UNIT 1

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.

1.1. WEARABLE SYSTEMS - INTRODUCTION

- Wearable technology is any kind of electronic device designed to be worn on the user's body. Such devices can take many different forms, including jewelry, accessories, medical devices, and clothing or elements of clothing.
- The term wearable computing implies processing or communications capabilities, but in reality, the sophistication among wearables can vary.
- The most sophisticated examples of wearable technology include artificial intelligence (AI) hearing aids, Google Glass and Microsoft's HoloLens, and a holographic computer in the form of a virtual reality (VR) headset. An example of a less complex form of wearable technology is a disposable skin patch with sensors that transmit patient data wirelessly to a control device in a healthcare facility.

1.1.1. FEATURES OF WEARABLE DEVICES

1. Activity Monitoring.
2. Bluetooth Enabled.
3. Digital Display.
4. Health Monitoring.
5. Location Tracking.
6. Smart Watches.
7. Water Resistant / Outdoor Rated.
8. Wrist

1.1.2. OBJECTIVES OF WEARABLE TECHNOLOGY

- The most common uses for wearable technology are for helping to monitor and alert the wearer about their personal health information or for social communication purposes – like calling, texting, social media, etc.

- Wearable systems can be broadly defined as mobile electronic devices that can be unobtrusively embedded in the user's outfit as part of the clothing or an accessory.
- In particular, unlike conventional mobile systems, they can be operational and accessed without or with very little hindrance to user activity.
- To this end they are able to model and recognize user activity, state, and the surrounding situation: a property, referred to as context sensitivity. Wearable systems range from micro sensors seamlessly integrated in textiles through consumer electronics embedded in fashionable clothes and computerized watches to belt worn PCs with a head mounted display.
- The wearable computing concept is part of a broader framework of ubiquitous computing that aims at invisibly enhancing our environment with smart electronic devices.

1.2. NEED FOR WEARABLES SYSTEMS

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

a. Sense

b. Process (Analyze)

c. Store

d. Transmit

e. Apply (Utilize)

Of course, the specifics of each function will depend on the application domain and the wearer, and all the processing may occur actually on the individual or at a remote location (e.g., command and control center for first responders, fans watching the race, or viewers enjoying the mountaineer's view from the Mount Everest base camp).

What is sensor?

A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena.

Principle of sensor

Every sensor has different principle of operation, based on the type of physical quantity it is measuring. The idea is to create a change in the property/properties of sensor (such as resistance, density, shape, temperature etc) as a function of the physical quantity under measurement.

Different types of sensors

1. Temperature Sensor
2. Proximity Sensor
3. Accelerometer

4. IR Sensor (Infrared Sensor) Pressure Sensor
5. Light Sensor
6. Ultrasonic Sensor
7. Smoke, Gas and Alcohol Sensor etc...

Wearable devices?

Wearable technology (also called wearable gadgets) is a category of technology devices that can be worn by a consumer and often include tracking information related to health and fitness.

Working of Wearable devices

Sensors can also be attached around a wearable device to allow them to monitor various activity in the area. Most sensors can track motion, brain activity, heart activity, and muscle activity.

Miniature computers are also inside some wearable devices, similar to how smartphones have miniature processors inside of them.

Need for wearable systems

A wearable device is often used for tracking a wearer's vital signs or health and fitness related data, location, etc.

Medical wearables with artificial intelligence and big data are providing an added value to healthcare with a focus on diagnosis, treatment, patient monitoring and prevention.

To diagnose, monitor and prevent future illnesses, healthcare professionals now routinely use wearable devices such as fitness tracker or phones. By monitoring physiological data and behavior these devices boost self-awareness and encourage behavior change.

Smart clothing

Fig. 1.1. Smart Clothing

Clothing that monitors the wearer's physical condition. Smart shirts and body suits provide biometric data, such as pulse rate, temperature, muscle stretch, heart rhythm and physical movement, and the data are transmitted via Bluetooth to an app in real time.

1.2.1. ELEMENTS OF WEARABLES 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.

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

In general, such systems should also contain some elementary processing capabilities to perform signal pre-processing and reduce the amount of data to be transmitted. A key technology for wearable systems is the possibility of implementing robust, cheap microsystems enabling the combination of all the above functionalities in a single device. This technology combines so-called micro-electro-mechanical systems (MEMS) with advanced electronic packaging technologies.

The former allows complex electronic systems and mechanical structures (including sensors and even simple motors) to be jointly manufactured in a single semiconductor chip.

1.2.2. LAYERS OF WEARABLES SYSTEMS

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.

1.2.3. IMPORTANCE OF WEARABLE SYSTEMS

Recent developments embed signal processing in their systems, e.g. extraction of heart rate, respiration rate and activity level. Activity classification and more advanced processing on e.g. heart signals can be achievable exploiting miniaturization and low-power consumption of the systems.

Examples of data classification are : classification of movement patterns such as sitting, walking or resting by using accelerometer data or ECG parameters such as ST distance extracted from raw ECG data; another example is the estimation of the energy consumption of the body and the combined use of a triaxial accelerometer and a wearable heart rate sensor was exploited to accurately classify human physical activity; estimation of upper limb posture by means of textile embedded flexible piezoresistive sensors. Examples of integrated systems for health monitoring are two classes of sensors which can be easily integrated into wearable systems are reported and described.

More specifically, inertial sensors to monitor biomechanical parameters of human body and sensors to capture physiological signs are addressed, describing the operating principles and indicating the possible fields of application.

For example, Internet is currently available almost everywhere in different forms, using either cable or wireless networking technologies. With the advancement of mobile and satellite communication technologies along with broadband communication techniques, e-health services can be de- livered anywhere at any time.

Especially, when wireless devices are integrated with sensors, it is possible to acquire and monitor human signals at any environment at any time. Hence, Internet can be used as a major tool to deliver e-health services to both developing and developed countries. E-health services can take advantages of wireless body area network (WBAN), which can act as an enabling technology.

WBAN systems could offer great advancement for a ubiquitous health care, which has the potential to improve many aspects of everyday living leading to improved quality of life of many patients. Telemedicine and e-health services could o□er several significant advantages, including speedup of diagnosis, therapeutic care for emergencies, o□ering specialist services to remote and rural locations, and supporting patients' mobility and lifestyles.

A WBAN monitors physiological signals from some tiny sensors with wireless transmission capability placed either inside or around a person's body, which are used to collect important health data of a person during a particular activity medical or sport or training-related activities. These nodes form a network between the sensors and a control device. Figure 1.2 shows a generic WBAN application scenario.

Basically, a WBAN system consists of a number of tiny sensor nodes and a gateway node used to connect them to remote locations (i.e., hospital, call center) as shown in Fig 1.2.

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

In literature, a number of di□erent terminologies or names have been used for the gateway device; mainly terminologies such as body control unit (BCU) or central control unit (CCU) or personnel control unit (PCU) are used. The gateway device can be a smart phone or any portable device that can aggregate collected sensor data and forward them to remote stations.

The gateway node can connect the sensor nodes to a range of communication networks. These communication networks can be either a standard telecommunication network, mobile/wireless network, a dedicated medical center/hospital LAN (local area network) or a public WLAN (wireless local area network) hotspot, commonly known as the Wi-Fi.

A WBAN allows a user to store collected data in his/her PDA (personal digital assistant) or iPod or any other portable devices and then transfer that information to a suitable computer when a communication link is available.

Future applications of WBAN could introduce numerous possibilities to improve health care and sports training facilities. In recent years, the WBAN concept has attracted the attention of medical and ICT researchers. Standard ICT systems are already in use in medical areas mostly related to patient record keeping and scheduling tasks.

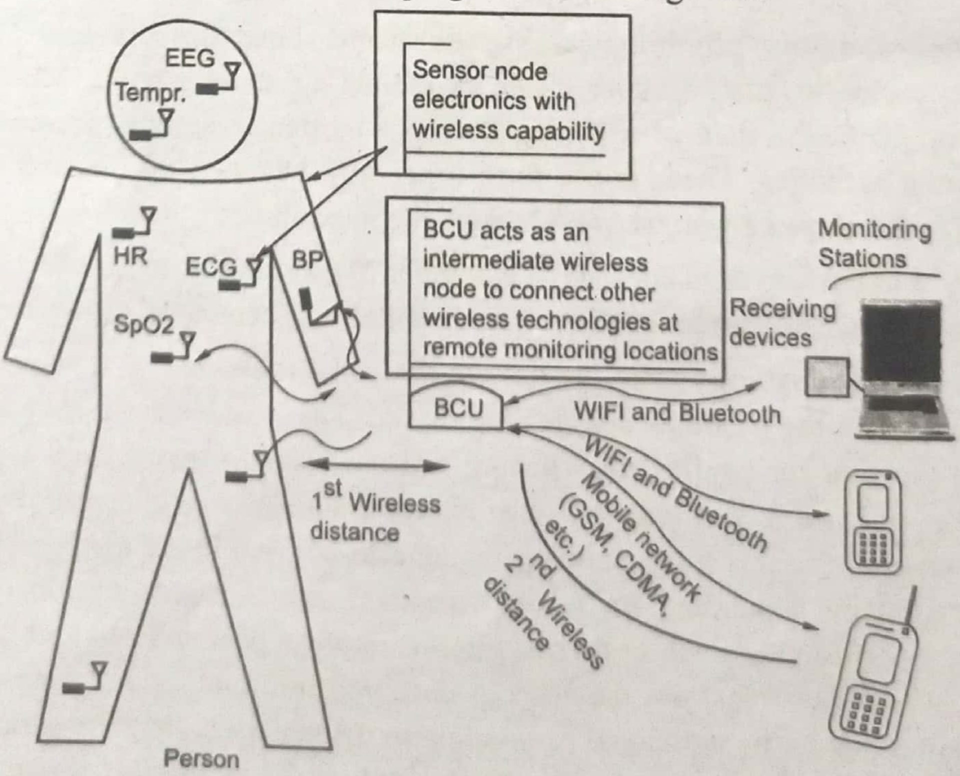


Fig. 1.2. A wireless body area network scheme.

Another major area of health care where the WBAN will find its application is the aged care, where the quality of life of elderly people can be significantly improved if the health of older people is invasively monitored and appropriate health care is provided.

1.3. DRAWBACKS OF CONVENTIONAL SYSTEMS FOR WEARABLE MONITORING

1. The conventional approaches for personal healthcare rely primarily on traditional methods, including bulky instruments and complicated procedures, which, in some cases, are time-consuming and inconvenient.
2. Moreover, such traditional approaches still require large equipment, blood drawing and conventional bench-top assay techniques.
3. Besides, invasive methods of obtaining test samples can also cause discomfort and pain to patients. In comparison, as an emerging analytical tool, wearable sensors can attach to different body parts to capture various biochemical and physiological parameters.
4. In many cases, health monitoring relies on physical, chemical, and biological information transmitted through the skin.
5. Taking advantages of non-invasive sampling and high accuracy, wearable sensors can measure the abnormal conditions of the physical or chemical components of the human body in real-time, revealing the human body status in time.
6. People can use wearable sensors to track the basic vital signs of the human body, such as body temperature, respiration rate, blood pressure, pulse rate and glucose level.
7. Besides, environmental conditions including allergen particles in the air, ultraviolet and other radiation, and the concentration of air pollutants can also be acquired.
8. Tracking these indicators can greatly benefit diagnosis, postoperative rehabilitation and adjuvant treatment of chronic diseases patients.

Advantages of Wearable Technology

- **Rapid data results can help drive improvements.** Having immediate data to make decisions and drive improvements may be helpful, rather than waiting for more formal or detailed assessments.
- **Detailed data can supplement loss analysis and loss trends.** Additional data can help identify specific trends in your claims history.
- **Can help build a business case for senior management.** It can be challenging to help senior management make decisions or determine if some of your funding should be spent on improvements. The data from wearable technology devices can help support your business case for that spend.
- **Data from wearable sensors offers promising job risk analysis and evaluation opportunities for safety and ergonomics practitioners.** Most ergonomic assessments or evaluations require additional time to observe and manually collect data. Having instant data can save time and expedite ergonomic assessments or evaluations.

- **Enhance employee wellness programs.** More organizations are starting to promote wellness programs for employees. Some wearable technology devices can assist with easily tracking wellness program data that could supplement or support your efforts.

Disadvantages of Wearable Technology

- Requires a time commitment to review and analyze data. A team or committee may need to review the large amount of data that is generated from the devices.
- Requires financial commitments and planning. You may need senior management or finance team approval prior to the full implementation stage. The cost of wearable technology depends on how many employees and locations are involved.
- Devices could lead to distraction. For many employees, wearing this device for an entire shift can be distracting, especially if the device has haptic feedback or vibration reminders.
- Data security and privacy could be compromised with legal, financial, and personal consequences. An information technology (IT) department will need to ensure the data generated from the devices is secured for authorized individuals and ensure proper consent is obtained from each individual whose data is being collected.
- Devices could lead to over-trust or under-trust. This could be challenging when reviewing all the data to determine realistic trends. Sometimes this results in trusting or not trusting all the reviewed data before making any decisions or improvements.

1.4. APPLICATIONS OF WEARABLE SYSTEMS

- Wearable technology is not a new category one of the most popular early incarnations of the wearable technology was HP's calculator watch, which was introduced in the 1980s.
- In 2010, Nike+ Sportband was introduced as a device that can communicate with the sensor hidden in the shoes to tell people the details about running.
- In 2012, the major companies in international consumer electronics sector display their wearable devices at trade shows.
- In 2013, the introduction of Google Project Glass that has opened the era of wearable technology.
- The wearable technology will drive innovation just like the personal computers of the 1980s and the current mobile computer tablets," said Mary Meeker, called the Internet Queen. "Some people have laughed at the wearable technology, such as Google's glasses, and it is just like that some people laugh at personal computers and internet.
- Wearable devices have not been as widely accepted as today's smart phones, but in the entertainment, health care, security and other fields, they have begun to play their unique role.
- Using the "wearable device" as a keyword, we search in the Web of Science database. From the macro perspective, some studies demonstrate the design, implementation and

prospects of wearable devices. Focusing on the use of wearable equipment in a particular area, there are medical, sports, fitness and education applications.

- Nowadays, wearable devices have been used in the field of infotainment, such as Apple's Apple watch, Google's Google glass, Sony's Smart watch, etc., and they are launched by major electronics companies. These devices mainly meet the needs of information communication and people's entertainment.
- The current wearable technology is also widely used in the field of security protection. Using built-in chip technology to detect and track the user's geographical location, and the data transmitted to the terminal equipment, the wearable devices can prevent the user from being lost to ensure users' security outdoor.
- At present, the wearable devices mainly meet the needs of the elderly and children to prevent them from being lost. For example, GTX of United States and the Aetrex shoe company jointly developed positioning shoes, which are embedded GPS chip, especially for patients with Alzheimer's disease.
- Wearable technology has a very broad prospect for development in the medical health field.
- Today, these wearable devices such as smart bracelets, watches and collars can help healthcare professionals detect data such as blood sugar, heart rate and exercise status so that they can keep track of metrics and assign a health management program to users to protect sudden changes in the body caused by sudden disease. Wearable devices will bring a revolution for the medical equipment industry.
- Google Glass is also thought to be a good way for trainees to easily acquire intraoperative footage for self-review.
- The medical devices in the future will be more and more miniature, and be worn and even embedded within the human body.
- In sports and training field, the United States company Zepp has developed wearable devices that are suitable for and can be used in the baseball, golf and tennis.
- Athletes wear a lightweight motion sensor, which can capture their movements, and stream sports data to the data server (or mobile client) wirelessly. Athletes and coaches can analyze and play back the actions by looking at the corresponding data to improve their performance.

Applications in K-12 PE Classes

- Wearable technology can be applied in K-12 physical education classes and help students to establish health habits and help teachers adjust exercise intensity and density according to the information such as heart rate displayed on apps.
- The following case comes from the seventh primary school of Zhaoqing City, Guangdong Province, and the teacher is Zhao. This class is called "durable run campus orienteering" In the physical education class.

- This course takes full advantage of the full color LED display, tablet computer, smart bracelet, orienteering marking device and other equipment. Tablet computer, smart bracelet and orienteering marking device can help collect students' data and upload them to the teacher side in real time, and then do statistical analysis. Then students' information can be displayed through the stage LED. Students can see their own real-time movement, and teachers at any time can get to know the movement of students and grasp the situation.
- The order of class contents is: classroom routine → classroom introduction (the method of Flipped Classroom) → jogging + game, warm up → campus orienteering exercise.
- The teacher uses a variety of wearable devices, such as smart wristbands, orienteering marking device, in order to achieve the training requirements for students in this class:

1) Campus orienteering exercise

- According to the problems of preview and courses' key and difficult points, the teacher explains the professional actions and precautions of orienteering. Then, the teacher sends the first map to the tablets of each student through Network disk.
- Students plan the personalized map that owned their group on the paper maps, and upload the pictures they take to the tablets.
- Students start the orienteering exercise under the two maps. Students test the physical data as soon as finishing the orienteering.
- After finishing the test, showing the students' exercise load and trajectory in some parts of groups.

2) Rules of campus orienteering

- Getting four-student crews (each group has two tablets, two sports bracelets, two orienteering machines).
- Students must have two different routes of campus orienteering race according to the two maps offered by tablets.
- The personalized maps that students planned by themselves can't be the same as the routes that teachers hand out.
- Each group must record the sports time through the orienteering machine and routes by scanning QR codes.
- Students must then complete the corresponding exercise once they arrive at every site.
- In this lesson, wearable devices greatly help teachers and students understand students' changes in heart rate, as well as the moving trajectory in the process. It plays a great help for the teacher's class reflection, adjustment of physical exercise. At present, the school is still communicating with the relevant enterprises, expecting enterprises to develop wearable devices and supporting platform more suitable for physical education class, to ensure that the wearable devices can provide in-time feedback about the students' data about heart rate, exercise load. What is more, the wearable devices can make real-time statistics, analysis and provide better feedback.

Oculus Rift - A Virtual Reality Headset

We usually think that three main sources of power to promote the rise of the Internet is three Gs: the Game, the Gamble, and the Girl. Even now, three Gs is also the traffic sources and benefit sources of many Internet giants, largely because they represent a standard for both basic and long-term human impulse. Historically, games also change with the transition of platforms.

- Oculus Rift, designed for electronic games at first, can provide virtual reality experience through goggles. You Visit has adapted over 1000 virtual college tours so they can be viewed on Oculus Rift headsets. Virtual tours would allow students to go into campus spaces not typically open to visitors. The Oculus Rift headset is also enabling students to explore potentially dangerous situations from the safety of the classroom. One virtual education expert has created a virtual construction worksite where engineering students can identify unsafe areas without exposure to harm.

Cellphone-Charging Shirt

- Researchers at the University of South Carolina converted the fibers of a t-shirt into activated carbon, turning into a wearable hybrid super-capacitator that can charge portable electronic devices. The inventors claim that the process they used on the t-shirt is less expensive, and greener, in comparison to conventional methods of creating electric storage devices.

Other applications

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

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

1. Forecasting changes in mood, stress, and health
2. Measuring blood alcohol content
3. Measuring athletic performance
4. Monitoring how sick the user is
5. Detecting early signs of infection
6. Long-term monitoring of patients with heart and circulatory problems that records an electrocardiogram and is self-moistening
7. Health Risk Assessment applications, including measures of frailty and risks of age-dependent diseases
8. Automatic documentation of care activities

9. Days-long continuous imaging of diverse organs through a wearable bio adhesive stretchable high-resolution ultrasound imaging patch or e.g. a wearable continuous heart ultrasound imager (potential novel diagnostic and monitoring tools)
10. Sleep tracking
11. Cortisol monitoring for measuring stress
12. Measuring relaxation or alertness e.g. to adjust their modulation or to measure efficacy of modulation techniques

Epidermal skin technology

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

Health monitoring

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

Entertainment and gaming

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

Fashion and smart clothing

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

Military

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

Sports and fitness

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

1.5. TYPES OF WEARABLE SYSTEMS

1.5.1. SMART WATCHES

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

1.5.2. FITNESS TRACKERS

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

1.5.3. SMART JEWELRY

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

1.5.4. GAME SIMULATORS

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

1.5.5. SMART CLOTHING

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

1.5.6. SMART GLASSES

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

1.5.7. HEARTBEAT TRACKERS & BLOOD PRESSURE MONITORS

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

1.5.8. SMART EARBUDS

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

1.5.9. SMART CONTACT LENS

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

1.5.10. IMPLEMENTATION SCENARIO OF WIRELESS BODY AREA NETWORK

The control device can be placed on the body like a mobile phone as shown in Fig. 1.3(a), or it can be placed at an accessible location. Most suitable technologies for this link are ZigBee, Bluetooth, 6loWPAN, and WMTS.

The main task of the BCU is to transfer data to a PC or to a smart phone. Wireless technologies used on this segment (BCU to PC or to an Internet device) could be a mobile communication network, a satellite link, or a Wi-Fi link. When the Internet is used, the data collected at this PC can be transferred to remote stations in remote medical centers across the network.

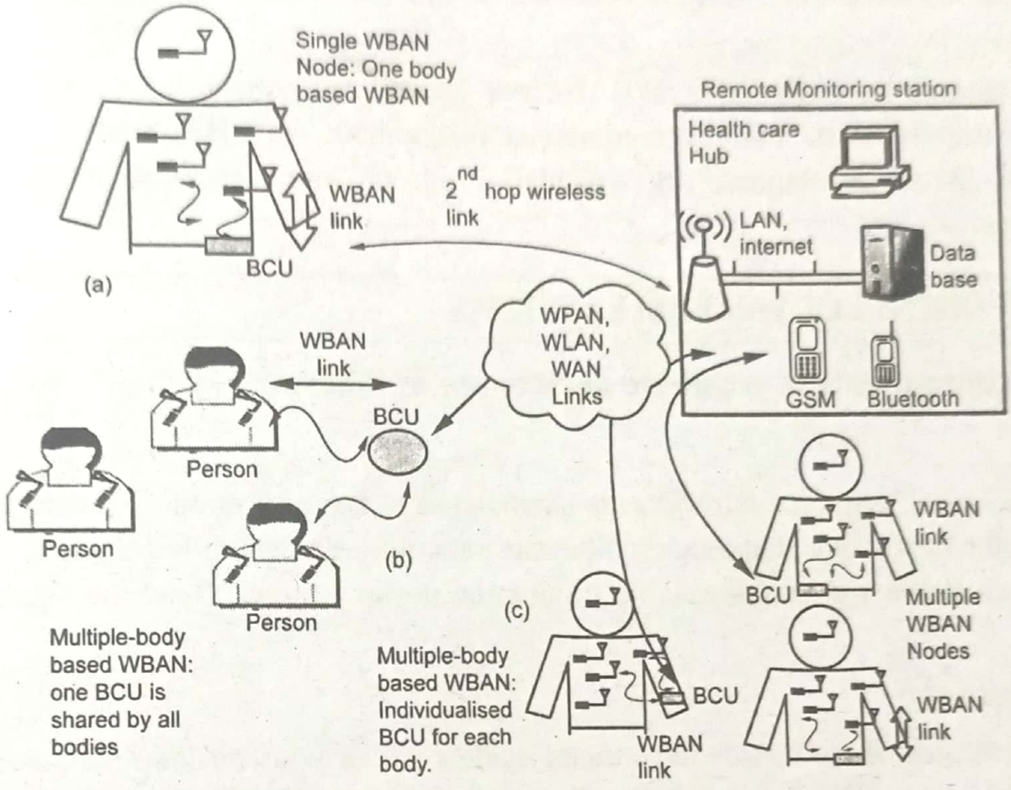


Fig. 1.3. Implementation scenario of Wireless body area network (a) single WBAN node, (b) a WBAN node with multiple bodies, and (c) multiple WBAN nodes. See also Color Insert.

As described in Fig 1.3, the collected sensor data can easily be transferred to remote stations (i.e., medical centers) with the existing wireless and information technology infrastructures such as satellite, mobile communication system, Internet, etc.

Accessing the medical data of injured people through Internet is an e□ective solution at the moment, which will allow medical professionals at the hospital to collect and evaluate data while patients are being transferred to the hospital in an emergency vehicle. If provisioned, these data can also be accessed outside the emergency areas as they will be made available online.

The control device will be similar to smart phones we use in our daily life to receive and monitor the data obtained from sensors. They will be like minicomputers, which will most likely be connected via a wireless technology such as Bluetooth, Wi-Fi, 3G/2G networks or the satellite (VSAT: very small aperture terminal).

These technologies over flexible communication links that can be configured to send data from medical sensors to remote medical centers (second wireless link in Fig 1.2 and Fig 1.3), which can be accessed by medical professions at any time. The BCU can be attached to the body as a wristwatch or around belt.

The first scenario sharing a single WBAN node can be used for home care where there is need for only one body monitoring. Scenarios presented in Fig. 1.3(a),(b) can be used at a disaster area, in emergency rooms in hospitals, and in ambulance while patients are taken to the hospital.

Above discussion shows that WBAN is a specialized sensor network with definite application requirements. For the commercial deployment of WBANs, it is necessary to develop an industrial standard by considering its di□erent application scenarios and requirements.

1.6. COMPONENTS OF WEARABLE SYSTEMS

The main components of wearable devices are as follows

1. Control

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

2. Input/Output

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

3. Conductive Textiles

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

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

4. Sensors

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

5. Power

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

6. Actuators

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

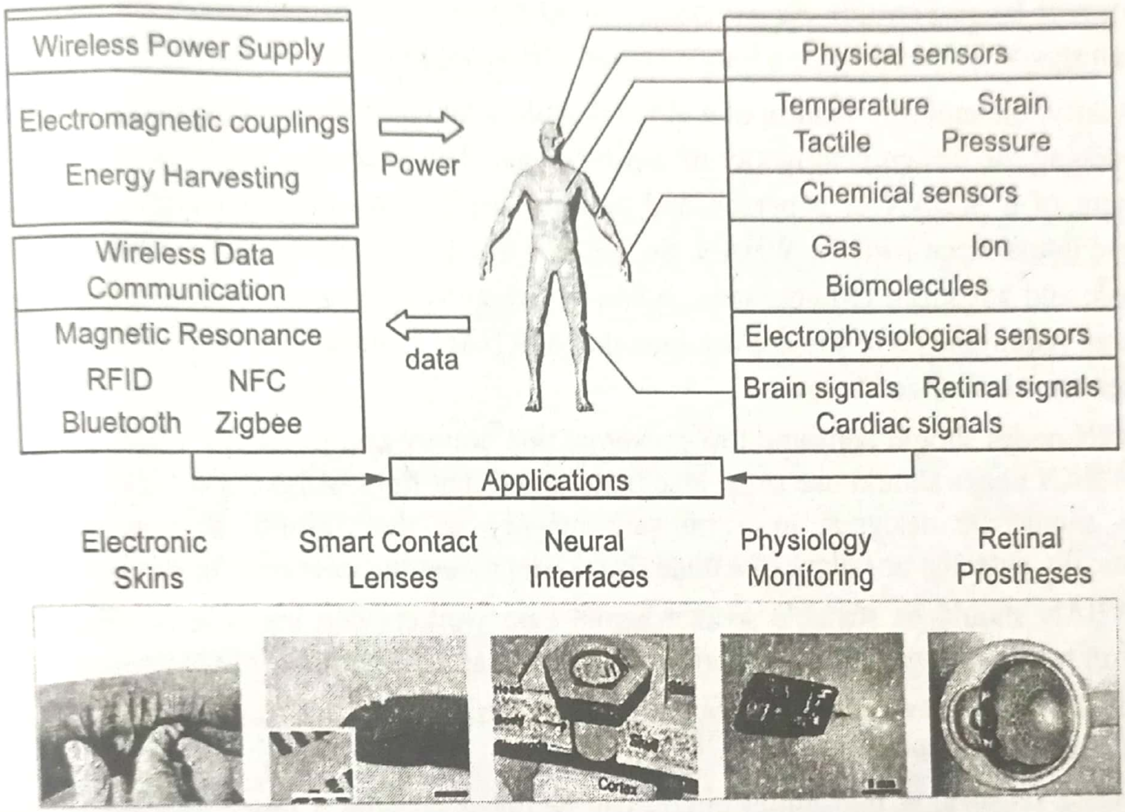


Fig. 1.4. Components in wireless, wearable sensor systems

7. Networking

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

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

Wireless Bodey Area Network (WBAN)

A WBAN is a special purpose wireless sensor network designed to transmit data within a very short distance. The quality of service (QoS) of a WBAN will depend on applications, which are primarily medical applications. As discussed earlier, WBANs could be used in other applications such as sports training, rehabilitation purposes, or military applications where the QoS will be dictated by the nature of those applications.

For medical applications where the source of information is physiological signals such as heart rate, blood pressure, ECG, etc., the system generally demands low latency and high reliability. Also, most of the physiological signal sources produce shorter data bursts at a regular sampling frequency. Hence, a WBAN transmission data rate requirement is low to medium for each connection.

The range of a WBAN network should not a□ect the sensor node designs because the gateway will be responsible for seamless long-distance services; hence, a modular design approach should be taken when a long distance WBAN application design is developed.

Similarly, the mobility feature of a WBAN will be taken care by the gateway or a router, thus reducing the design complexity of sensor nodes. The gateway should be able to detect movement of a WBAN or a person and connect itself to available external networks to exchange information with the WBAN. So, the WBAN design requirements can be classified into basic and advanced requirements. Advance design requirements will be influenced by the design requirements of the applications that a WBAN is used. The basic WBAN design attributes are summarized below:

WBAN nodes should consume low power so that battery could last for a very long time. Also, WBAN nodes should use small size batteries so that light-weight nodes can be used.A WBAN should be designed in a fail-safe manner so that failure of a node can be automatically detected or failure of a node should not a□ect the operation of the network.

A WBAN should be scalable so that health care workers can increase or decrease the number of nodes on a patient's body without any manual intervention of IT personnel.

To achieve the above design attributes, WBAN designers should consider the following points in their design work:

Wireless sensors: A transmitter circuit can be designed with a few components, which may consume extremely low power when designed with an integrated circuit technology. Appropriate sleep and wake-up cycles should be incorporated with the designed hardware to reduce the power consumption to a minimum level.

Reliable data communication: Reliable, error free, and robust information should be received from sensors. A WBAN will use a wireless channel to transmit data, which is inherently unreliable. Error checking and correction mechanisms should be incorporated so that the unreliability of the transmission channels can be countered.

The wireless technologies used in a medical environment should operate in the frequency bands that are immune to interference and thus increase the coexistence of sensor node devices with other network devices available at the same location. The wireless technology used should have less interference effect on other medical equipment. Any network outage should be automatically detected, and the sensor data should be delivered in a fail-safe manner, which could be a critical requirement for a patient monitoring system.

Wireless network security and privacy: Key software components should be defined and developed to accommodate secure and effective wireless networking. Protocols should be designed in such a manner that a WBAN data cannot be collected by intruders.

A WBAN will use a wireless transmission channel, which opens up the possibility of external intrusion while transmitting data. Data encryption techniques could be used, but designers should keep in their mind that undue complexities should not be introduced at the sensor node level to avoid higher battery power and larger physical size.

Handover mechanism: Handover mechanism should be integrated in a WBAN using the gateway or a router. Handover features should not overload the sensor node design.

Miniaturized antenna: Unobtrusive small antenna design should be used, which will operate at high frequencies. Directional or narrow beam antenna design could be considered for specific medical applications.

Gateway devices: A WBAN node may have a wearable or implantable node. Gateway devices should be developed to interface with the existing wireless networks used in health care systems. Gateway devices should implement advanced algorithms, which are more power hungry so that sensor node design and requirements remain simple.

Alarm option: An alarm option should be included when an outage occurs or a sensor node fails.

Comfort: Sensor node electronics could be designed using flexible and stretchable technology so that sensor nodes can easily be embedded in textiles (i.e., patient's clothes). It can be attached to the human body using a plaster to eliminate movements.

1.7. SENSORS FOR WEARABLE SYSTEMS

1.7.1. SENSORS

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

Wearable systems include sensors for detecting physiological signs placed on-body without discomfort, and possibly with capability of real-time and continuous recording. The system should also be equipped with wireless communication to transmit signals, although sometimes it is opportune to extract locally relevant variables, which are transmitted when needed.

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

In general, such systems should also contain some elementary processing capabilities to perform signal pre-processing and reduce the amount of data to be transmitted.

A key technology for wearable systems is the possibility of implementing robust, cheap microsystems enabling the combination of all the above functionalities in a single device.

This technology combines so-called micro-electro- mechanical systems (MEMS) with advanced electronic packaging technologies.

The former allows complex electronic systems and mechanical structures (including sensors and even simple motors) to be jointly manufactured in a single semiconductor chip.

A generic wearable system can be structured as a stack of different layers. The lowest layer is represented by the body, where the skin is the first interface with the sensor layer. This latter is comprised of three sub-layers: garment and sensors, conditioning and filtering of the signals and local processing.

The processing layer collects the different sensor signals, extracts specific features and classifies the signals to provide high-level outcomes for the application layer.

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

1.7.2. BIOMECHANICAL SENSORS

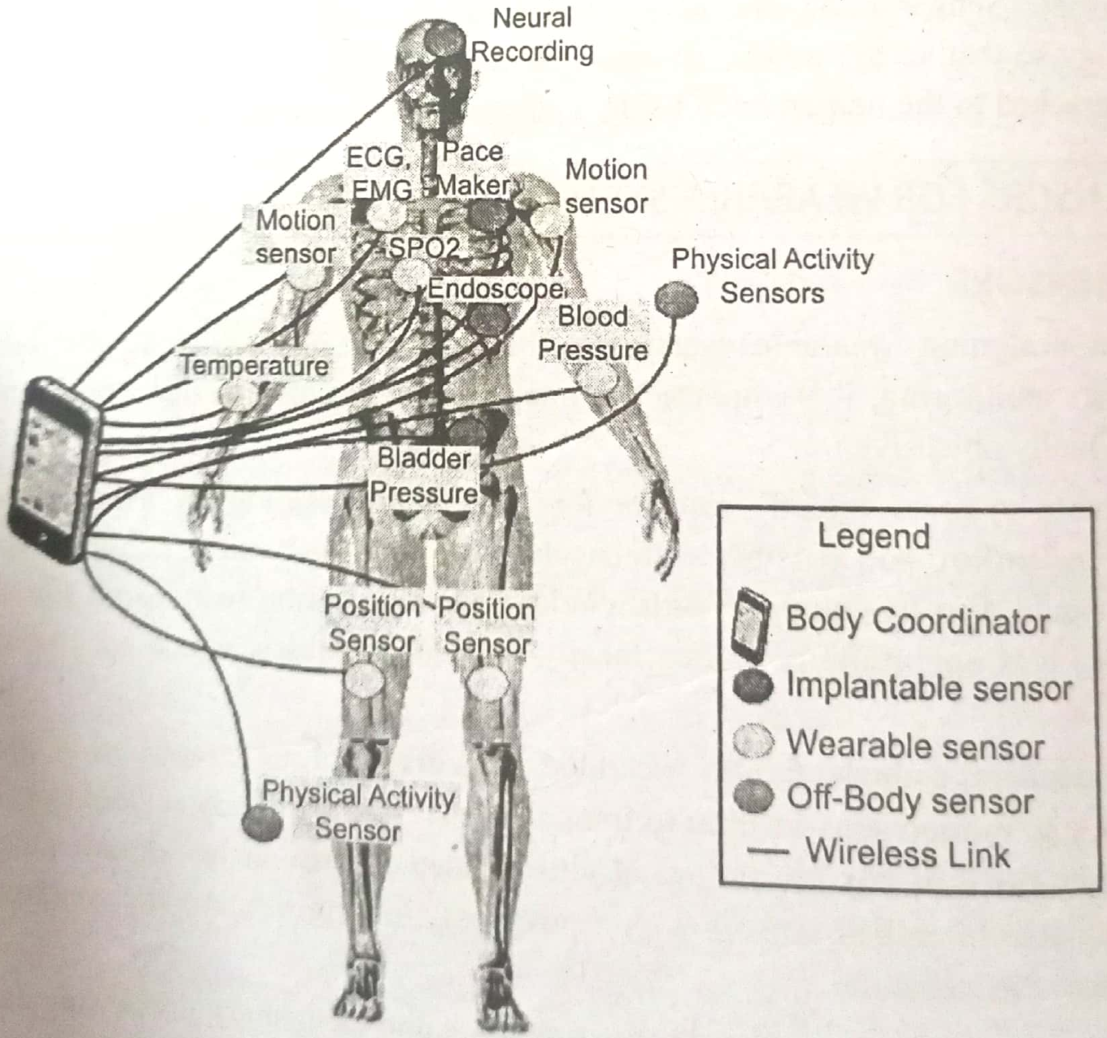


Fig. 1.5. Biomedical Sensor

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.

1.7.3. DIFFERENT SENSORS USED FOR SMART CLOTHING

Wearable electronics refer to textiles and clothing with integrated electronic technology or other computing devices that provide smart functionalities. These smart textiles augment creativity, intellect, communication, memory and physical senses. This definition does not only apply to garments but to everything that can be worn on the body. Once combined with electronic technology, watches, caps, shirts and glasses, for instance, can all contribute to the very wide spectrum of wearable electronics.

Wearable technology that relies on sensors to measure how the body maneuvers offers consumers data about themselves. With evolving sensors technology, wearables now have a deeper measuring ability.

Accelerometer

Accelerometers are sensors used in wearables. Their brand of acceleration, such as gravity and linear, demonstrates their sensing capabilities. Meanwhile, their measuring ability enables the programming of measured data for different purposes. For instance, a user who runs can access his or her top speed output along with acceleration. Further, accelerometers can track sleep patterns.

Gyroscopes

Gyroscopes are also a common wearable sensor. They differ from accelerometers by recording only angular accelerations. In some implementations, the accelerometer is used to measure rotational acceleration, while some systems would like to incorporate both for filtering errors. Gyroscopes increase the precision of the data tracked and numerous types are available, including gas bearing, mechanical and optical.

Magnetometers

Magnetometers can be integrated to create an inertial measurement unit (IMU) with accelerometers and gyroscopes. All of these sensors can feature three axes each, are very similar to a compass and can improve balance. While gyroscopes and accelerometers are usually used with them, magnetometers match them by filtering the motion orientation.

Global positioning system (GPS)

GPS is a common sensor used on many devices such as smartphones and smartwatches. It is used for scanning and informing users of their location. Information is sent to a satellite to quantify exact location and time. This serves as a transmitter and a receiver in which the information is returned to the sensor to notify the location.

Heart rate sensors

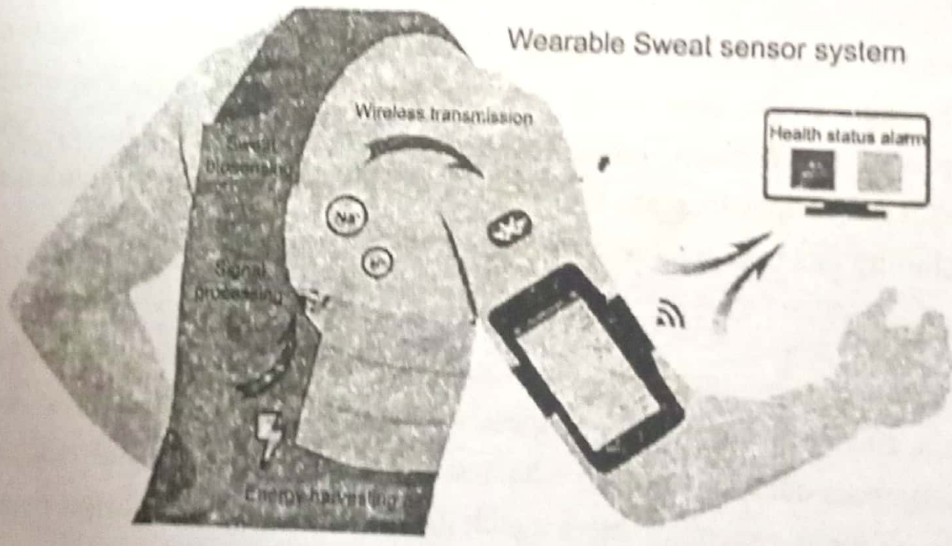
Various techniques and sensors are available for measuring heart rate. One method uses capacitive sensing to idealize the electrode (sensor) and the skin as two parts of a conventional capacitor. Photo plethysmography is a technique that uses light to track blood flow volume changes. Fitness trackers like Fitbit rely on this approach using a photodiode. There is a continuous green light transmitted to the skin of the wearer, which measures the light absorption by the photodiode. This information is transferred so that pulse can be calculated. An increase in the blood passing through the user's bloodstream, the more light the diodes absorb.

Pedometers

Pedometers are typically found in wearables focused on physical health and can count the user's steps while running or walking. There are two variants of pedometers: electrical and mechanical. The former is the most popular form today and depend on MEMS technology for efficiency, but still operate on mechanical pedometer-based principles.

The pendulum function is used to assess the pedometer user's steps. A tiny metal pendulum is used in two-ended pedometers, one with a screw. The hammer swings and hits the other every time a user takes a step and then returns to its original location. The mechanism is linked via spring to an electronic counting circuit. At first, there is no current, and therefore an open circuit is closed each time the hammer hits the other side. Thus, current starts flowing. Once the pendulum moves back to its initial point, the circuit closes again, and the pendulum rotation starts anew. This allows the circuit to understand each step.

Pressure sensors



Usually, pressure sensors operate from strain gauges. When pressure is applied to sensors, the circuit causes a change in resistance. Mechanical quantities like force are observed in many ways and are transformed into resistance-dependent electronic measurements. This method of measuring pressure is achieved through the construction of a Wheatstone Bridge, which can track static or dynamic resistance changes. The sensing device will comprise one, two or four arms in the configuration of the Wheatstone Bridge. The number depends on the use of the device (how many in tension and compression). The sensor mechanism allows them to be integrated into external factors such as ball contact monitoring equipment.

Integration of sensors into wearables

A microcontroller is a key component to enable wearable technology to operate. It is commonly seen as a small computer (the chip system) that allows the integration of the internet of things (IoT) with the desired application. Most significantly, it eliminates the use of many electronic components to execute different functions on a single chip. Duc to its ease in programming, reprogramming, cost, size, connectivity with other sensors and the ability to handle complex functions, including graphic displays, it is best used in wearable technology.

1.8. INERTIAL MOVEMENT SENSORS

The inertial sensor, also known as the inertial navigation system (INS), uses an accelerometer and gyro to determine spacecraft attitude in relation to the inertial system. The accelerometer is used to test the motion acceleration of the carrier, which is then used to calculate the real-time location of the carrier.

Inertial sensors are composed of accelerometers and gyroscopes, which measure specific force and turn rate, respectively. The so-called inertial measurement unit contains three mutually orthogonal accelerometers and three mutually orthogonal gyroscopes. Therefore, the acceleration and turn rate measurements are triads.

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

On the other hand, the recent advances in technology have led to the design and development of new tools in the field of motion detection which are comfortable for the user, portable and easily usable in non-structured environments. Current prototypes realized by these emergent technologies utilize micro-transducers applied to the subject body (as described in the current paragraph) or textile-based strain sensors.

The first category, instead, includes devices based on inertial sensors (mainly accelerometers and gyroscopes) that are directly applied on the body segment to be monitored.

These sensors can be realized on a single chip (MEMS technology) with low cost and outstanding miniaturization. Accelerometers are widely used for the automatic discrimination of physical activity and the estimation of body segment inclination with respect to the absolute vertical. Accelerometers alone are not indicated for the estimation of the full orientation of body segments.

The body segment orientation can be estimated by using the combination of different sensors through data fusion techniques (Inertial Measurement Units, IMU). Usually, tri-axial accelerometers (inclination), tri-axial gyroscopes (angular velocity), magnetometers (heading angle) and temperature sensors (thermal drift compensation) are used together. Main advantages of using accelerometers in motion analysis are the very low encumbrance and the low cost.

Disadvantages are related to the possibility of obtaining only the inclination information in quasi-static situations (the effect of the system acceleration is a noise and the double integration of acceleration to estimate the segment absolute position is unreliable). Accelerometers are widely used in the field of wearable monitoring systems, generally used in the monitoring of daily life activities (ADL).

Physical activity detection can be exploited for several fields of application, e.g. energy expenditure estimation, tremor or functional use of a body segment, assessment of motor control, load estimation using inverse dynamics techniques or artificial sensory feedback for control of electrical neuromuscular stimulation.

Usually, three-axial accelerometers are used. They can be assembled by mounting three single-axis accelerometers in a box with their sensitive axes in orthogonal directions or using a sensor based on one mass. An accelerometer measures the acceleration and the local gravity that it experiences. Considering a calibrated tri-axial accelerometer (i.e. offset and sensitivity are compensated and the output is expressed in unit of g), the accelerometer signal (y) contains two factors: one is due to the gravity vector (g) and the other depends on the system inertial acceleration (a), both of them expressed in the accelerometer reference frame:

The inclination vector (z) is defined as the vertical unit vector, expressed in the accelerometer coordinate frame. In static conditions, only the factor due to gravity is present and the inclination of the accelerometer with respect to the vertical is known.

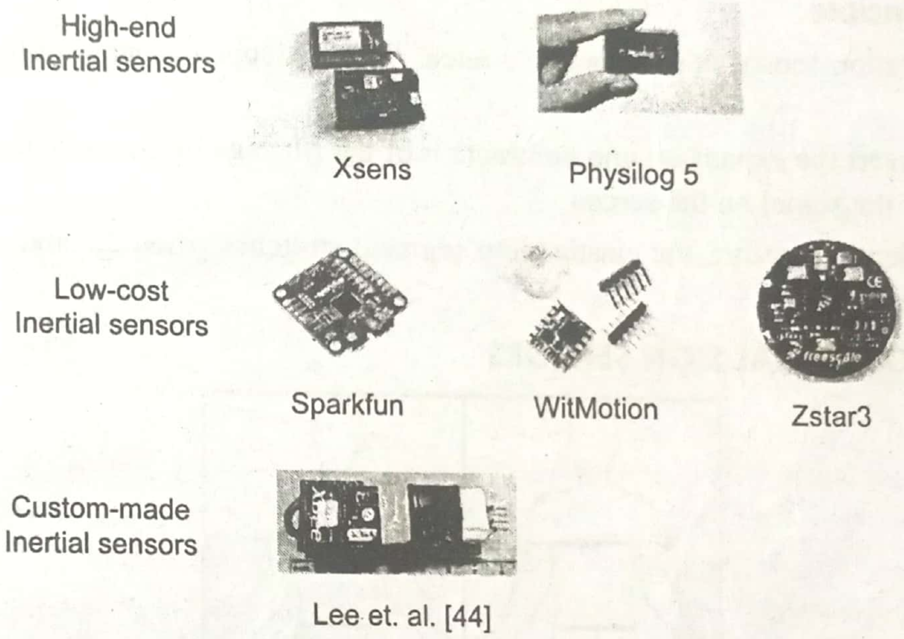
In dynamic conditions, the raw accelerometer signal does not provide a reliable estimation of the inclination, since the inertial acceleration is added to the gravity factor. This estimation error grows as the subject movements become faster (e.g. running, jumping).

Many algorithms have been developed and tested to perform a reliable estimation of the subject body inclination: most of them use low pass filters with very low cut-off frequency in order to extract z (i.e. introducing a considerable time delay), others implement more complex techniques which use a model-based approach mainly based on Kalman filter techniques.

An example of integration of these sensors in a garment was developed in the frame of the Proetex project (FP6-2004-IST-4-026987), which aimed at using textile and fibre based integrated smart wearables for emergency disaster intervention personnel.

The ProeTEX motion sensing platform is used to detect long periods of user immobility and user falls to the ground and it is realized by means of two tri- axial accelerometer modules. One accelerometer is placed in the higher part of the trunk (collar level) in order to detect inactivity and falls to the ground.

The second sensor is placed in the wrist region and its aim is to achieve more accuracy in inactivity detection, since an operator can move his arms while his trunk is not moving. The core of the motion sensor is the processing algorithm which allows to perform a reliable estimation of the body inclination even in the case of intense physical activity such as running or jumping. This algorithm allows a good estimation of subject activities and generated fall alarms with very high sensitivity and extremely low level of false positives.



1.9. RESPIRATION ACTIVITY SENSOR

Respiration

Respiration is the biochemical process in which the cells of an organism obtain energy by combining oxygen and glucose, resulting in the release of carbon dioxide, water, and ATP (the currency of energy in cells).

What happen during Human Respiration?

Usually mean the passages that transport incoming air to the lungs and to the microscopic air sacs called alveoli where gases are exchanged.

Respiration Sensor

The respiration sensor is a sensitive girth sensor worn using an easy fitting high durability woven elastic band fixed with a length adjustable webbing belt.

Various method of measuring respiratory rate

1. Respiratory rate measurement using Piezoelectric Sensor (PZO).

2. Respiratory rate measurement from Laser Doppler Vibrometer (LDVi).
3. Respiration rate measurement System using Pyroelectric Sensor.
4. Impedance Pneumography method.
5. Capnometry.

Purpose of Respiratory Sensor

It detects chest or abdominal expansion/contraction and outputs the respiration waveform.

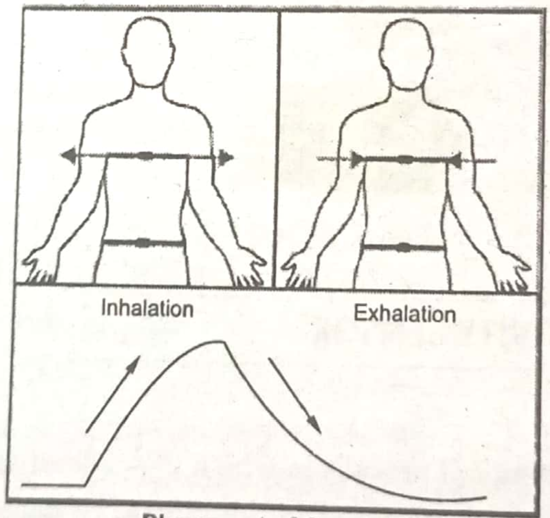
Construction

The sensor is latex-free, magnet-free and Velcro-free, and can be worn over clothing.

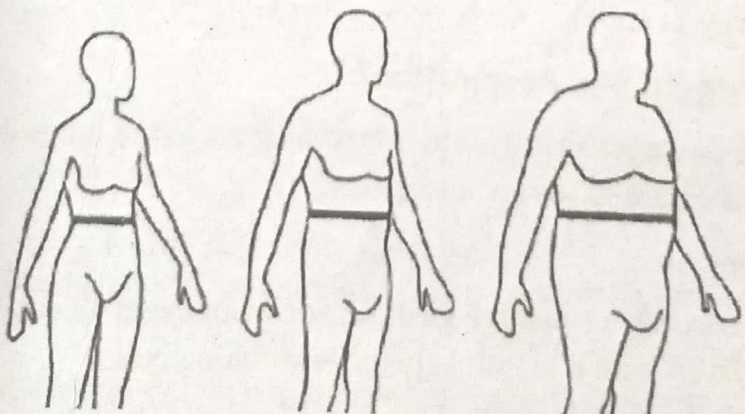
Operating Principle

1. The respiration sensor is sensitive to stretch. When strapped around a client's chest or abdomen,
2. It will convert the expansion and contraction of the rib cage or abdominal area, to a rise and fall of the signal on the screen.
3. For the client's comfort, the elastic strap segment stretches when the abdomen expands during breathing.

1.9.1. PHYSIOLOGICAL SIGN SENSORS



Placement of Sensor



Placement of single sensor for small, medium, or large clients

Fig. 1.6. Placement of Sensor

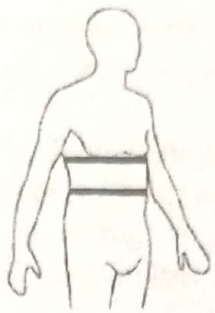


Fig. 1.7. Two Sensor Placement

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 bio- chemical markers are envisaged and described.

1.9.2. 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. In literature, there are several methods to do this, both directly, by measuring the amount of air exchanged during the respiration activity, and indirectly, by measuring parameters physically correlated to breathing, such as changes in thorax circumference and/or cross section, or trans-thoracic impedance.

1.9.3. DIRECT AND INDIRECT METHODS

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

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 there- fore 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), impedance plethysmography, piezoresistive and/or piezoelectric pneumography. These systems are minimally invasive and do not interfere with physical activity. In the following, these four technics are described.

Application

Monitoring of respiratory rate, respiratory cycle regularity, relative amplitude of the cycle, and others. When multiple sensors are used simultaneously it enables diaphragmatic versus thoracic breathing assessment (e.g for biofeedback)

1.10. INDUCTIVE PLETHYSMOGRAPHY

Respiratory inductance plethysmography (RIP) is a method of evaluating pulmonary ventilation by measuring the movement of the chest and abdominal wall. Accurate measurement of pulmonary ventilation or breathing often requires the use of devices such as masks or mouthpieces coupled to the airway opening.

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.

1.10.1. WORKING PRINCIPLE

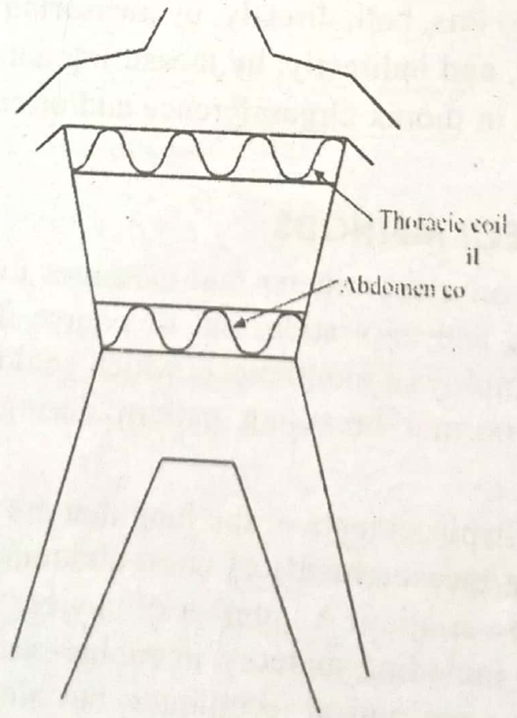


Fig. 1.8. The respiratory inductive plethysmography system including the rib cage and abdominal sensor bands

The conductive wires are insulated and generally sewn in a zig- zag fashion onto each separate cloth band (see Fig.1.8). They can be considered as a coil and are used to modulate the output frequency of a sinewave current produced by an electric oscillator circuit. As a matter of fact, the sinewave current generates a magnetic field, and the cross-sectional area changes due to the respiratory movements of the rib cage and of the abdomen determine a variation of the magnetic field flow through the coils. This change in flow causes a variation of the self-inductance of each coil that modulates the output frequency of the sinusoidal oscillator.

This relationship allows for monitoring the respiratory activity by detecting the frequency change in the oscillator output signal. For accurate volumetric measurements using RIP, it is assumed that the cross-sectional area within the rib cage and the abdomen coil, respectively, reflects all of the changes occurring within the respective lung compartment, and further that the lung volume change is the sum of the volume changes of the two compartments. Under optimal situations, lung volume can be approximated with an error less than 10%.

1.11. IMPEDANCE PLETHYSMOGRAPHY

Introduction

- Impedance PlethysmoGraphy (IPG), is a non-invasive medical test that measures small changes in electrical resistance of the chest, calf or other regions of the body.
- These measurements reflect blood volume changes, and can indirectly indicate the presence or absence of Cardiac, Venous or Arterial pathology.
- This procedure provides an alternative to venography or arteriography, which is invasive.

Cardiac

- For the chest, the technique was developed by NASA to measure the split second impedance changes within the chest, as the heartbeats, to calculate both Cardiac output and lung water content.
- This technique has progressed clinically, often now called BioZ (Biologic Impedance), as promoted by the leading manufacturer in the US and allows low cost, non-invasive estimations of cardiac output and total peripheral resistance.
- It uses 4 pair of surface electrodes.

Arterial

- For Arteries, blood flow in any area like thigh, calf, arm or forearm can be measured by Impedance Arteriography.
- Pulsatile flow of arteries will give characteristic Electrical Resistance that can be recorded as a Graph.
- Along with simultaneous recording of ECG, parameters like PAT, PTT can be measured.

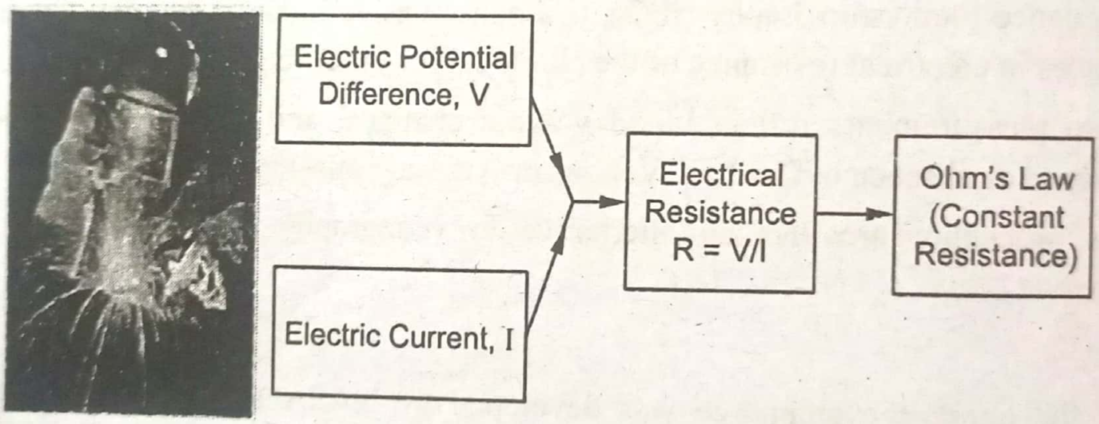
Venous

- For leg veins, the test measures blood volume in the lower leg due to temporary venous obstruction.
- This is done by inflating a cuff around the thigh to sufficient pressure to cut off venous flow but not arterial flow, causing the venous blood pressure to rise.
- When the cuff is released there is a rapid venous return and a prompt return to the resting blood volume.
- Cuff Inflation and Deflation will alter the Electrical Resistance of respective region, that will give a characteristic Graph.
- Delayed emptying of veins in any venous pathology will change the normal response.

Principle

- In this technique, the electrical impedance of any part of the body is measured by constant current method and variations in the impedance are recorded as a function of time.
- Since blood is a good conductor of electricity, the amount of blood in a given body segment is reflected inversely in the electrical impedance of the body segment.

Concepts at a Glance



- Pulsatile blood volume by heart, that is systemic blood circulation causes proportional decrease in the electrical impedance.
- Variation in the electrical impedance thus gives adequate information about the blood circulation.

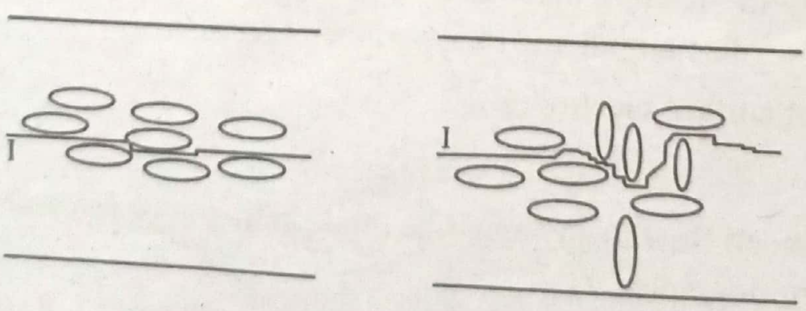


Fig. 1.9.

Technique

- Constant current is passed through the body segment of interest with the help of 2 surface electrodes.

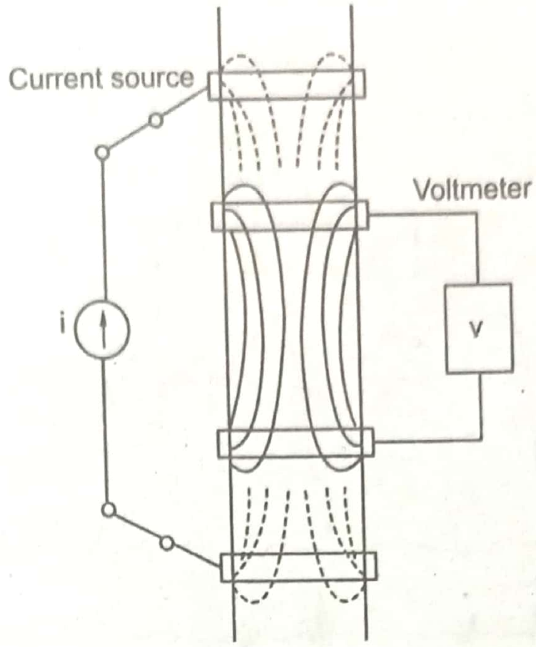


Fig. 1.10.

Voltage signal developed along the current path is sensed with the help of another pair of electrodes.

The amplitude of the signal sensed is directly proportional to the electrical impedance of the body segment.

Amplification and detection of this signal gives instantaneous electrical impedance Z of the body segment.

Difference between the instantaneous electrical impedance and initial value of electrical impedance (Zo) gives variation in the impedance as a function of time, called the $\Delta Z\,(t)$ waveform.

First time derivative of the impedance (dZ/dt) is obtained to give the rate of change of impedance.

With the help of this dZ/dt, used in different equation, peripheral arterial – venous blood flow & stroke volume can be measured.

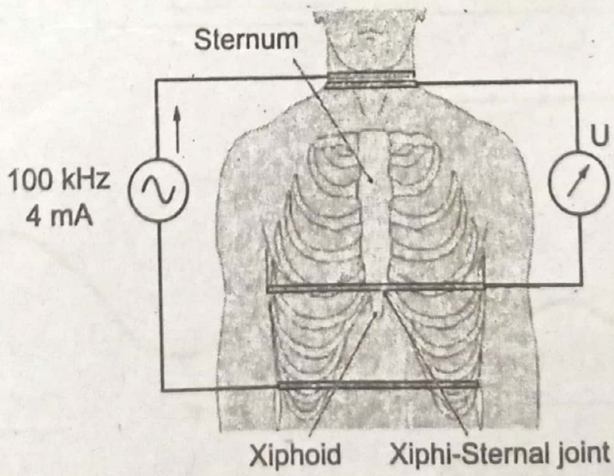


Fig. 1.11. Impedance Cardiography

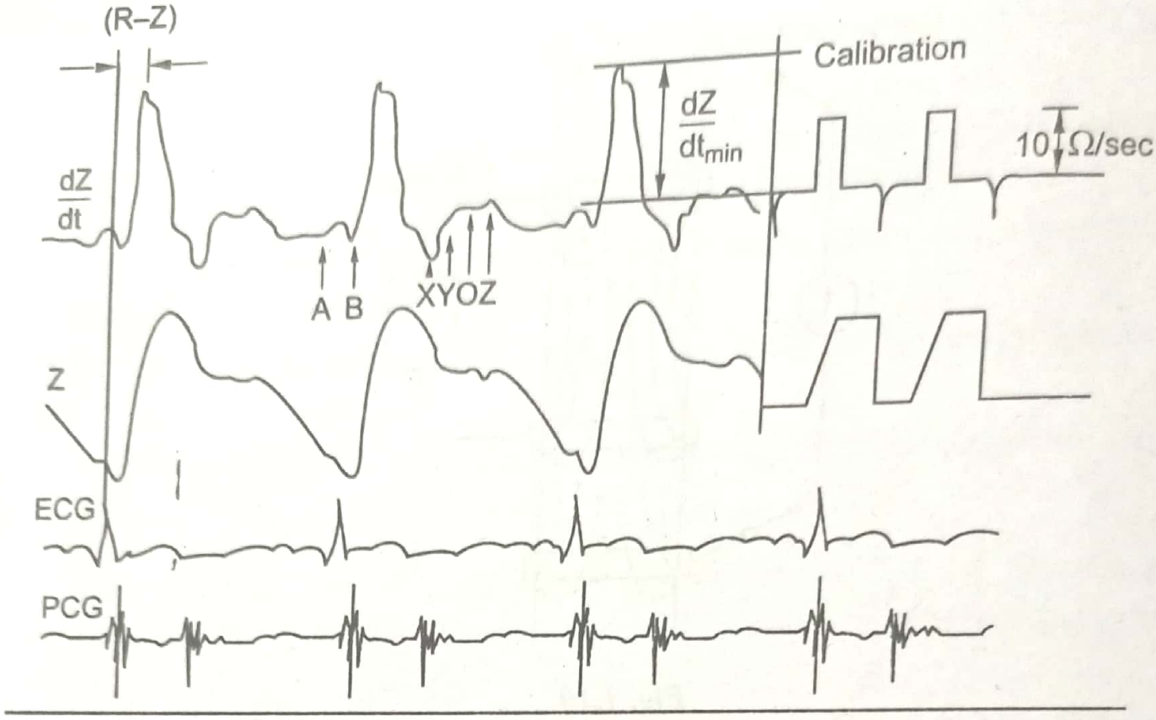


Fig. 1.12. ICG

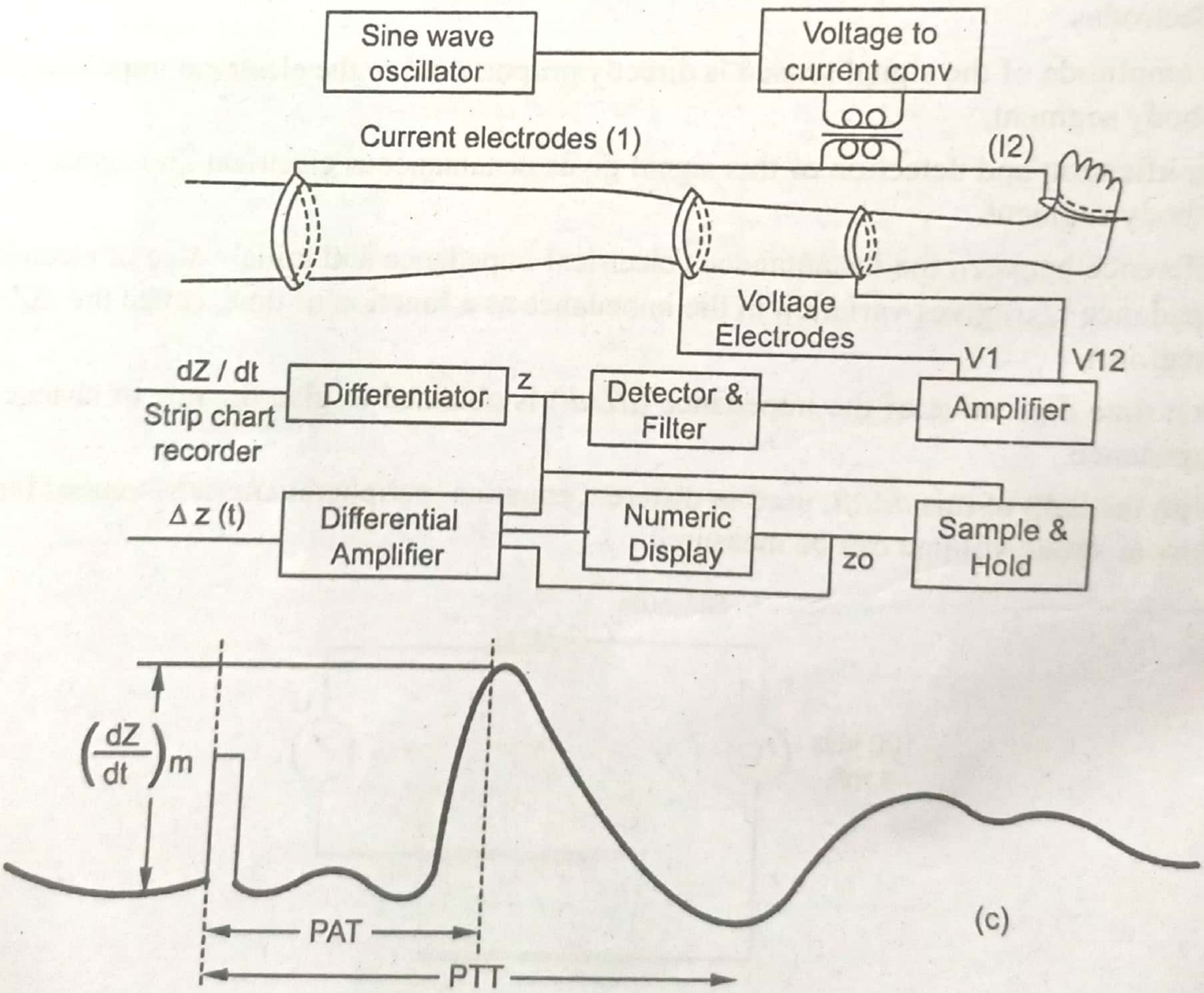


Fig. 1.13. Impedance Arteriography

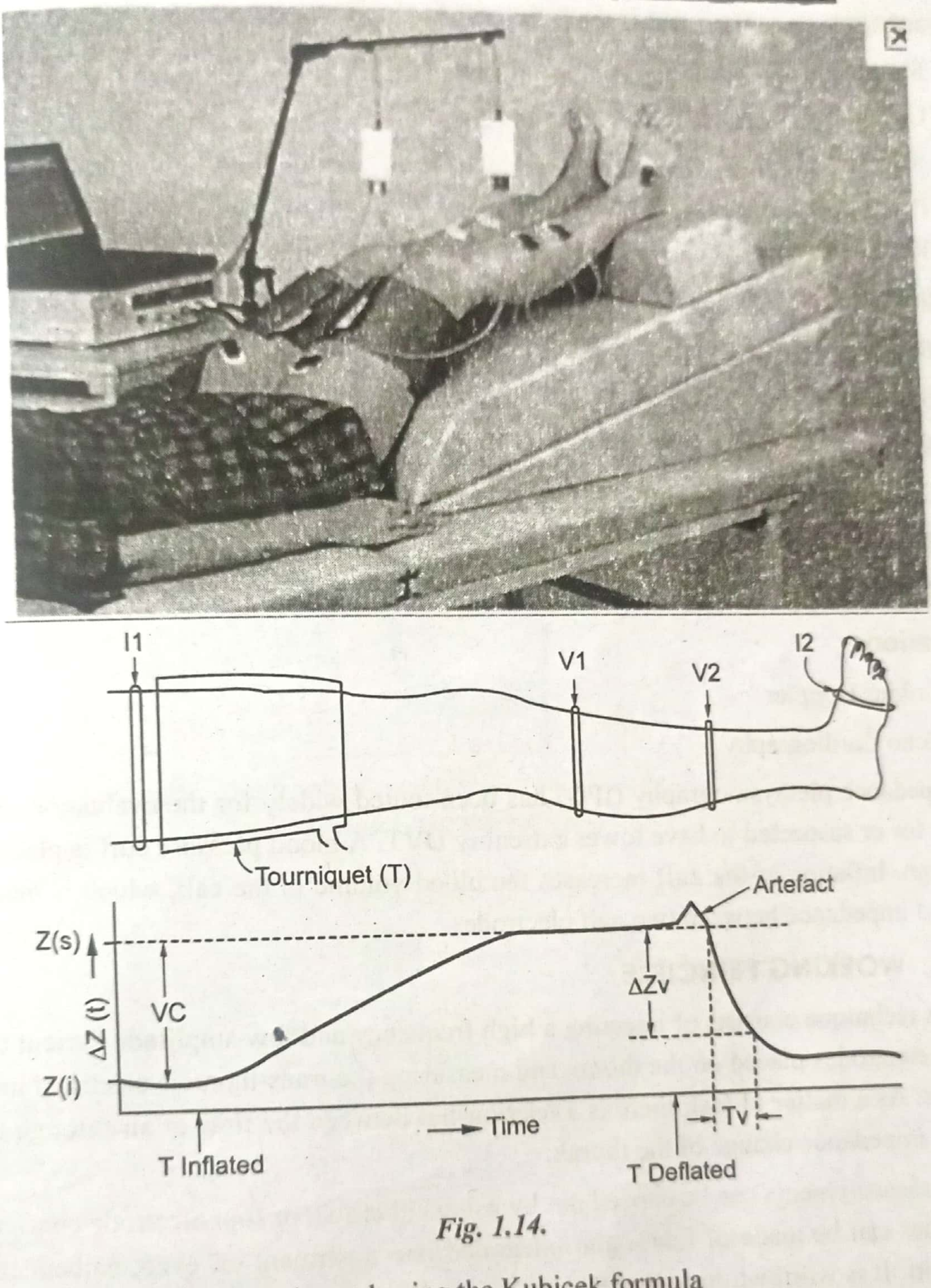


Fig. 1.14.

- Stroke volume is then estimated using the Kubicek formula
- Stroke volume = $k\,p\,(L/Zo)^2$ [LVET (dZ/dt) max]
- Where k is a constant which accounts for variation in body composition based on age, gender, relative fat content, chest circumference;
- L is the inter – electrode distance;
- p is the blood specific resistivity computed using hematocrit as [13.5 + (4.29 Hematocrit)].

Advantages

- Simple
- Cheap
- Effective
- Portability
- Repeatability

Applications

- Research
- Screening
- Vascular Diagnosis
- Continuous Hemodynamic Monitoring – ICU
- Pharmacological studies – OPD
- Adjustment of Pacemaker settings

Limitations

- Colour Doppler
- Echo Cardiography

Impedance plethysmography (IPG) has been touted widely for the evaluation of patients at risk for or suspected to have lower extremity DVT. A blood pressure cuff is placed around the thigh. Inflation of the cuff increases the blood volume in the calf, which is measured as reduced impedance between two calf electrodes.

1.11.1. WORKING PRINCIPLE

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. As a matter of fact, there is a relationship between the flow of air through the lungs and the impedance change of the thorax.

The measurements can be carried out by using either two or four electrode configurations. Electrodes can be made of fabric and integrated into a garment or, even, embedded into an undershirt. It is worthwhile noting that by measuring the trans-thoracic electrical impedance it is possible to non-invasively monitor, in addition to breathing rate also tidal volume, functional residual capacity, lung water and cardiac output. In Fig., the scheme of principle is depicted.

1.12. PNEUMOGRAPHY

A pneumograph, also known as a pneumatograph or spirograph, is a device for recording velocity and force of chest movements during respiration.

1.12.1. PNEUMOGRAPHY BASED ON PIEZORESISTIVE SENSOR

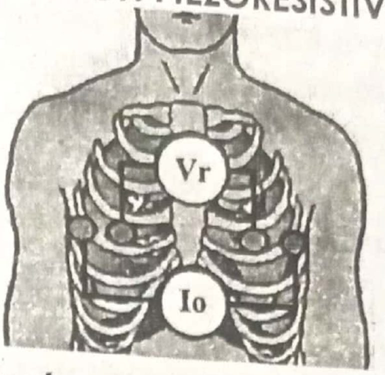


Fig. 1.15. Principle scheme ofimpedance plethysmography system which can be integrated into a wearable system

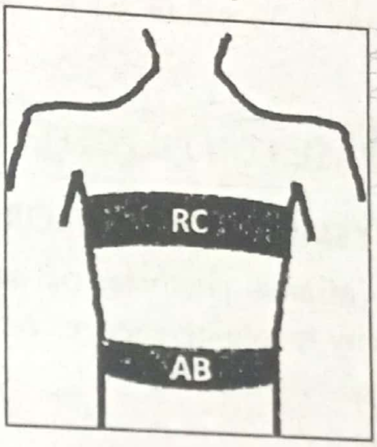


Fig. 1.16. Picture showing howtwo piezoresistive belts can beembedded into a garment to monitor abdominal and thoracic respiratory activity

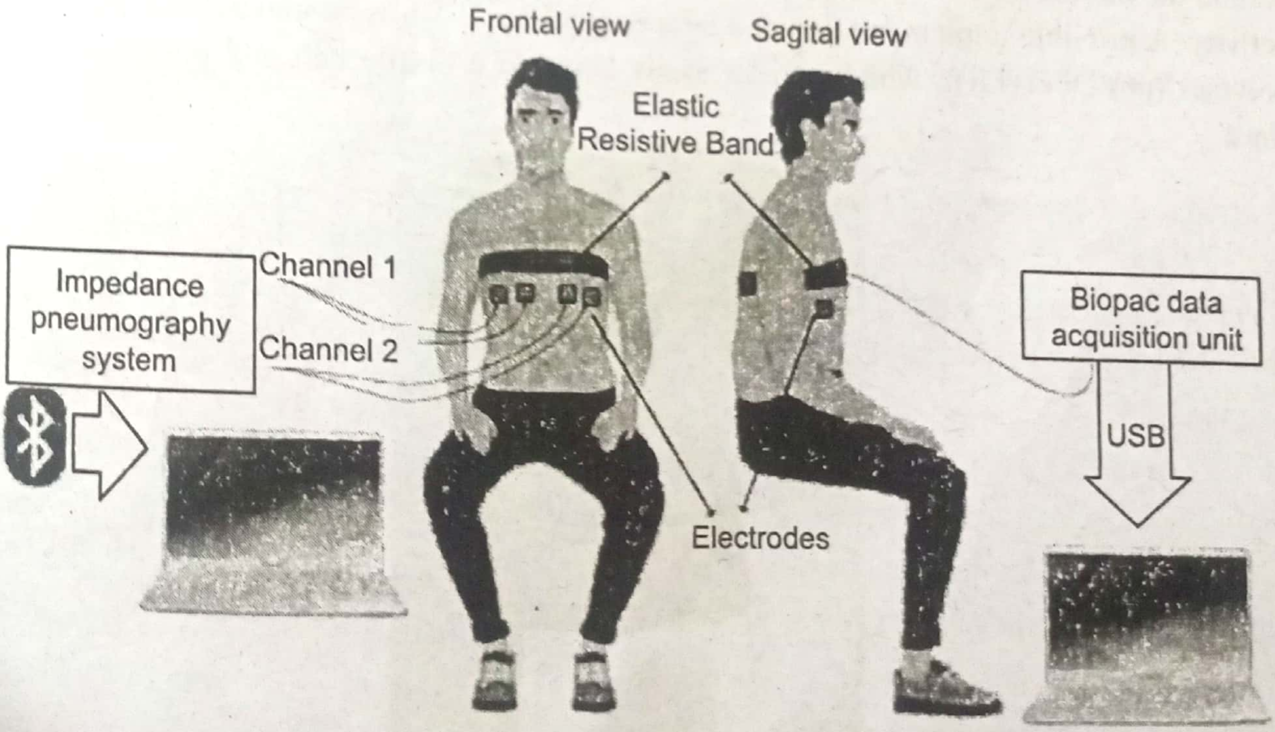


Fig. 1.17. Wireless Impedance Pneumography System for Unobtrusive Sensing of Respiration

Piezoresistive pneumography is carried out by means of piezoresistive sensors that monitor the cross-sectional variations of the rib cage. The piezoresistive sensor changes its electrical resistance if stretched or shortened and is sensitive to the thoracic circumference variations that occur during respiration.

Piezoresistive sensors can be easily realized as simple elastic wires or by means of an innovative sensorized textile technology. It consists of a conductive mixture directly spread over the fabric.

The lightness and the adherence of the fabric make the sensorized garments truly unobtrusive and uncumbersome, and hence comfortable for the subject wearing them. This mixture does not change the mechanical properties of the fabric and maintains the wearability of the garment. Figure 1.15 shows where the two conductive wires or bands could be applied.

1.13. PLETHYSMOGRAPHY BASED ON PIEZOELECTRIC SENSOR

1.13.1. FUNCTION OF PLETHYSMOGRAPH SENSOR

The Plethysmograph is an infrared photoelectric sensor used to record changes in pulsatile blood flow. It operates by recording changes in blood volume as the arterial pulse expands and contracts the microvasculature.

1.13.2. WORKING PRINCIPLE

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.

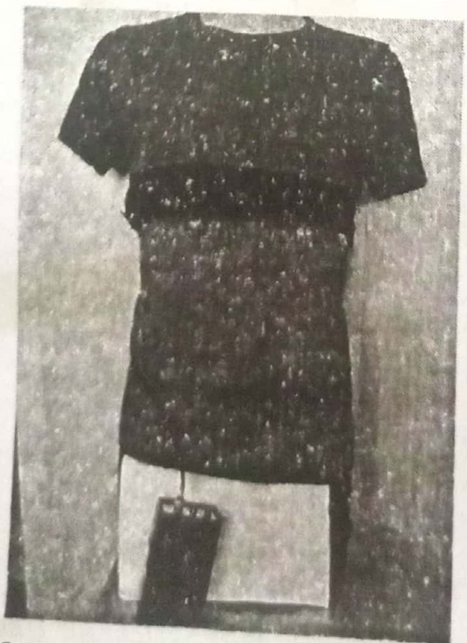


Fig. 1.18. Concept of a wearable system equipped with a piezoelectric band

In Fig.1.18, a possible application is reported. The sensor is sensitive to the thorax movements and produces a signal directly proportional to the thorax expansion in terms of charge variation, which was converted in an output voltage proportional to the charge by means of a charge amplifier. A suitable local processor can enable implementation of the Fast Fourier Transform in real time and extraction of the breathing rate.

1.13.3. GALVANIC SKIN RESPONSE

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.

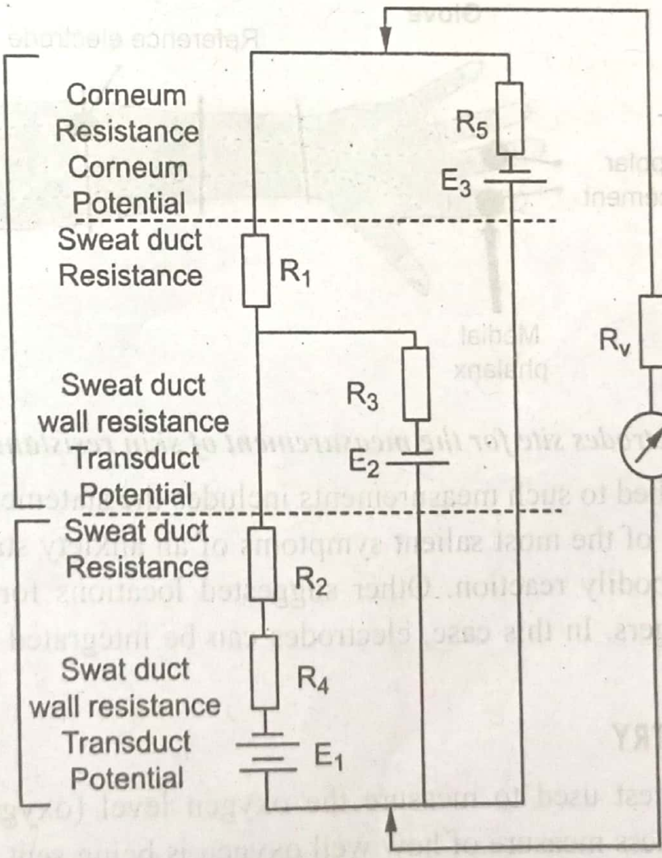


Fig. 1.19. A simplified equivalent circuit describing the electrodermal system. Components are identified in the text

An electrical equivalent model underlying EDR is represented in Fig 1.19. 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. 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. 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.

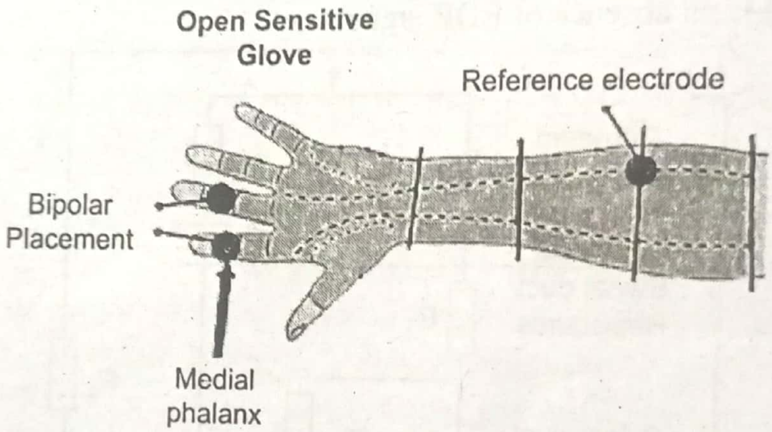


Fig. 1.20. Suggested electrodes site for the measurement of skin resistance and skin potentials

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. Other suggested locations for electrode placement can be between two fingers. In this case, electrodes can be integrated into a glove (see Fig 1.20).

1.13.4. PULSE OXIMETRY

Pulse oximetry is a test used to measure the oxygen level (oxygen saturation) of the blood. It is an easy, painless measure of how well oxygen is being sent to parts of your body furthest from your heart, such as the arms and legs.

Pulse oximetry was introduced in 1983 as a non-invasive method for monitoring the arterial blood oxygen saturation. Recognized worldwide as the standard of care in anesthesiology, it is widely used in intensive care, operating rooms, emergency, patient transport, general wards, birth and delivery, neonatal care, sleep laboratories, home care and veterinary medicine. Currently, several wearable pulse oximeters are being developed to ansfer this standard technique to a most effective remote home-care monitoring.

Being pulse oximeter non-invasive, easy to use, readily available, and accurate, the odern wearable system developed can supply information about blood oxygen saturation, eart rate and pulse amplitude. A pulse oximeter shines light of two wavelengths through a issue bed such as the finger or earlobe and measures the transmitted light signal.

.13.4.1. Principle of operation

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.

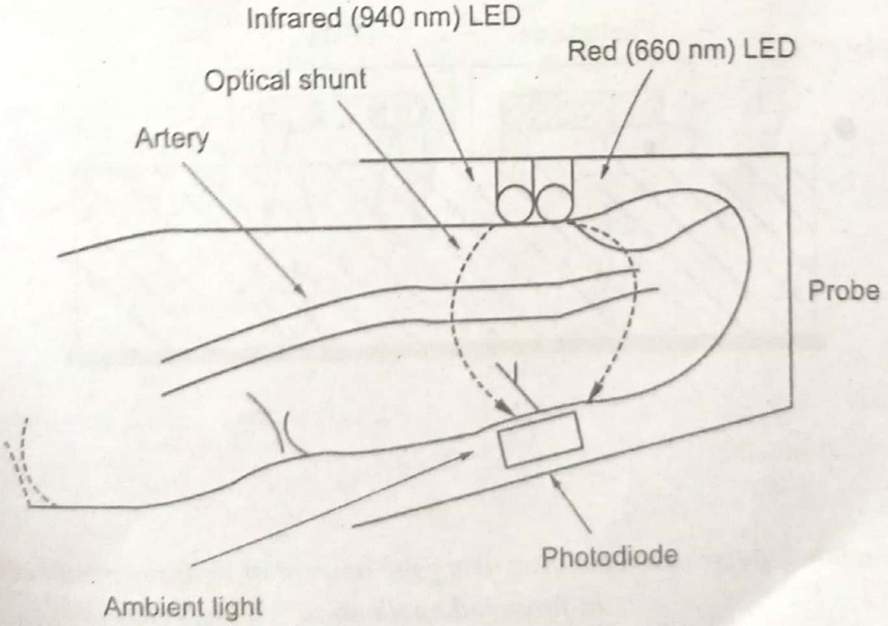


Fig. 1.21. Transmission pulseoximeter measuring the transmission of light by two LEDs through the finger of apatient

Systems following the principles above shown provide an empirical measure of arterial blood saturation. However, with state-of-the-art instrumentation and proper initial calibration, the correlation between the pulse oximeter measurement, SpO_2, and arterial blood's actual oxygen saturation, SaO_2, is adequate-generally less than 3% discrepancy provided SaO_2 is above 70% for medical applications.

In general, when the calibration is difficult or impossible, these systems can be redirected at considering only a led and a photodiode so that the obtained measurement is a photo plethysmography. Really, most pulse oximeters on the market implement photo plethysmography measurements. The signal for the photo plethysmograph is derived from the same waveforms used to calculate SpO_2. The photo- plethysmograph may be used in a clinical setting in the same manner as a plethysmograph.

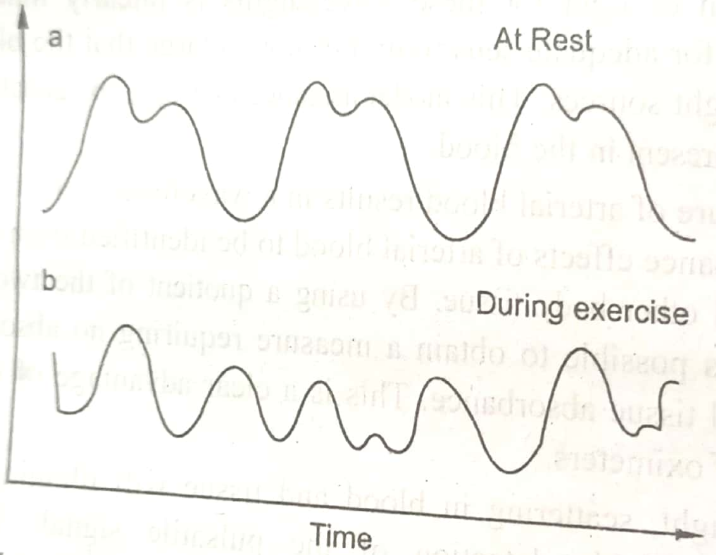


Fig. 1.22. The plethysmographic waveform of a subject at rest is periodic (a) and during exercise is not periodic (b)

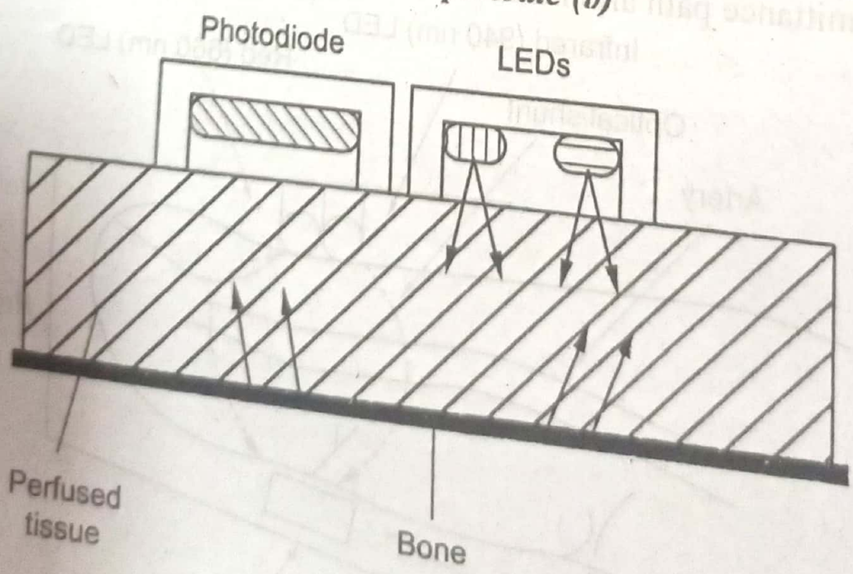


Fig. 1.23. Reflectance pulse oximeter measuring the amount of light reflected back to the probe in forehead application

However, the accuracy of the photo plethysmograph suffers from motion artifacts, and the patient must have adequate blood perfusion near placement of the pulse oximeter probe. Just as with the conventional plethysmogram, signal processing can derive heart rate from the photo plethysmogram waveform. Hence, most pulse oximeters also display heart rate. Similar to computing $Sp0_2$, temporal low-pass filtering abates the effect of motion artifacts on heart rate estimation.

Generally, pulse oximeters are applied to a fingertip (see Fig 1.21), but as above-mentioned they are heavily affected from motion artifact (see Fig. 1.22) so that large part of the signal has to be strongly treated or completely removed, to avoid this signal lost latest research applications aim at positioning the sensor on the forehead (see Fig.1.23), where it has been noted that the signal shows lower artifact noise and better characteristics.

1.14. WEARABLE GROUND REACTION FORCE SENSOR

The sensor measures the forces and moments generated between the foot and ground during normal activities like walking, running and jumping. The battery powered sensor attaches to a shoe or boot with simple strap bindings and is environmentally sealed.

1.14.1. RADIANT THERMAL SENSORS

The interest of the market devices for safety and security has rapidly grown over the last few years. In particular, the use of Radio Frequency (RF) technology for contact-less sensing has been promoted largely into several research projects.

Body temperature is usually captured by means of thermal sensors placed in direct contact with skin. Skin temperature is strongly dependent on the body site and it is sensitive to local increasing of blood circulation. Reference body temperature, indeed, should be internal. Often skin contact with thermal sensors could be difficult and obtrusive, therefore radiant technology is preferred.

The state of the art on radiant thermal sensors covers several high-potential commercial products. Meridian Medical Systems is aiming at fabricating a radiometer as a Monolithic Microwave Integrated Circuit (MMIC) capable of detecting temperature of the heart. Although their research aims at implementing microwave radiometers for medical imaging, it seems they use a traditional approach based on MIC/MMIC.

It is worthwhile mentioning that radiometer exists from a long time, and their approach using hybrid components is well known. Even though MMIC can reach good performance, their level of integration is limited traditionally to the analog-RF part only. Thermal stabilization and calibration circuits need to be implemented by means of external circuitry, resulting in bulky and expensive implementations inadequate for the mass-market.

In fact, the system-on-chip implementation proposed in CMOS technology aims at implementing efficiently on the same die both the analog-RF and the digital calibration circuits. Only this result leads to consider that microwave radiometers can be implemented as a real system-on-a-chip device characterized by superior performance and highest level of integration. This is the real innovation expected for enabling microwave radiometry for the next-generation of mass-market wearable devices for medical imaging, and safety and security of emergency operators.

1.14.2. CONSTRUCTION AND FABRICATION

Tyco Electronics is developing a 24 GHz UWB radar sensor in MIC technology for short-range applications. Moreover, this device is targeted at general purpose applications (i.e. military, collision avoidance short-range automotive, etc.) and therefore only marginally related with our specific target. Anyway, as an additional consideration to all the limitations of the MIC approach cited above concerning the microwave radiometer and therefore still valid also in this case, it is worth mentioning that its bandwidth is limited to 500 MHz.

A possible application of microwave radiometers could be designing a dedicated system to assist the fire fighters in their work, for instance by detecting a fire behind a door or a wall. This sensor can be mounted on two textile microstrip board.

The former can contain the radiometric sensor and it is placed in the front side of the fireman jacket (this to detect the fire coming from the front). The latter can contain the low data-rate radio transceiver for sending out the information collected by the sensor, and this can be placed in the back side, for instance close to the neck. The system idea is shown in Fig.1.24. The radiometer consists of a patch antenna array, a low noise 13 GHz radiometer module and a data acquisition and process unit.

It is worthwhile noting that the sensor is mounted on the same microstrip board of the antenna. The ZigBee transceiver (IEEE802. 15. 4) transmits the data to the personal server (or a remote unit as well) of a wireless body area network (WBAN). The wireless platform allows collecting the data acquired by multiple sensors to realize an extended monitoring of the vital and environmental data.

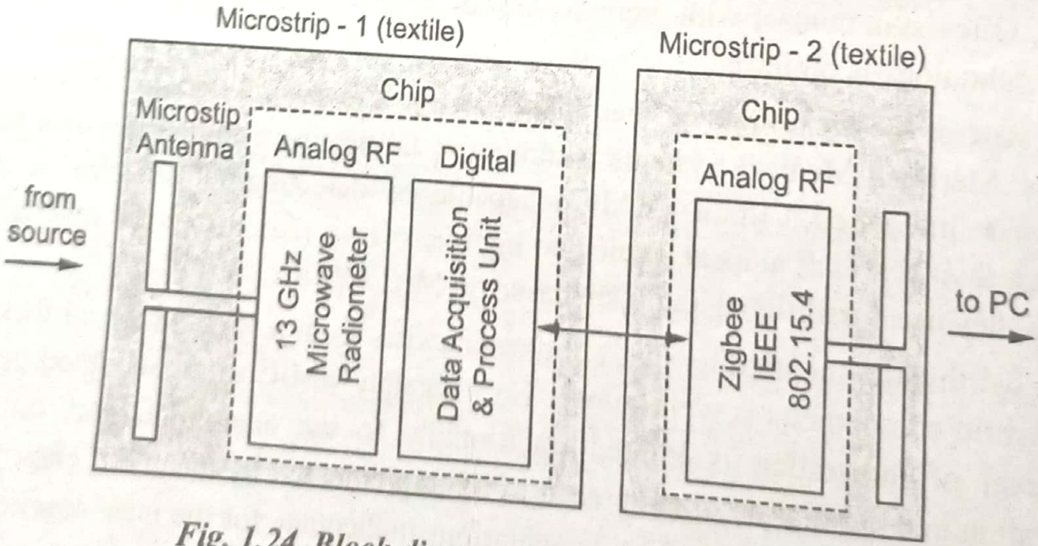


Fig. 1.24. Block diagram of the overall system

Moreover, such a wireless platform allows us to implement re-configurable systems, which can be managed by remote operators taking care of the safeguard of the rescue team. Hereinafter, how a fire in front of the subject with a separation wall between fire and subject can be detected. This inter-wall fire detection is tried in indoor environment to simulate a condition as close as possible to the operative scenario.

In particular, the setup shown in Fig. 1.25 has been used for the proof-of-the concept. To model the scenario sensed by a microwave radiometer, the approach described could be adopted. This approach is based on the filling factor q, a quantity defined as the ratio between the area of the fire AFIRE and the area of the antenna footprint

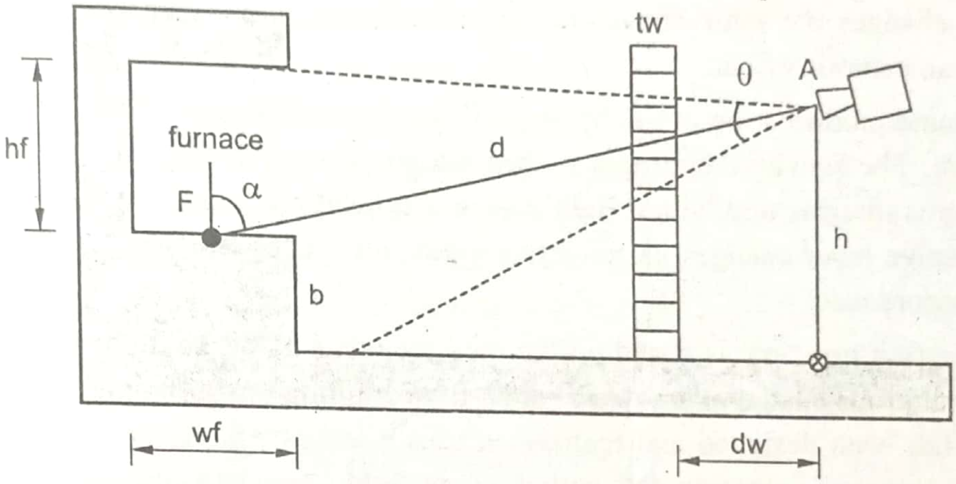


Fig. 1.25. Basic setup used for the inter-wall fire detection experiments

By considering Fig.1.25, the footprint area can be evaluated approximating the main beam of the antenna with a cone of angular aperture *y* (half power beam width) and by cutting this cone with the profile of the illuminated scene, the soil and the furnace in this case. The radiometric contrast r_T is defined as the increase of the antenna temperature due to the fire with respect to the condition without any fire.

Applying the radiative transfer theory, the radiometric contrast can be derived as follows:

$$r_T \; ¼ \; t_W \; ½ \; E_F \, T_F - E_S T_S - \partial E_F - E_S \phi E_W \, T_W]q; \qquad \ldots (1.1)$$

where t_W is the transmissivity of the wall, e_F, e_S and e_W are the emissivities of the fire, soil, and wall, respectively, and T_F, T_S and T_W their physical temperatures. In conclusion, the innovative low-cost, system-on-a-chip microwave radiometer could represent a very promising solution for the realization of a next-generation of wearable sensors. The SoC microwave radiometer will allow an extended detection capability in the cases where traditional devices, such as IR devices, fail.

1.14.3. BIOCHEMICAL MARKERS

Last achievements in research have enabled the possibility of detecting biochemical markers through wearable instrumentation. CSEM researchers have developed non-invasive biosensors for the detection of stress markers (such as lactate in sweat) and wound healing (focussing on pH and infection markers detection). The high level of miniaturization allows the integration in textile garments for the non-invasive monitoring of biological markers.

In the frame of the BIOTEX project, a miniaturized label-free system for application in wound dressing has been developed. Within the PROETEX project, CSEM researchers are currently realizing a wearable biosensor for real-time stress assessment of professional rescuers to improve their safety during the intervention.

In both cases, the sensing principle is based on responsive hydrogels that shrink or swell in presence of the target marker to be detected. The hydrogels are sensitive to pH changes or they can be functionalized to the target molecule by incorporating specific enzymes. In the case of stress monitoring, the hydrogel is functionalized with lactate oxidase, the presence of the lactate changes the ionic concentration in the hydrogel and consequently the hydrogel volume by an osmotic effect.

The volume modification of the hydrogel causes a modification of the refractive index of the structure. The sensitive hydrogel is then integrated on a waveguide grating chip. If the grating chip is interrogated with a light source it reflects the light at a specific wavelength. As the sensitive layer changes its refractive index, the wave- length of the reflected light is shifted in accordance.

The detection principle is based on the measurements of the refractive index through an optical signal propagated along a wave guide. By exploiting this principle, a wearable optical bio-sensor has been designed and realized: it uses a sensitive layer on a waveguide grating chip, the biosensor is interrogated with a white light source (using a white led) and the reflected light is detected by a mini-spectrometer in order to measure the wavelength shift.

Electrochemical sensors can be integrated into flexible (i.e. plastic, textile) substrates to develop wearable systems for the detection of biochemical markers. Some researchers are developing a portable electrochemical system based on Ion Sensitive Electrodes (ISE) integrated into a fabric substrate.

ISE can measure the sodium concentration in sweat and this measurement can be related to the operator dehydration that can lead to severe physio- logical consequences being able to go until the death. A portable electronic board connected to the sensing part has been developed. This board drives the electro- chemical sensor, compensates the effect of temperature, performs analog acquisition and converts measurement data to digital value.

Signal processing is implemented on board to correct raw data (gain, offset) and to convert them to ion concentrations. The system was evaluated in terms of sensitivity, selectivity and reproducibility initially in model solution and then in natural sweat, showing very promising performances.

A more recent technique employed for biochemical marker detection in wearable systems is based on Organic Field Effect Transistors (OFET). Researcher at University of Cagliari developed a flexible OFET able to detect pH changes in chemical solutions thanks to a functionalized floating gate.

The sample solution is brought into contact with a portion of the floating gate, which is properly functionalized to achieve the sensitivity to a particular chemical species. The sensing mechanism is based on the detection of the electrical charge associated with the chemical species placed over the probe area.

The charge immobilized on the floating gate generates an electrical field and thus induces a phenomenon of charge separation inside the electrode, affecting the channel formation in the transistor. This mechanism can be described in terms of a shift of the effective threshold voltage of the OFET. By properly functionalizing the floating gate surface, sensitivity to different species and the detection of different reactions can be achieved, with the same sensor.

1.14.4. GAS SENSORS

Researchers from Dublin City University (DCU) are involved in the integration of sensing platforms into wearables for the detection of environmentally harmful gases surrounding emergency personnel. Special attention is being paid to carbon monoxide (CO) and carbon dioxide (CO_2). These gases are associated with fires and mining operations, and it is of the highest importance to warn and protect operators from potential harm caused by over-exposure to high concentrations of these gases.

The goal is rapid detection of the status of an environment (low, medium or high hazard) and real-time communication of this information to the garment wearer.

Critical in this identification of potential toxification is a reliable method of measuring CO/CO_2 exposure. Commercially available sensors have been carefully selected and are being integrated into the outer garments of firefighters. The sensors provide sufficient sensitivity to reliably alert users to the presence of these harmful gases.

Another important aim is to achieve wireless transmission of sensor signals to a wearable wireless base station that gathers, processes and further transmits the data. When selecting the appropriate commercially available sensors for the gas sensing application, special attention was paid to sensor size, robustness, sensitivity and power requirement. Electrochemical sensors satisfy most of these requirements, especially in terms of size and power requirements.

CO is detected using an amperometric sensor in which the current between the electrodes is proportional to the concentration of the gas. On the other hand, the CO_2 sensor is potentiometric. In this case, the reference and working electrodes are placed in an electrolyte that provides a reference CO_2 concentration. The measured potential is based on the difference in concentration between the reference electrode and the outside air.

Both types of sensors are very sensitive and give an accurate reading (in parts per million). This means that both low concentrations of these gases (which can be hazardous over long periods of exposure) and high concentrations (which pose an immediate danger) can be accurately detected. The signal obtained from these sensors is transmitted wirelessly to the wearable base station using Zigbee.

The CO_2 sensor is placed in a specially designed pocket located on the firefighter's boot. The pocket is designed not to obstruct the firefighter's activities. The prototype currently used for testing is shown and note the side pocket containing the CO_2 sensor along with the wireless sensing module and a battery. The pocket has a waterproof membrane that protects the sensor from humidity, but allows gas to pass through. The CO sensor will be integrated in the firefighter's outer garment (i.e. jacket).

All sensed information will be fed to a wearable local base station that shares the data with a remote centralized base station. The ultimate goal is to achieve local communication between firefighters and civil workers in the operations area, as well as longer range communications between these personnel and the support team outside the operations area.

1.14.4.1. Cardiopulmonary Activity Systems

One of the most challenging points in the healthcare system is to use a single device to simultaneously gather cardiac and pulmonary information, which usually are both obtained from different systems and whose interdependences are left to the clinic experience only. An innovative cardiopulmonary wearable system that matches this dual request is based on Ultra Wide Band (UWB) technology.

The main advantage of this monitoring radar system is the absence of direct contact with the subject skin, dramatically reducing the typical disturbance due to motion artifact. Before introducing the system concept of the system let us give a brief overview on the current state of the art.

The most widespread system used to monitor the cardiac activity is the electrocardiograph (ECG), which provides information about the heart electrical activity. Another complementary technology for monitoring the cardiorespiratory activity is pulse oximetry, which measures the saturation level of the oxygen in the blood.

Other systems for the monitoring of the cardiac activity are based on ultrasounds (echocardiograph or echo Doppler). Ultrasound-based systems are generally cumbersome and they can be used only by specialized operators. Anyway, all the presented measurement techniques require the direct contact with the body to carry out the measurement.

Unlike the traditional techniques (electrocardiograph, echocardiograph and pulsed oximetry), radar systems allow the monitoring of the heart activity in a non-invasive and contactless way for the patient. Microwave Doppler radars have been used to detect the respiration rate since 1975. These first devices were bulky and expensive, but the recent microelectronic advances led to develop CMOS fully integrated radars for non-contact cardiopulmonary monitoring.

Doppler radars typically transmit a continuous wave signal and receive the echo reflected by the target. The frequency of the reflected signal varies from that of the transmitted one by an amount proportional to the relative velocity of the target with respect to the radar. Another class of radar employed for the monitoring of vital parameters is based on pulse transmission.

Pulse radars operate by sending short electromagnetic pulses and by receiving the echoes back-scattered by the target. The time delay between the transmission of the pulse and the reception of the echo is proportional to the distance of the radar from the target.

It is worthwhile mentioning that radar sensors monitor the mechanical movement of the heart wall instead of the electrical activity of the heart (such as the electrocardiograph), therefore when mechanical anomalies occur earlier than the electrical ones, this device can be used to prevent in advance possible cardiac failures.

1.14.4.2. UWB Radar Sensor

Moreover, the UWB pulses are not influenced by blankets or clothes. From a circuit design point of view, UWB transceivers present a lower complexity with respect to traditional radiofrequency systems, leading to low power consumption for a long life of the battery. In fact, UWB systems do not require a stable frequency reference, which typically requires a large area on silicon die and high-power consumption.

Moreover, the extremely low level of transmitted power density (lower than 41.3 dBm/MHz) of the UWB radar should reduce the risk of molecular ionization (see Fig.1.28). The main block of the novel wearable wireless interface for human health care described herein is the UWB radar sensor (see Fig.1.26).

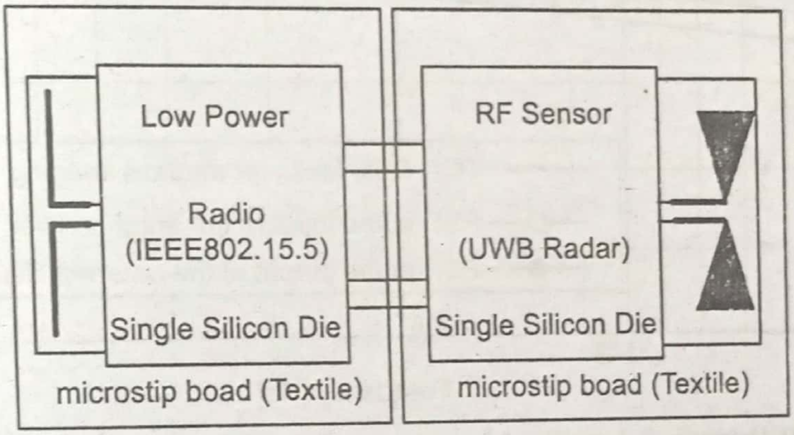


Fig. 1.26. Wearable Wireless UWB radar sensor interface for human health care

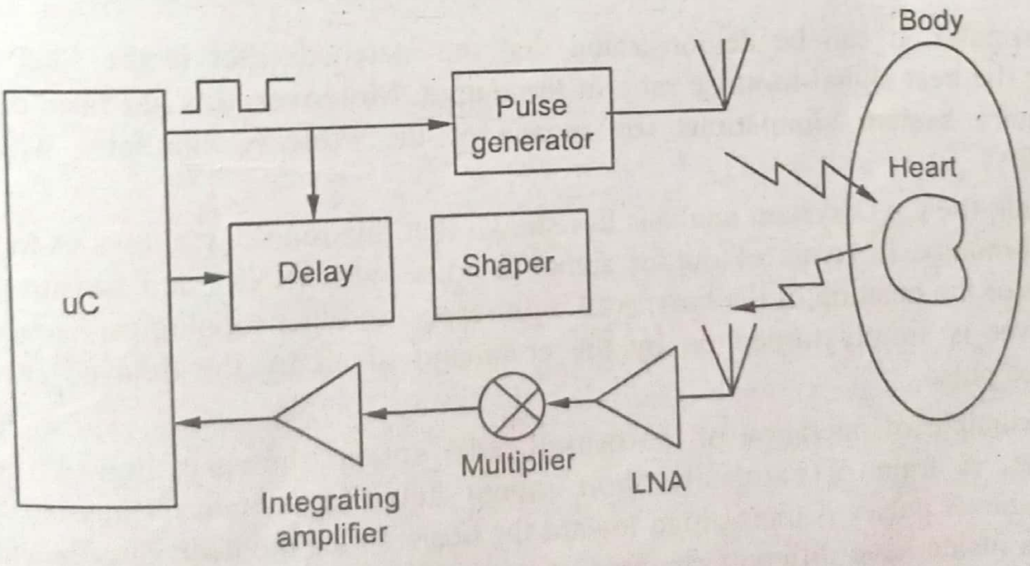


Fig. 1.27. Block diagramof the UWB radar sensor

The block diagram of the proposed radar sensor for the detection of the heart and breath rates is shown in Fig.1.27. The radar exploits a correlation- based receiver topology followed by an integrator, which averages the received pulses to have an output signal containing the information on the heart and breath tones. The operating principle of a cross-correlator radar is explained hereinafter.

An electromagnetic pulse is transmitted toward the target. The echo received from the target is multiplied by a delayed replica of the transmitted pulse; the output signal of the multiplier is then integrated. It is worthwhile noting that the output signal will reach its maximum in the case of perfect time alignment between the two signals at the input of the multiplier itself. In other terms, the cross- correlator has a frequency response equal to that of a matched filter.

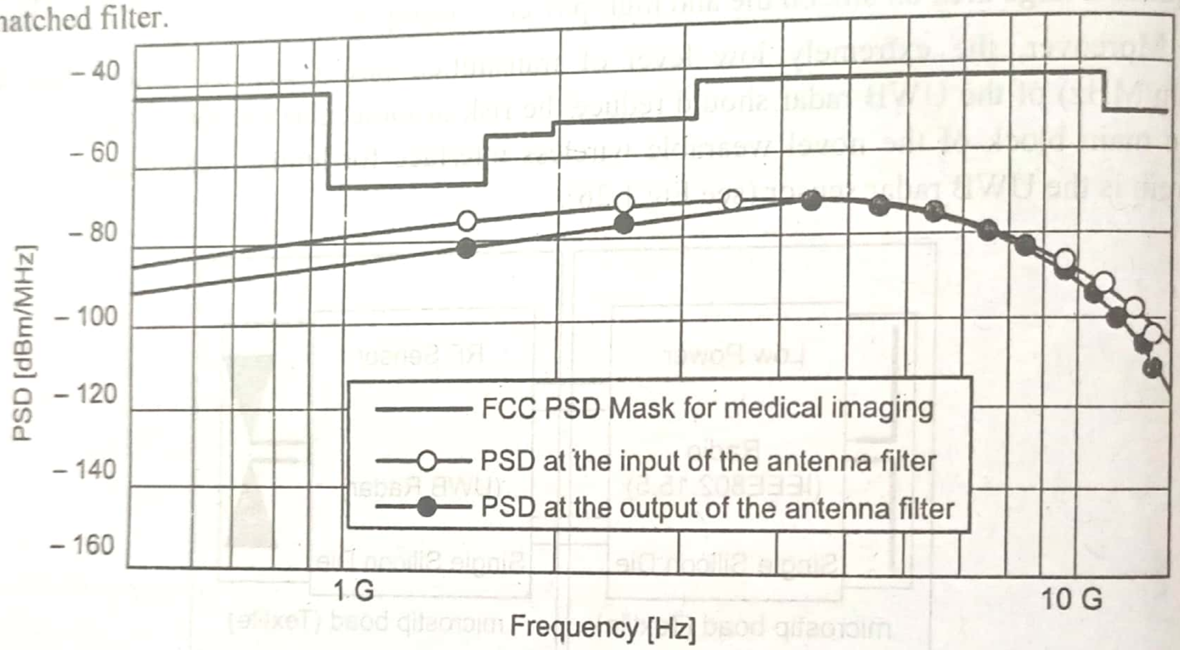


Fig. 1.28. FCC PSD mask for medical imaging and Power spectral density (PSD) of a pulse sequence with PRF equal to 1 MHz vs. frequency

In particular, it can be demonstrated that the matched filter is the filter that allows obtaining the best signal-to-noise ratio at the output. Moreover, this has been confirmed by prelimi nary system simulations (by means of the Ptolemy simulator within Agilent ADS2005A).

In detail, the CAD system analysis has shown that this topology allows us to achieve the best performance in terms of output signal-to-noise ratio (SNR) and sensitivity to small variations of the position of the heart wall with respect to other topologies, like that in which the receiver is simply turned on by the command given by the delayed replica of the transmitted pulse.

The principle of operation of the overall radar system shown in Fig.1.27 is explained hereinafter. A train of extremely short (about 200 picoseconds) Gaussian monocycle electromagnetic pulses is transmitted toward the heart. Since the heart muscle and the blood that flows inside have different characteristic impedance, a partial reflection of the energy associated with the radiated pulse occurs at the surface of separation of these two different media.

TWO MARK QUESTIONS WITH ANSWERS

What is the need of Wearable system?

- A wearable device is often used for tracking a wearer's vital signs or health and fitness related data, location, etc.
- Medical wearables with artificial intelligence and big data are providing an added value to healthcare with a focus on diagnosis, treatment, patient monitoring and prevention.
- To diagnose, monitor and prevent future illnesses, healthcare professionals now routinely use wearable devices such as fitness tracker or phones. By monitoring physiological data and behavior these devices boost self-awareness and encourage behavior change.

Write the drawbacks of Conventional system for monitoring.

The conventional approaches for personal healthcare rely primarily on traditional methods, including bulky instruments and complicated procedures, which, in some cases, are time-consuming and inconvenient.

What are the applications of Wearable Systems?

Wearable technology has many uses, including health and fitness tracking, chronic disease management, interactive gaming, performance monitoring and navigation tracking.

Brief note on components of wearable devices.

1. Control

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

2. Input/Output

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

3. Conductive Textiles

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

(*i*) Thread for making circuits

(*ii*) Fabric for capacitive touch sensors

(*iii*) Hook-and-loop for switches

4. Sensors

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

5. Power

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

6. Actuators

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

5. ***Mention the types of sensors used in wearable system.***

- Accelerometer
- Gyroscopes
- Magnetometers
- Global positioning system (GPS)
- Heart rate sensors
- Pedometers
- Pressure sensors

6. ***Define Inertia movement sensor.***

The inertial sensor, also known as the inertial navigation system (INS), uses an accelerometer and gyro to determine spacecraft attitude in relation to the inertial system. The accelerometer is used to test the motion acceleration of the carrier, which is then used to calculate the real-time location of the carrier.

7. ***Define 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.

8. ***Write short notes on Pulse oximetry sensor.***

Pulse oximetry is a test used to measure the oxygen level (oxygen saturation) of the blood. It is an easy, painless measure of how well oxygen is being sent to parts of your body furthest from your heart, such as the arms and legs.

9. ***Explain the role of sensors in military applications.***

Sensors are a critical part of the technologies as these provide solutions to the whole defence ecosystem, including complex controls, measurements, monitoring and execution. Military and defence systems include drones, spacecrafts, missiles, military vehicles, ships, marine systems, satellites and rockets.

10. ***Explain respiration measurement using wearable devices.***

The respiration sensor is a sensitive girth sensor worn using an easy fitting high durability woven elastic band fixed with a length adjustable webbing belt.

Various method of measuring respiratory rate

1. Respiratory rate measurement using Piezoelectric Sensor (PZO).
2. Respiratory rate measurement from Laser Doppler Vibrometer (LDVi).
3. Respiration rate measurement System using Pyroelectric Sensor.
4. Impedance Pneumography method.
5. Capnometry.

11. ***What is Radiant thermal senors?***

- The radiant temperature sensor provides non-contact and remote measurement of radiant temperature from windows or walls.
- Ideal for the measurement of thermal environments in spaces where radiation has a major influence on perceived temperature.
- Can be installed in a variety of ceilings including facility plates or sound-absorbing ceilings.
- Thermopiles are used as sensing elements.

12. ***Describe the concepts of wearable system.***

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

13. ***Write advantages of Wearable devices.***

- Convenience
- Accessibility
- Customization

14. ***What are the applications of Wearable Systems in health monitoring?***

Wearable sensors are emerging as a new technology to detect physiological and biochemical markers for remote health monitoring. By measuring vital signs such as respiratory rate, body temperature, and blood oxygen level, wearable sensors offer tremendous potential for the noninvasive and early diagnosis of numerous diseases such as Covid-19.

15. ***What are the types of Biomechanical sensors used in wearable system?***

The use of wearable sensors in measuring force and motions of human structures can potentially bring benefits to health care, sport, and well-being. Examples of wearable sensors for biomechanical measurements include accelerometers, gyroscopes, magnetometers, ultrasound, optical, nanomaterial-based, EMG, and force sensors.

16. ***What are the types of Phyiological sign sensors used in wearable system?***

Physiological Sensors: Pulse, HR, ECG, EEG, BP, EMG, Pulsoxymetrie, PPG, ACC, Glucose, Gyroscope, motion tracker or Body temperature.

REVIEW QUESTIONS

1. (*i*) Explain the drawbacks of Conventional measurement and monitoring systems.
   (*ii*) Mention the advantages of latest wearable devices for measurement and monitoring systems.
2. With neat sketches explain the applications of Wearable systems.
3. With neat diagrams explain the types of Wearable systems.
4. What are the applications of Wearable Systems in industries?
5. Explain in detail about the wearable systems advantages and disadvantages and its applications.
6. Explain in detail about the wearable systems need, types and components with neat diagrams.
7. Explain in detail about Impedance Plethysmography and its types with neat diagrams
8. Explain in detail about Radian at thermal sensors with neat diagrams. (UN, CO1)
9. Explain in detail about Inertia movement sensors with neat diagrams.
10. Explain in detail about Respiration activity sensors with neat diagrams.
11. Explain in detail about Wearable ground reaction force sensors with neat diagrams.
12. Explain in detail about different types of Biomechanical Sensors used for wearable systems.
    (*i*) Intertia movement sensor
    (*ii*) Respiration activity sensor
13. Explain in detail about the following
    (*i*) Wearable ground reaction force sensor
    (*ii*) Pulse oximetry sensor

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