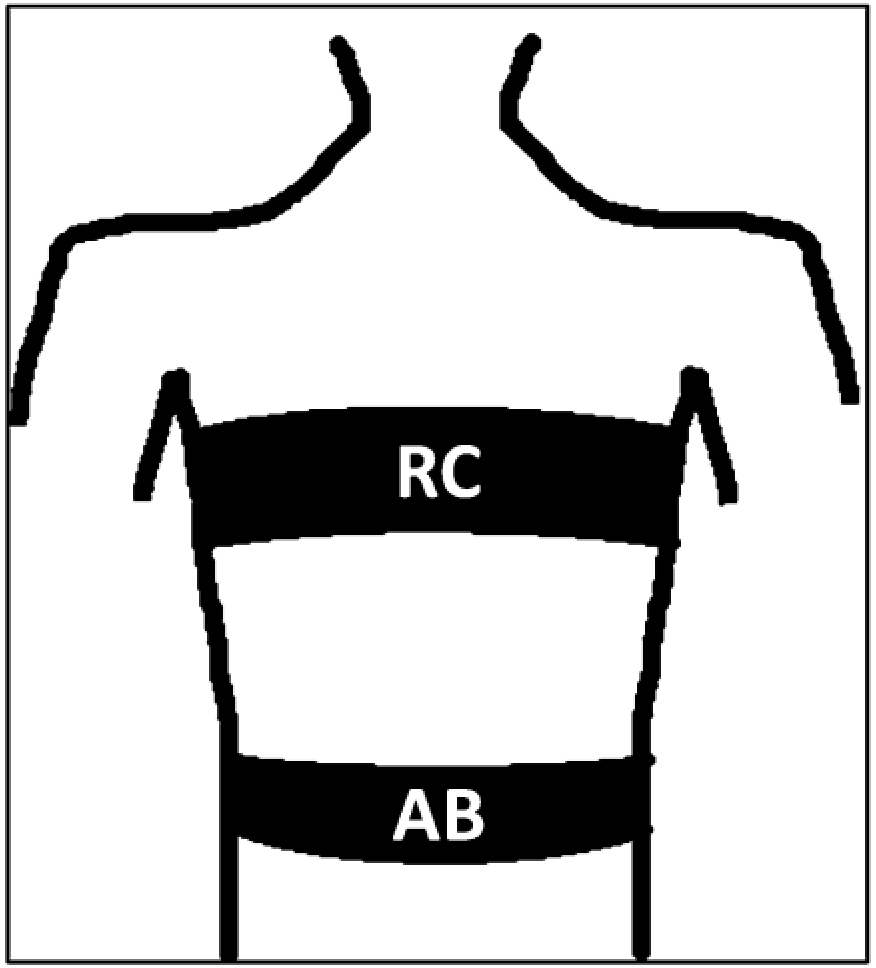


It is worthwhile noting that by measuring the trans-thoracic electrical impedance it is possible to non-invasively monitor, in addition to breathing rate also tidal volume, functional residual capacity, lung water and cardiac output. In Fig. 1.2, the scheme of principle is depicted

Pneumography Based on Piezoresistive Sensor

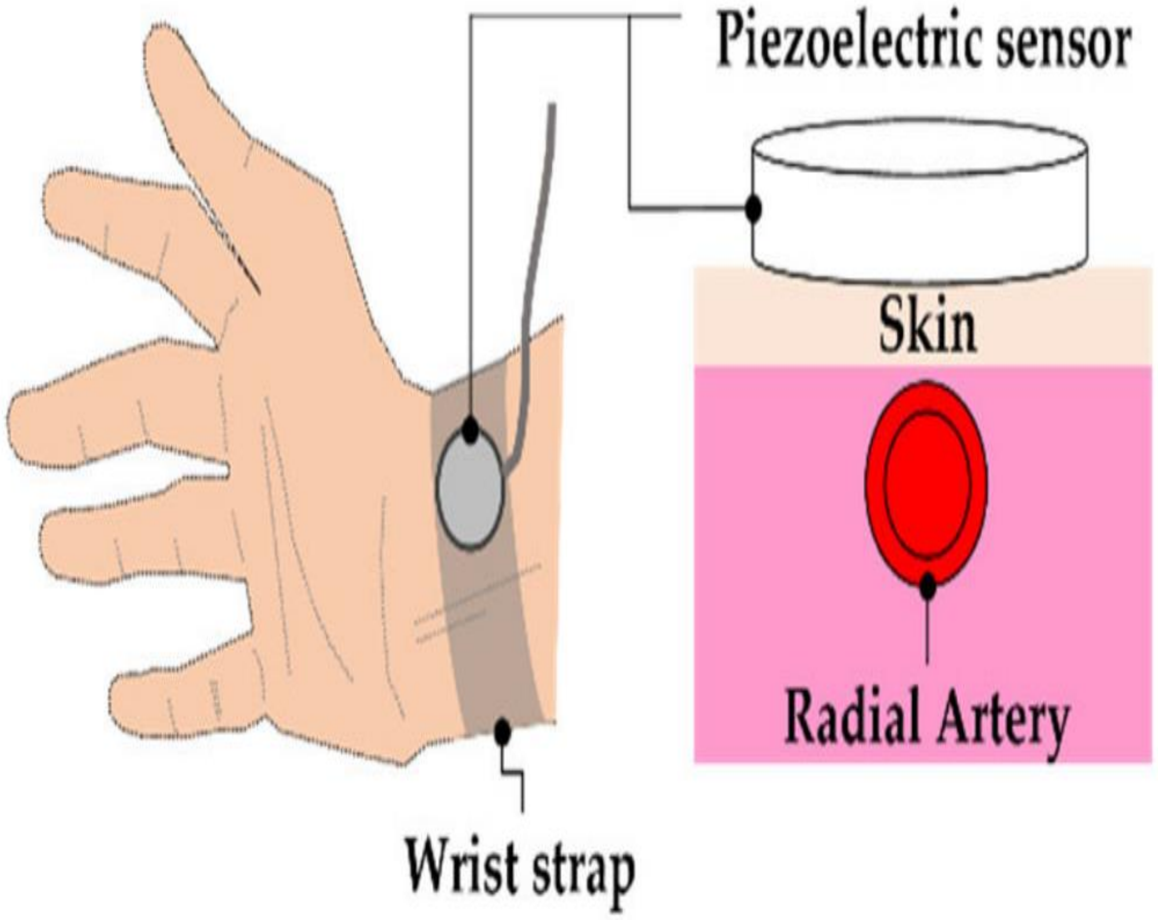
Piezoresistive pneumography is carried out by means of piezoresistive sensors that monitor the cross-sectional variations of the rib cage. The piezoresistive sensor changes its electrical resistance if stretched or shortened and is sensitive to the thoracic circumference variations that occur during respiration. Piezoresistive sensors can be easily realized as simple elastic wires or by means of an innovative sensorized textile technology

Fig. 1.3 Picture showing how two piezoresistive belts can be embedded into a garment to monitor abdominal and thoracic respiratory activity



It consists of a conductive mixture directly spread over the fabric. The lightness and the adherence of the fabric make the sensorized garments truly unobtrusive and uncumbersome, and hence comfortable for the subject wearing them. This mixture does not change the mechanical properties of the fabric and maintains the wearability of the garment. Figure 1.3 shows where the two conductive wires or bands could be applied.

Plethysmography Based on Piezoelectric Sensor



This method is based on a piezoelectric cable or strip which can be simply fastened around the thorax, thus monitoring the thorax circumference variations during the respiratory activity. A possible implementation can be a coaxial cable whose dielectric is a piezoelectric polymer (p(VDF-TrFE)), which can be easily sewn in a textile belt and placed around the chest.

Galvanic Skin Response

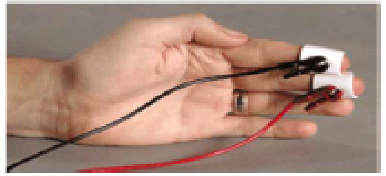
Galvanic skin response (GSR), also referred to as skin conductance response (SCR) or electrodermal activity (EDA), is the property that momentarily makes our skin a better conductor of electricity when we are physiologically aroused.

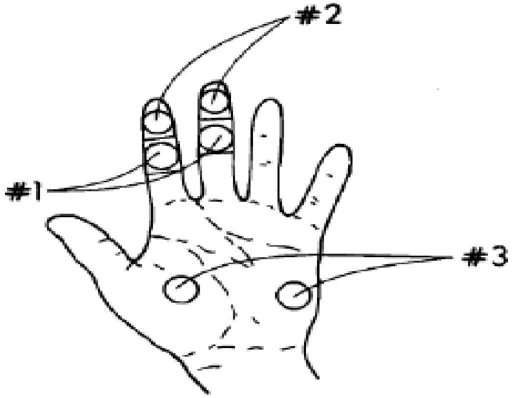
When we are aroused, a number of body processes get activated – for instance, our heart beats faster and pulse rise. We also sweat more, and as we sweat, our skin conductance increases.

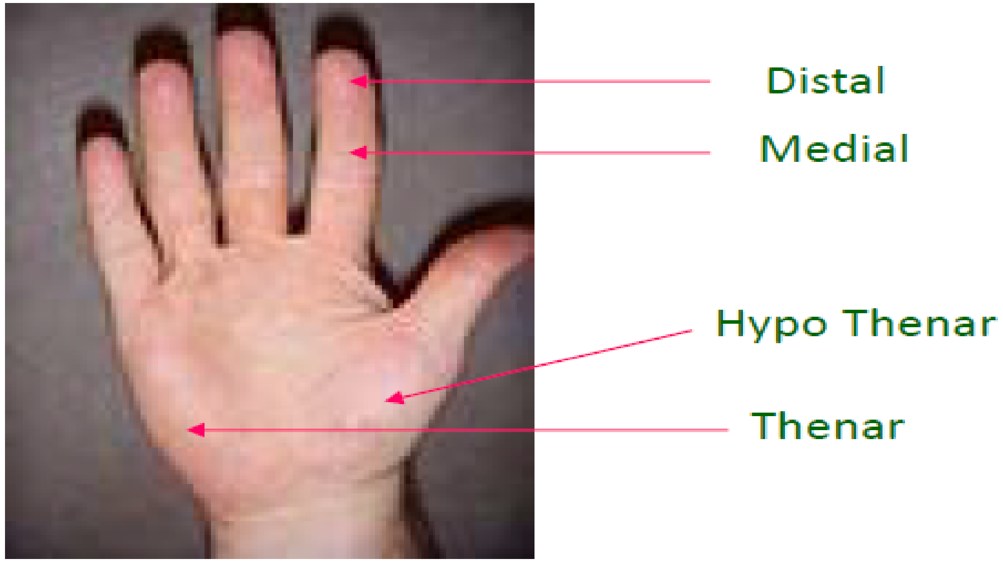
So, GSR is essentially triggered by sweating, and is measured in micro-Siemens (µS) or micro-Mho (µM). (It is actually a more complex phenomenon, particularly in light of recent research findings. Practitioner's, however, need not get into the finer details).

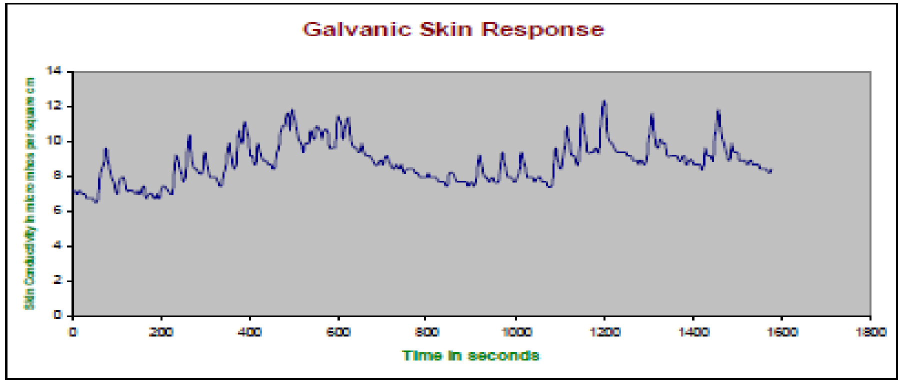
Galvanic Skin Response

- The GSR is affected when the sympathetic nervous system is active, in particular when a person is anxious (Psychological state of an individual).
- Endosomatic or Exso-somatic
- 5KΩ when tensed and 25 K Ω when relaxed
- Ag-AgCl Electrodes are used









One of the most interesting measurements of the electrical body response is the Galvanic Skin Response (GSR), which was easily transformed from laboratory to wearable instrumentation, and has become one of the most used wearable devices especially for the high correlation that has shown with the most significant parameters in the field of neuroscience. It is a part of the whole ElectroDermal Response (EDR), which is also constituted of the measure of skin potentials

In deep, EDR is associated with sweat gland activity. Convincing evidence, indeed, was experimentally found in which a direct correlation is seen between EDR and stimulated sweat gland activity. Furthermore, when sweat gland activity is abolished, then there is an absence of EDR signals

There are two major measures of the electrodermal response. The first, involving the measurement of resistance or conductance between two electrodes placed in the palmar region, was originally suggested by Fe´re´ [42]. It is possible also to detect voltages between these electrodes; these potential waveforms appear to be similar to the passive resistance changes, though its interpretation is less

The first type of measurement is referred to as exosomatic, since the current on which the measurement is based is introduced from the outside. The second type, which is less commonly used, is called endosomatic, since the source of voltage is internal. Researchers also distinguish whether the measurement is of the (tonic) background level, or the time-varying (phasic) response type.

An electrical equivalent model underlying EDR is represented in Fig. 1.5. This model provides only qualitative information. The active electrode is at the top (skin surface), whereas the reference electrode is considered to be at the bottom (hypodermis). R1 and R2 represent the resistance to current flow through the sweat ducts located in the epidermis and dermis, respectively. These are major current flow pathways when these ducts contain sweat, and their resistance decreases as the ducts fill

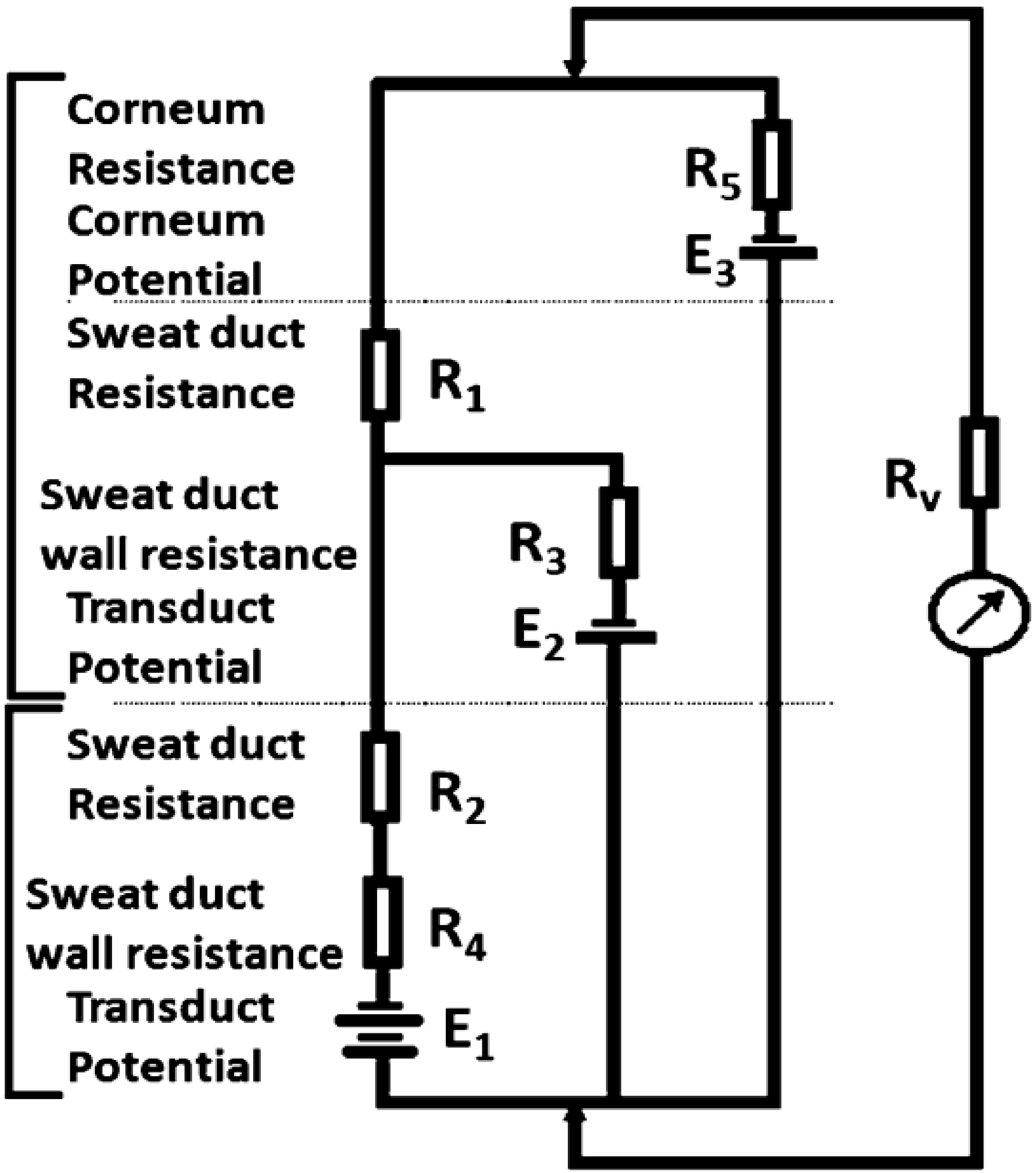


Fig. 1.5 A simplified equivalent circuit describing the electrodermal system. Components are identified in the text [44]

E1 and R4 represent access to the ducts through the duct wall in the dermis, whereas E2 and R3 describe the same pathway, but in the epidermis. Potentials E1 and E2 arise as a result of unequal ionic concentrations across the duct as well as selective ionic permeabilities. This potential is affected by the production of sweat, particularly if the buildup of hydrostatic pressure results in depolarization of the ductal membranes. Such a depolarization results in increased permeability to ion flow; this is manifested in the model by decreased values of R3 and R4. In particular, this is considered as an important mechanism to explain rapid-recovery signals. The potentials of E1 and E2 are normally lumen-negative.

The resistance R5 is that of the corneum, whereas E3 is its potential. The phenomenon of hydration of the corneum, resulting from the diffusion of sweat from the sweat ducts into the normally dry and absorbant corneum, leads to a reduction in the value of R5.

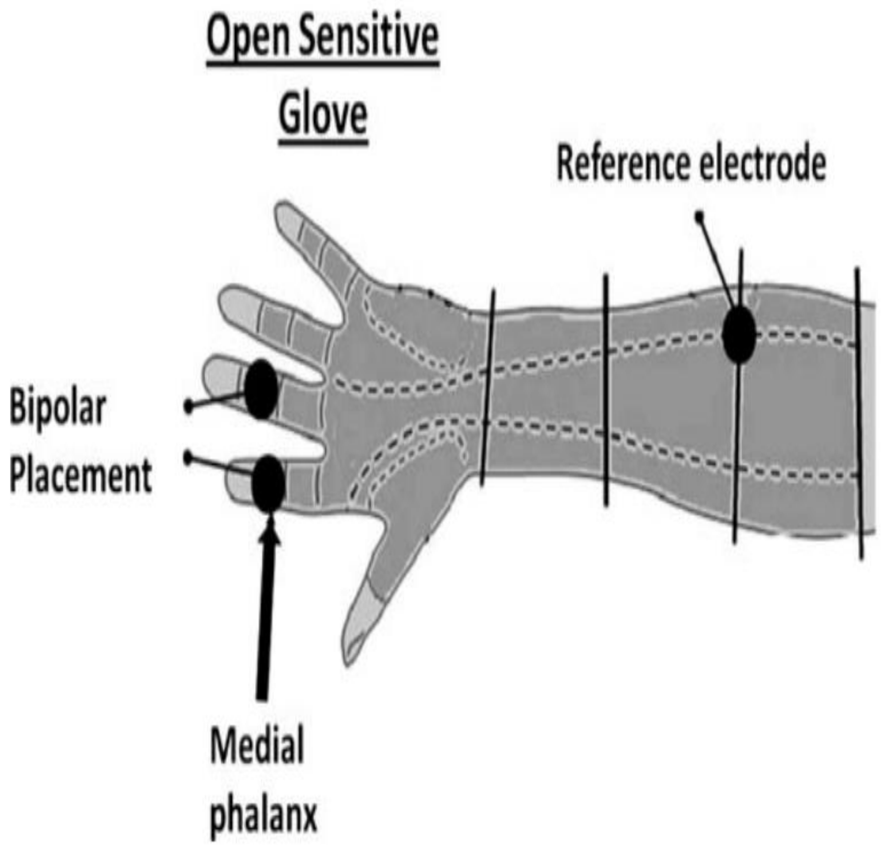


Fig. 1.6 Suggested electrodes site for the measurement of skin resistance and skin potentials

The applications of the measure lie in the area of psychophysiology and relate to studies in which a quantitative measure of sympathetic activity is desired. The importance attached to such measurements includes the statement in one recent paper that palmar sweat is one of the most salient symptoms of an anxiety state and, for some, the single most noticeable bodily reaction [45]. Other suggested locations for electrode placement can be between two fingers. In this case, electrodes can be integrated into a glove (see Fig. 1.6

Pulse Oximetry

A pulse oximeter is a small device that looks sort of like a chip clip or a big clothes pin

A pulse oximeter shines light of two wavelengths through a tissue bed such as the finger or earlobe and measures the transmitted light signal.

Being pulse oximeter non-invasive, easy to use, readily available, and accurate, the modern wearable system developed can supply information about blood oxygen saturation, heart rate and pulse amplitude

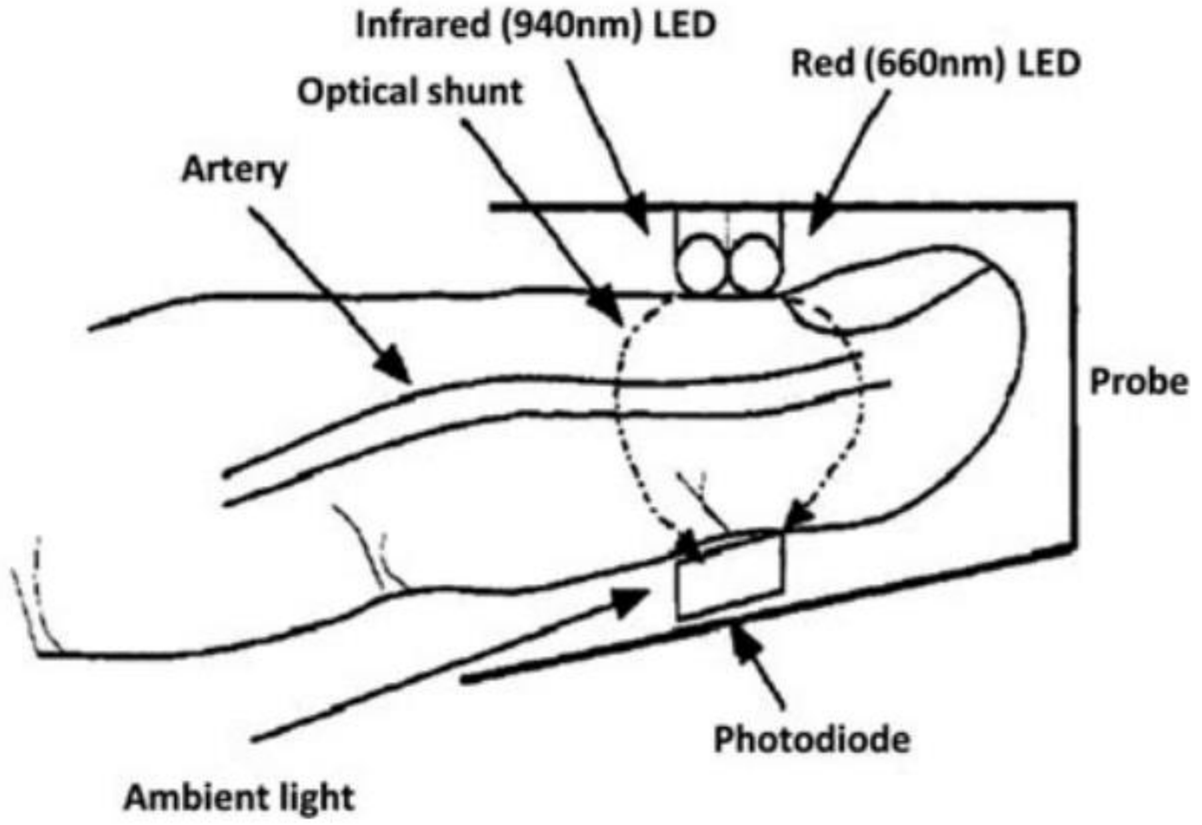
The device operates according to the following principles:

1. The light absorbance of oxygenated haemoglobin and deoxygenated haemoglobin at the two wavelengths is different. To be more precise, the set of associated extinction coefficients for the absorption of light for these wavelengths is linearly independent with great enough variation for adequate sensitivity but not so large that the blood appears opaque to either of the light sources. This model assumes that only oxygenated and deoxygenated haemoglobin are present in the blood.

2. The pulsatile nature of arterial blood results in a waveform in the transmitted signal that allows the absorbance effects of arterial blood to be identified from those of non-pulsatile venous blood and other body tissue. By using a quotient of the two effects at different wavelengths, it is possible to obtain a measure requiring no absolute calibration with respect to overall tissue absorbance. This is a clear advantage of pulse oximeters over previous types of oximeters

3. With adequate light, scattering in blood and tissue will illuminate sufficient arterial blood, allowing reliable detection of the pulsatile signal. The scattering effect necessitates empirical calibration of the pulse oximeter. On the other hand, this effect allows a transmittance path around bone in the finger.

Fig. 1.7 Transmission pulse oximeter measuring the transmission of light by two LEDs through the finger of a patient



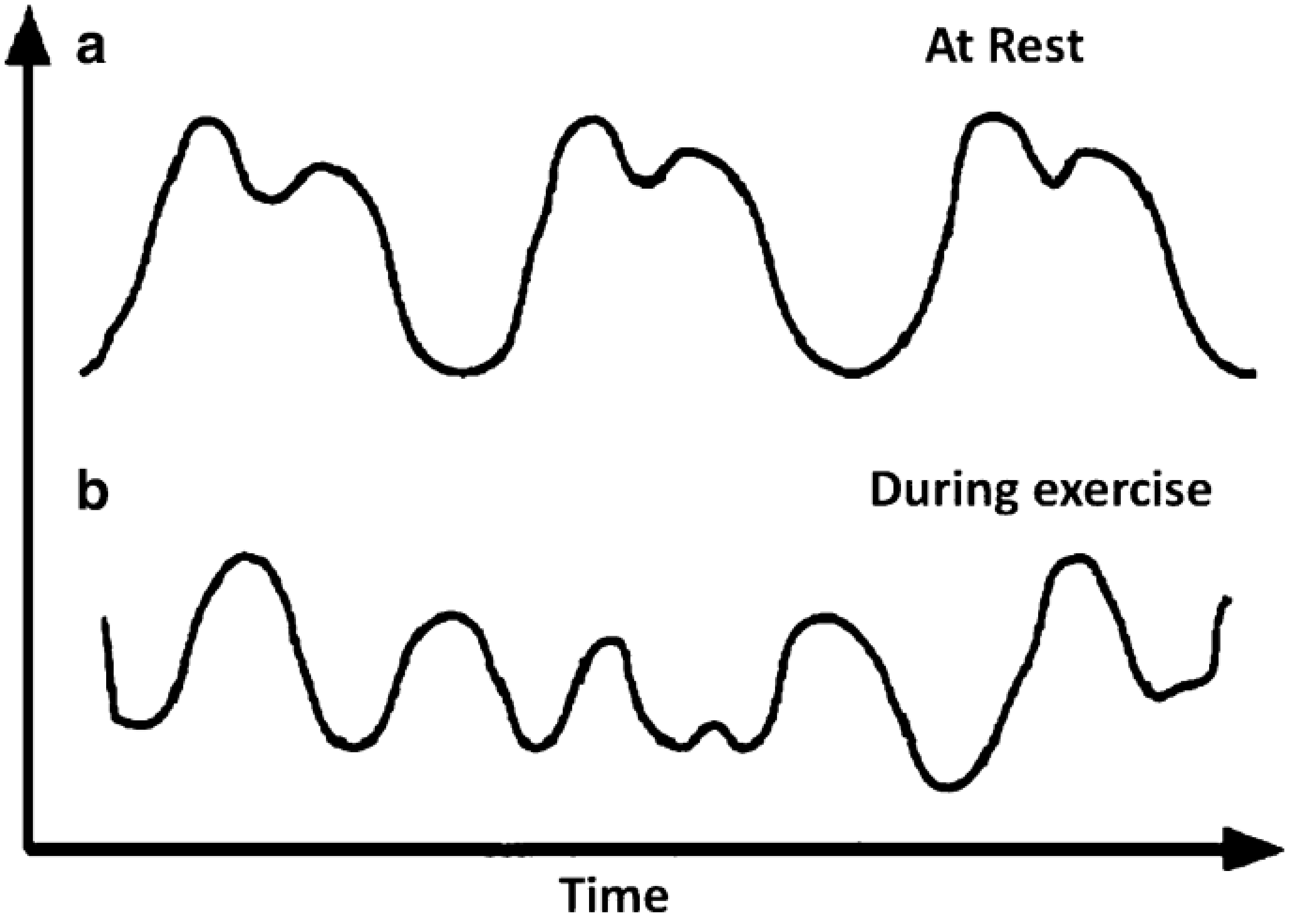


Fig. 1.8 The plethysmographic waveform of a subject at rest is periodic (**a**) and during exercise is not periodic (**b**)

Fig. 1.9 Reflectance pulse oximeter measuring the amount of light reflected back to the probe in forehead application