MLE31

WEARABLE DEVICES

OBJECTIVES OF THE COURSE

- Objectives
  - To understand the basic principles of Wearable Physiological Monitoring Systems
  - Study various types of wearable systems
  - Learn to design sensors/electrodes for recording various vital parameters
  - Learn to design a wearable computer & Wireless Body Area Networks

UNIT I

Introduction: What is Wearable Systems, Need for Wearable Systems, Drawbacks of Conventional Systems for Wearable Monitoring, Applications of Wearable Systems, Recent developments – Global and Indian Scenario, Types of Wearable Systems, Components of wearable Systems, Physiological Parameters commonly monitored in wearable applications.

Smart Sensors & Vital Parameters: Vital parameters monitored and their significances, Bio-potential signal recordings (ECG, EEG, EMG), Dry Electrodes design and fabrication methods, Smart Sensors – textile electrodes, polymer electrodes, non-contact electrodes, MEMS and Nano Electrode Arrays, Cuff-less Blood Pressure Measurement, PPG, Galvanic Skin Response (GSR), Body Temperature Measurements, Activity Monitoring for Energy Expenditure, Respiratory parameters. Sensors for Wearable Systems, Biomechanical Sensors, Physiological Sign Sensors.

UNIT II

Future Direction & E-Textiles: Fibers and Textiles for Bio electrodes, Fibers and Textiles for Sensing, Active Fiber Electronics and Woven Logics, Fibers and Textiles for Energy Harvesting and Storage, Smart Textiles for Actuation, Textile-Based Communication Devices, Smart Fabrics and Interactive Textiles Platforms. The Commercialization of Smart Fabrics: Intelligent Textiles, Analysis of the Markets: Today and Tomorrow, Common Backbone of Applications, Present Situation and Competitors in Terms of R&D and Commercialization, Market Segmentation, Market Volumes

UNIT III

Energy Harvesting for Self-Powered Wearable Devices: Principles of Energy Harvesting by Using Human Body Heat, Calculated Characteristics of Wearable TEGs, Human Body as a heat source for a wearable thermoelectric power supply, TEG's in wearable devices, Hybrid Thermoelectric- Photovoltaic Wearable Energy Harvesters, TEGs in Clothing, Development of New Technologies for Wearable Thermopiles

UNIT IV

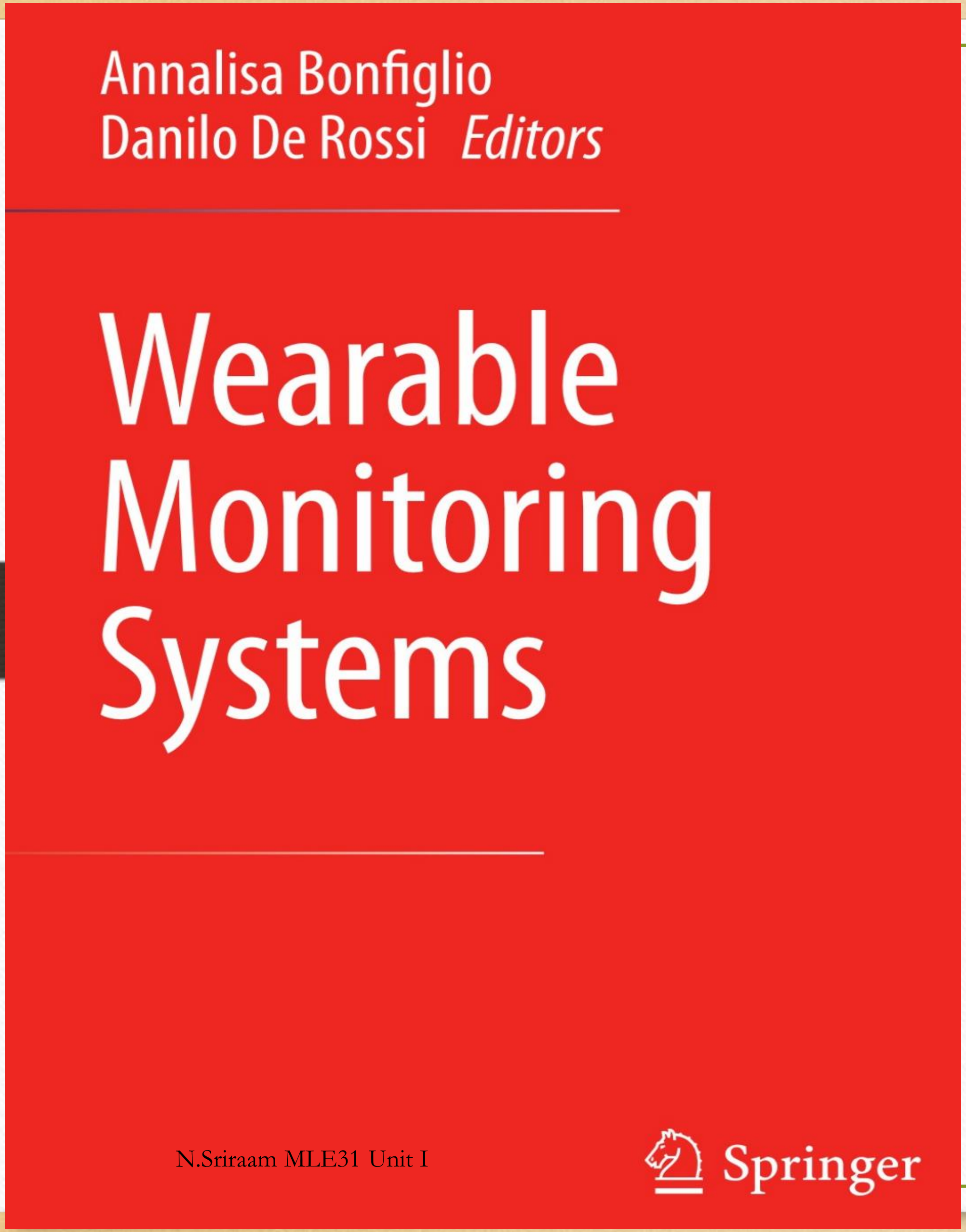
Wireless Communication Technologies for Wearable Systems: System-Level Considerations, Lower-Level Tradeoffs, Recent Applications of Wireless Technology in Wearable Health Monitoring Systems. Design of Wireless Health Platforms, System Architecture Requirements for Wireless Health Platforms, System Design, Micro LEAP: A Wireless Health Platform with Integrated Energy

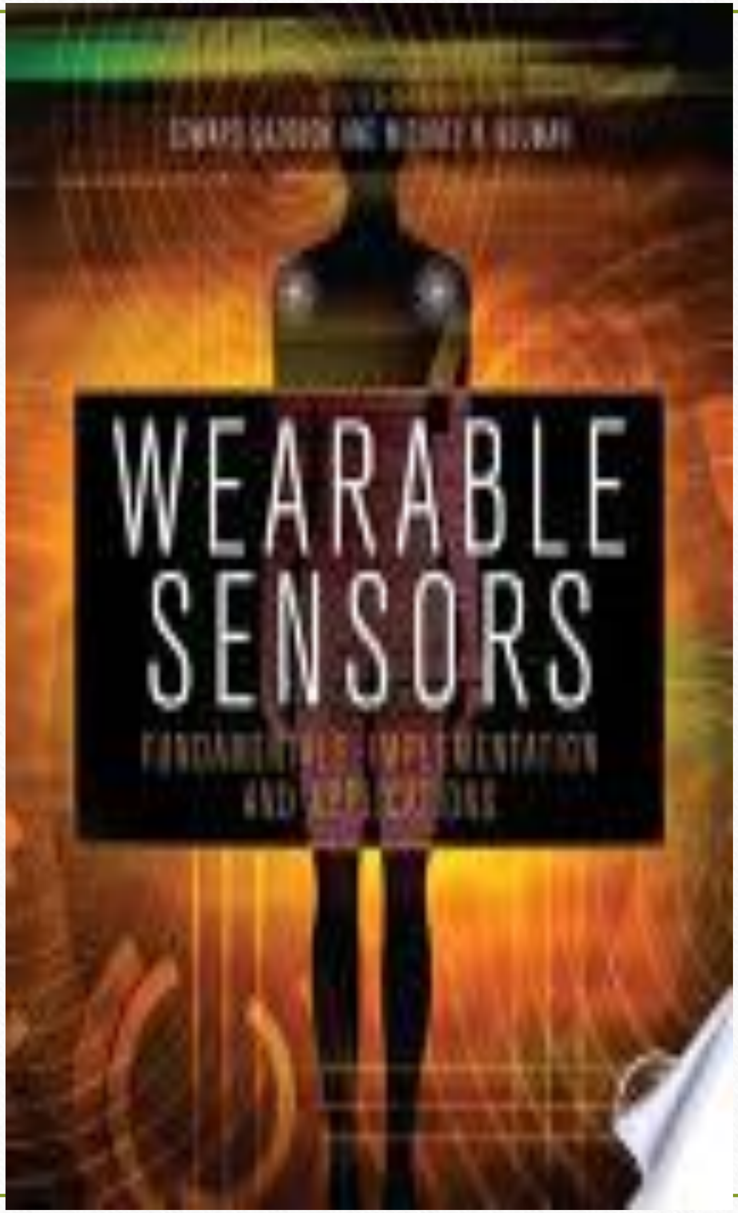
Accounting, Micro LEAP Application: Smart Cane, Micro LEAP Application: Episodic Sampling,Conclusion and Next Generation Platforms.

UNIT V

Wearable Electronic Systems: Applications to Medical Diagnostics/Monitoring, Historical Perspective, Present and Possible Clinical Applications, Sensing Constraints and Possibilities, Discussion and Conclusion. Scenarios for the Interaction Between Personal Health Systems and Chronic Patients, The New Paradigm of Personalized Health: p-Health, The AMI Vision, Challenges

of User Interaction Within the Patient-Centered Care Paradigm, Scenarios for the Application of AMI to p-Health.Wearable Systems for Disaster management, Home Health care, Astronauts, Soldiers in battle field, athletes, SIDS, Sleep Apnea Monitoring.


Annalisa Bonfiglio
Danilo De Rossi Editors
Wearable Monitoring Systems
Springer


WEARABLE SENSORS

What is Wearable Systems

- Devices that are worn on the body. They have been applied to areas such as behavioral modeling, health monitoring **systems**, information technologies, and media development. Learn more in: Wearable Kinesthetic System for Joint Knee Flexion-Extension Monitoring In Gait Analysis
- Defined as mobile electronic devices that can be always accessible and controlled by a user and can be unobtrusively embedded in the user's outfit as part of the clothing or an accessory. Learn more in: Adoption of Wearable Systems in Modern Patient Telemonitoring Systems

Wearable Systems

ubiquitous, ad hoc system integrated in the users outfit

- ***‚invisible'***, intelligent, always active, personal assistant

A perfect example of a wearable device

- **permanently useful**
- **augments user's perception**
- **context sensitive**
  - adjusts amplification to the situation
- **virtually unnoticeable**

What is Wearable Technology?

- Wearable technologies, known mostly just as “wearables,” are electronic devices that are physically worn by individuals in order to track, analyze and transmit personal data. These “smart” IoT devices can track biometric data from heart rate to sleep patterns, and are also becoming popular consumer technologies in the gaming and fashion industries.

Wearable Technology

- High computing power
  - complex signal and image processing,
  - high end graphics
  - Artificial intelligence
- Complex sensors
- Mobile networking
- Exotic I/O devices

- Ultra-compact and light weight
- Soft and flexible
- Robust
- Distributed
- Long battery life

1. WORLD OF WEARABLES (WOW)

In today's digital world the term "wearable" has a new meaning! It no longer conjures up images of clothing such as an elegant evening dress or a heated Sherpa jacket worn by a mountaineer at a base camp on Mount Everest. Rather, today it brings up images of accessories such as a smart watch on a business executive's wrist, a head-mounted display worn by an immersive gamer, a tiny sensor on a cyclist's helmet, or a smart garment a runner uses to track and monitor his steps. In recent years, the dimensions of fashion and protection typically associated with the traditional wearability of clothing have expanded to include "functionality" on the go. This functionality can essentially be characterized as mobile information processing – whether it is the executive checking e-mail, the gamer shooting at a target that is also being simultaneously chased by a fellow gamer on the other side of the world, the cyclist's trainer ensuring that the rider is maintaining proper posture on the curve, or the runner tracking his workout for the day. Just as clothing can

1.1 The Role of Wearables

Fundamentally, wearables can perform the following basic functions or unit operations in each of the scenarios shown in Figure 1:

- Sense
- Process (Analyze)
- Store
- Transmit
- Apply (Utilize)

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

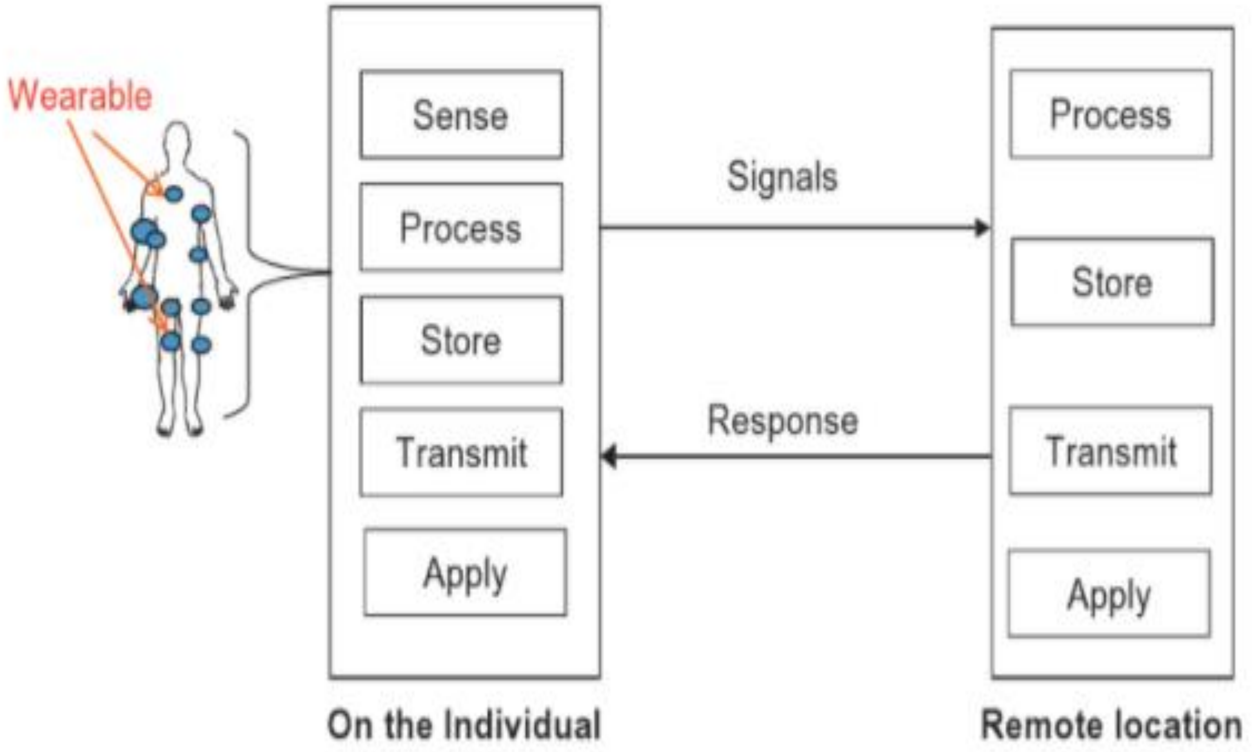


FIGURE 2 Unit operations in obtaining situational awareness: role of wearables.

WEARABLE SENSORS

1.2 Data-Information-Knowledge-Value Paradigm

Figure 3 shows the data-value transformation paradigm [6]. Let's consider a patient visiting a physician. In triage, the nurse documents the vital signs gathered using instruments (e.g., thermometer, blood pressure monitor, electrocardiogram, or EKG machine) that convert the raw signals (the *data*) from the body into meaningful *information* (temperature, heart rate, diastolic/systolic pressure) and thus add value as shown in the figure. When the physician processes this information, he or she gains insight into the potential condition of the patient. The physician adds value by drawing upon the *knowledge* – expertise and experience accumulated over time – to come up with a diagnosis and a plan of action or treatment. This course of treatment – in the form of medication and other interventions – is the *value* derived by (or delivered to) the patient resulting in the curing of the illness. Thus, the raw data gathered by the instruments is valuable only when it is properly transformed and harnessed to benefit the individual. For this transformation to occur seamlessly there is a need for an information/knowledge processing ecosystem.

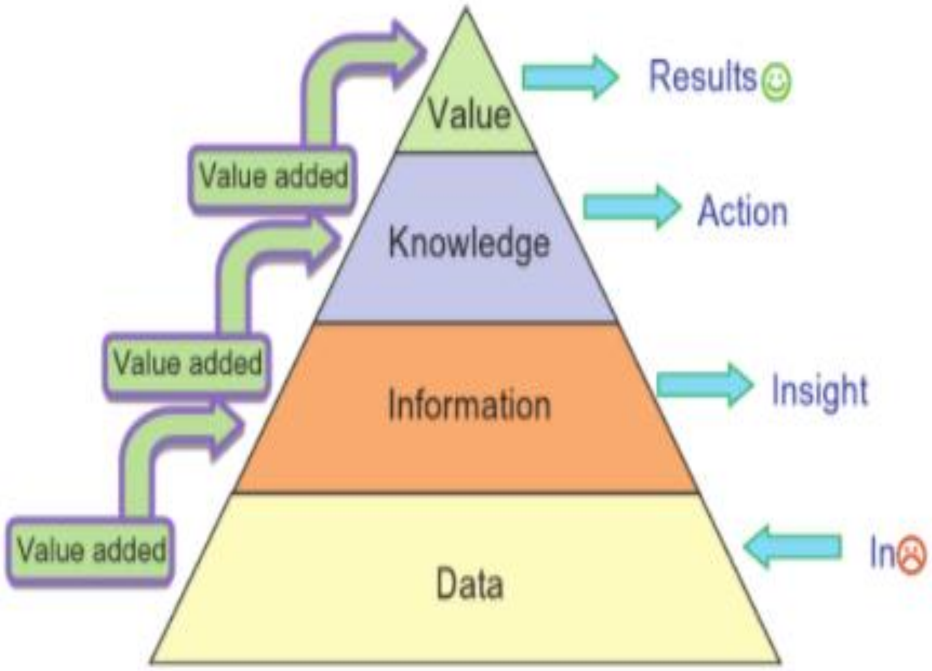


FIGURE 3 Data-information-knowledge-value transformation paradigm.

WEARABLE SENSORS

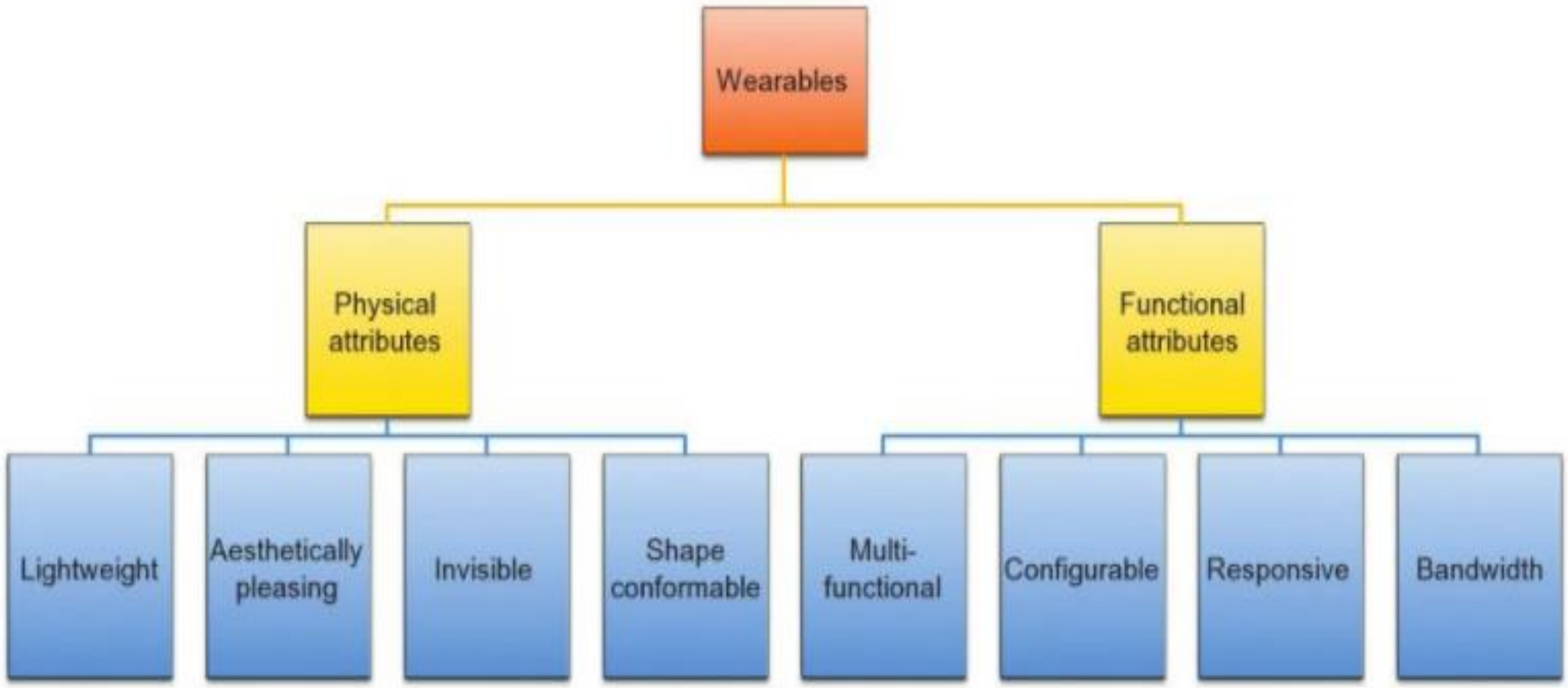


FIGURE 4 Key attributes of wearables.

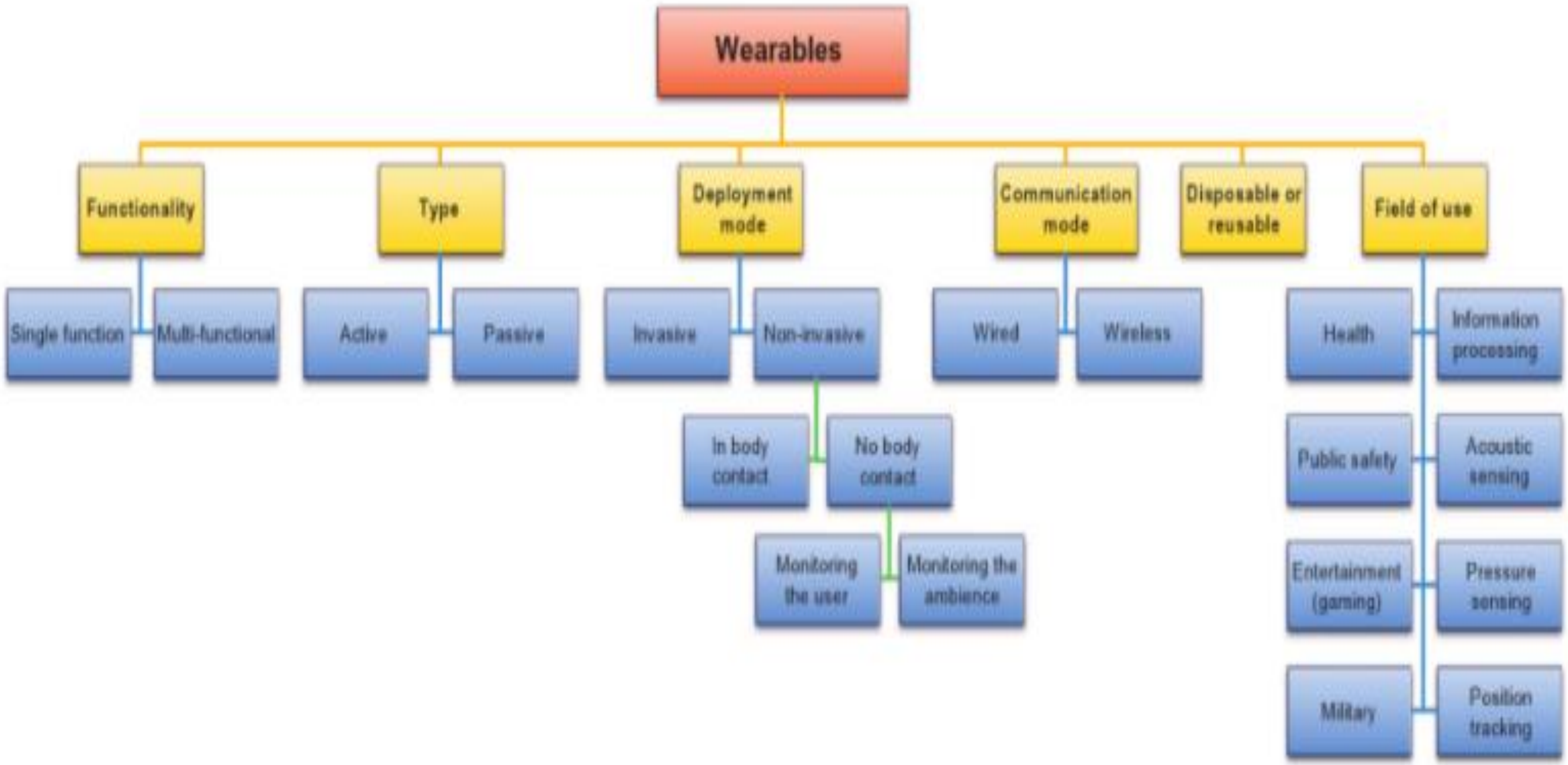


FIGURE 5 The taxonomy for wearables.

Wearable Computers

- A wearable computer is **any small technological device capable of storing and processing data that can be worn on the body**. ... Some popular examples of wearable devices include the Apple Watch, Google Glass and Fitbit

What is a Wearable Computer?

- A small portable computer that is designed to be worn on the body during use.
- Wearable computers differ from PDAs, which are designed for hand-held use.
- Wearable computers are usually either integrated into the user's clothing or can be attached to the body through some other means, like a wristband.
- They may also be integrated into everyday objects that are constantly worn on the body, like a wrist watch or a hands-free cell phone.

What is a Wearable Computer?

- A computer that is subsumed into the personal space of the user
- Controlled by the user, and has both operational and interactional constancy, i.e. is always on and always accessible.
- It is a device that is always with the user, and into which the user can always enter commands and execute a set of such entered commands, and in which the user can do so while walking around or doing other activities.
- The most salient aspect of wearable computers, in general
  - **Re-configurability**
  - **Functionality**
  - **Generality e.g. that their function can be made to vary widely, depending on the instructions provided for program execution.**
- Unlike these other wearable devices that are not programmable (reconfigurable), the wearable computer is as reconfigurable as the familiar desktop or mainframe computer.

What is a Wearable Computer?

- Wrist watch running Linux and XFree86.
- Clock and video conferencing application.
- What a wearable computer is depends on your definition…
  - But it must be **wearable**!

Why use Wearables?

- They are **wearable**!
  - Always with you, not as easily forgotten.
- Instant access, information anywhere.
  - Laptop requires time to prepare for use.
  - PDA requires use of both your hands.
- Wearables can become a part of you.
  - Transparent use, not just "a thing".


15:55
5321 steps
120
118
33%
7%
10%
25%
122
70
01 66
F
5.2
11:35
00:24:55
John
11:42
GROWTH DYNAMICS
2010
2011
2012
2013
2014
2015
2016
2017
Wearable Technology
Is The New Businesses

Wearable Computing

1. Components distributed in clothes and over the user's body
   - Smart shirt, trousers, socks, gloves etc.
2. Hands free and easy to use User Interfaces
   - Speech and Gesture recognition
3. Augmenting user 's view of the environment
   - Data displayed in head mounted see through display
4. Extending user 's senses
   -e.g. Infrared and sonar images overlaid over the real world
5. Aware of the environment
6. Always ON and acting on behalf of the user (proactive)

AIM of Wearable Computing

- To develop new interfaces that mediate (augment, deliberately diminish, or otherwise modify) non-computer activities

- Without interfering with the user's everyday tasks

- The design of wearable computers is still a topic of research, and a variety of user interfaces are being proposed.

Attributes of Wearable Computing

1. **UNMONOPOLIZING of the user's attention:**

   It does not **cut you off from the outside world like a virtual reality game**. You can attend to other matters while using the apparatus. It is built with the assumption that computing will be a secondary activity, rather than a primary focus of attention.

   In fact, ideally, it will provide enhanced sensory capabilities. It may, however, mediate (**Augment, Alter, or Deliberately Diminish**) the sensory capabilities

2. **UNRESRICTIVE to the user:**

   Ambulatory & Mobile, **"you can do other things while using it"**, e.g. you can type while jogging, etc.

3. **OBSERVABLE by the user:**

   It can get your attention continuously if you want it to. **Almost--always--observable:** within reasonable limitations (e.g. that you might not see the screen while you blink or look away momentarily) the output medium is constantly perceptible by the wearer.

Attributes of Wearable Computing

4. **CONTROLLABLE by the user:**

   Responsive. You can grab control of it at any time you wish. Even in automated processes you can manually override to break open the control loop and become part of the loop at any time you want

5. **ATTENTIVE to the environment:**

   Environmentally aware, multimodal, multisensory. (As a result this ultimately gives the user increased situational awareness).

6. **COMMUNICATIVE to others:**

   Can be used as a communications medium when you want it to. Expressive: allows the wearer to be expressive through the medium, whether as a direct communications medium to others, or as means of assisting the production of expressive media (artistic or otherwise).

Evolution of Wearable Computers

Apple Watch

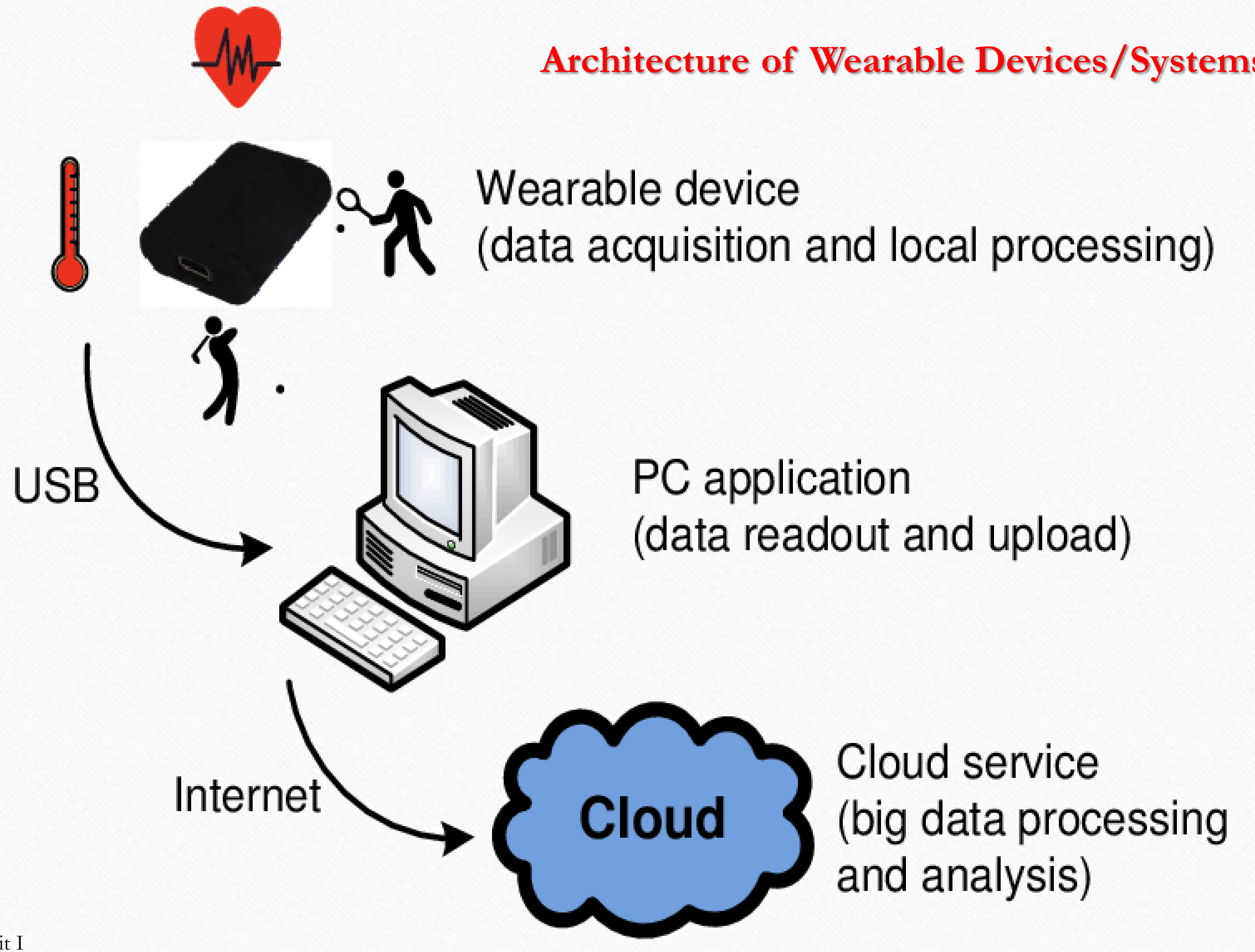
Apple watch – Courtesy of Apple

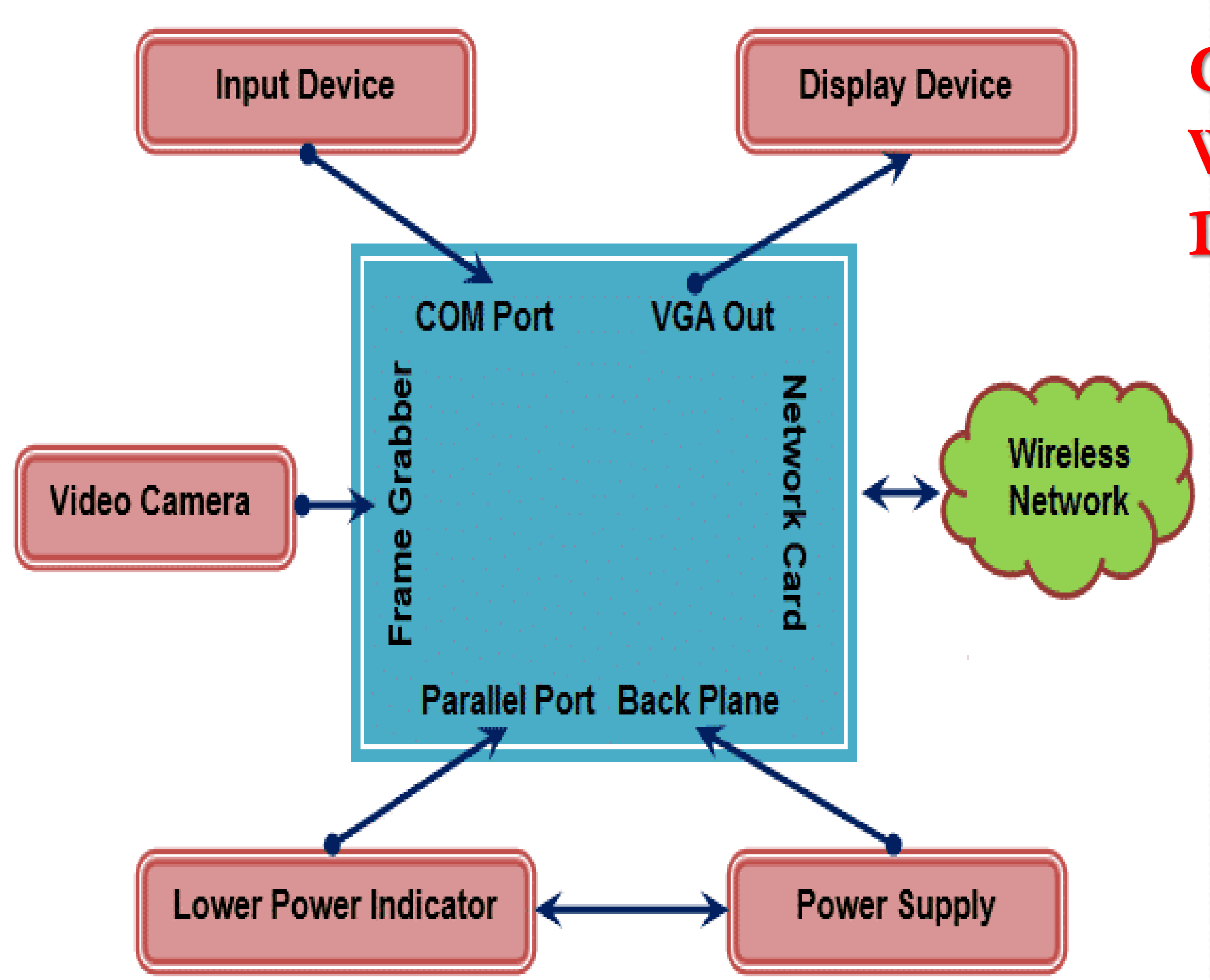
Recent Developments

Need for Wearable Devices

- Maintain Good and Healthy Lifestyle
- Citizens at Risk
  - hypertension, obese, diabetes, stress, etc.
  - Early detection through long-term trend analysis
  - will reduce the damage due to severe events dramatically.
  - Individuals who perform high risk jobs (Soldiers, fire fighters, astronauts, deep sea divers, etc)
- For Post-Event Patients
  - For Rehabilitation Purposes
- For Chronic Patients
  - to better understand and self manage the disease state

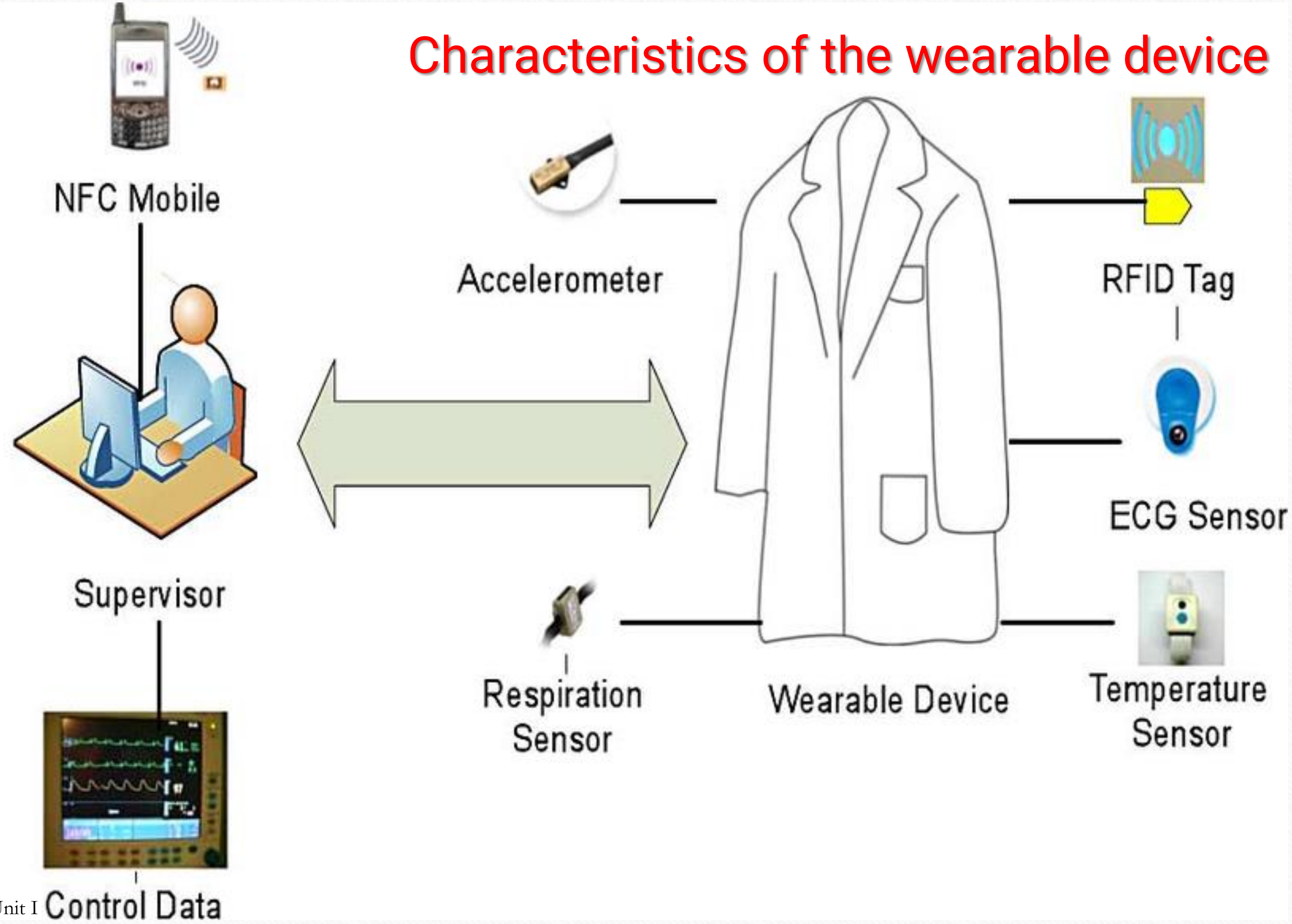
Architecture of Wearable Devices/Systems





General Block diagram of Wearable Computers/ Devices/Systems

Characteristics of the wearable device

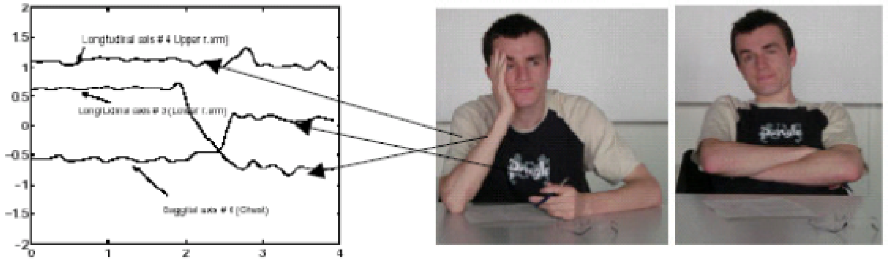


Four Layers of Wearable Devices

1. **permanently embedded micro sensors and transponders for artifact/location specific context**

- **autonomous, miniaturized sensor unit design**
  - ultra low power features extraction implementation
  - energy scavenging as power source
  - ultra wide band communication interface

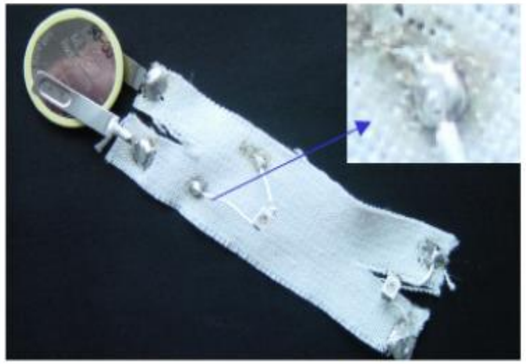
- **recognition experiments with a system prototype**

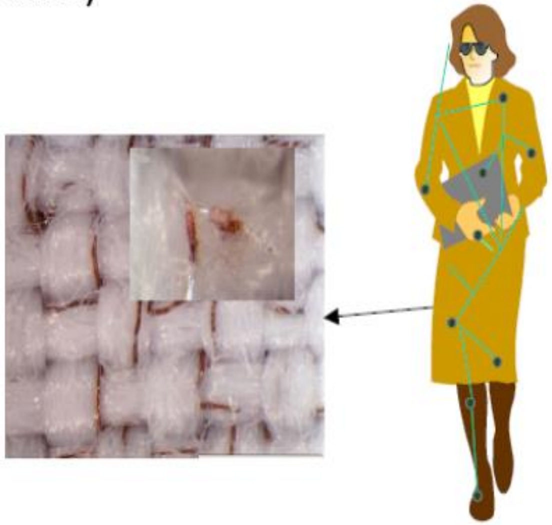


Four Layers of Wearable Devices

2. embedded communication and power generation

- electronics on textiles (Dr. Tünde Kirstein)



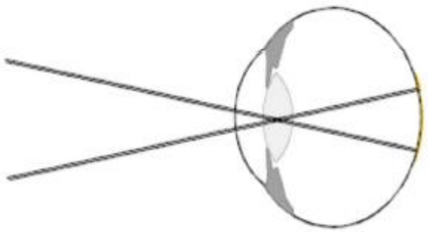


Four Layers of Wearable Devices

3. **consumer appliances and IO devices as accessories**
   - IO, communication and power infrastructure shared

- **intelligent display driver and frame buffer with wireless interface**
  - modeling of computation communication tradeoffs
  - design and implementation of ultra low power system

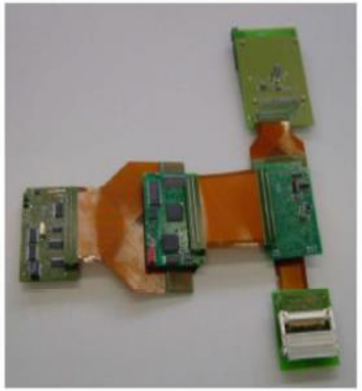
- **focus free virtual retinal display**



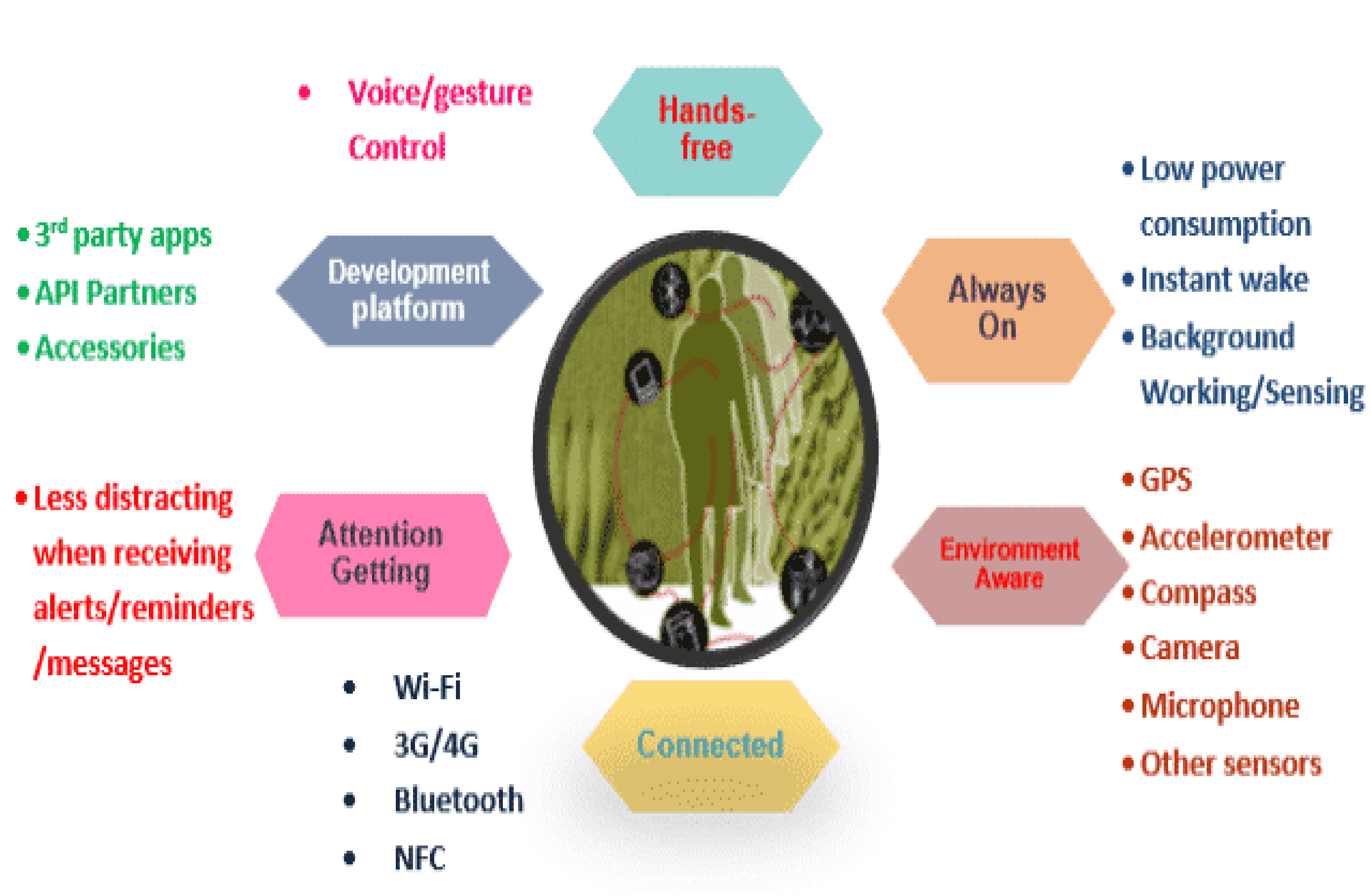
Four Layers of Wearable Devices

4. **central ‚computer like' module as accessory**

- **WearARM prototype**
  - advanced power management
  - body shape driven system partitioning and packaging
  - study of applications



Wearable Devices Attributes

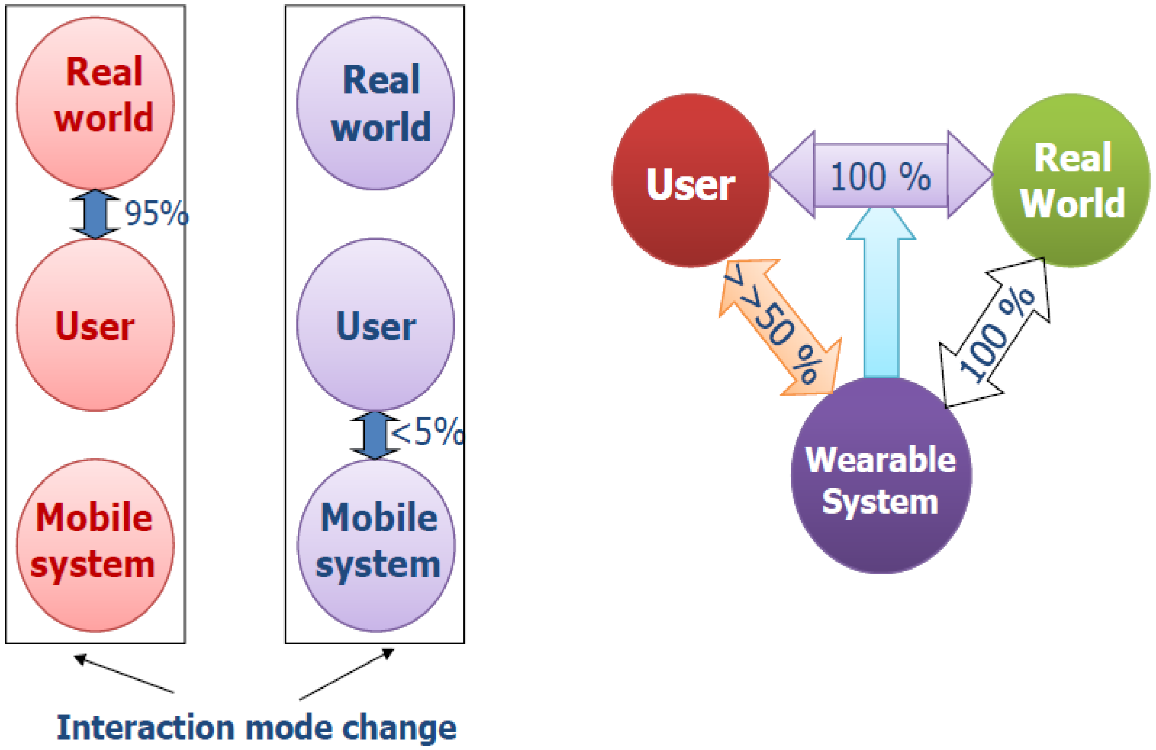


Features of Ideal Wearable Devices

- **Consistency:** The signal flows from human to computer and computer to human uninterruptedly to provide constant user interface.
- **Persistence:** These wearables are designed for everyday and continuous use over a lifetime.
- **Enhancement:** The assumption of the wearable computing is that the user is occupied with some other task along with computing. Thus, the gadget should serve to enhance the intellect or augment the senses.
- **Convenient:** It should be convenient to user.
- **Unrestrictive:** Wearable devices enable a person to do multitasking.
- **Interact seamlessly:** Adapts its input and output modalities to those most appropriate at the time.

Wearable versus mobile computing

Focus on the interaction of user - system - environment



What is Wearable Physiological Monitoring System (WPSM)

- The wearable physiological monitoring system is a washable shirt, which uses an array of sensors connected to a central processing unit with firmware for continuously monitoring physiological signals from a remote location.

- The data collected can be correlated to produce an overall picture of the wearer's health.

Why Do I Need a Wearable System?

Hospital Bedside Monitors

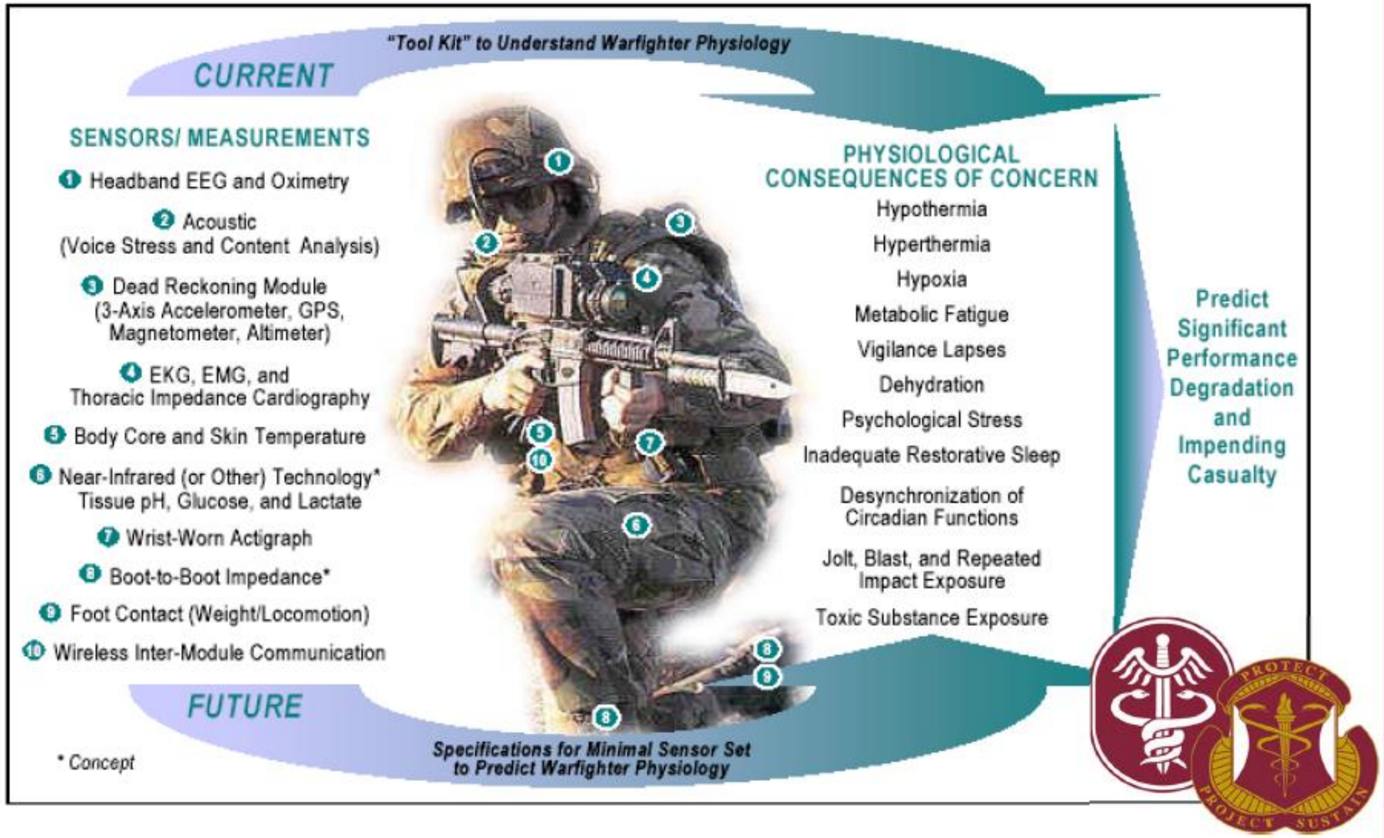
Vs

Wearable Devices

Problems Associated with Conventional Systems?

- The conventional sensors are difficult to wear for longer durations, as they cause discomfort to the wearer;
- Gels used in the electrodes cause irritations when used for longer durations.
- Gels used in the electrodes dry out over time, so the contact resistance between electrode and skin changes over time.
- The number of hampering cables running around the wearer.
- The size and weight of the conventional monitoring system are large for wearable applications.

US ARMY - Warfighter Physiological Status Monitoring



What are the Technologies Involved?

- Textiles and Materials
- Sensors (Wearable)
- Signal Conditioning & Processing Circuits (Analog)
- Signal Processing (Digital)
- Wearable Computers
- Wireless Communication
- Battery
- Remote Monitoring Station
- Application Software

Typical Applications of WPMS

- Monitoring the health status of Soldiers in a battle field
  - Life signs detection
  - Casualty locator
  - View remote physiology
  - Prioritize actions
- Elderly at Home
- Astronauts in Space
- Coal mine workers
- Fire fighters
- Sports personnel

3.2.1 *Wearable Motherboard Architecture*

The wearable motherboard architecture is shown in Figure 8. The signals from the sensors flow through the flexible data *bus* integrated into the structure to the multi-function

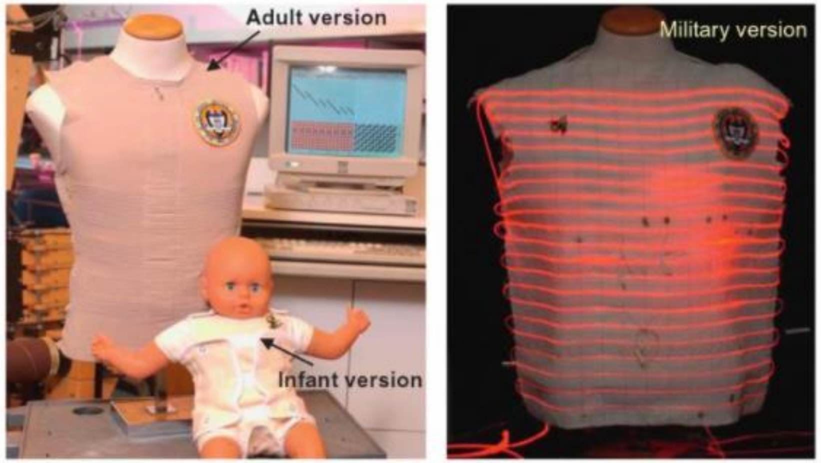


FIGURE 7 The wearable motherboard: adult, baby, and military versions.

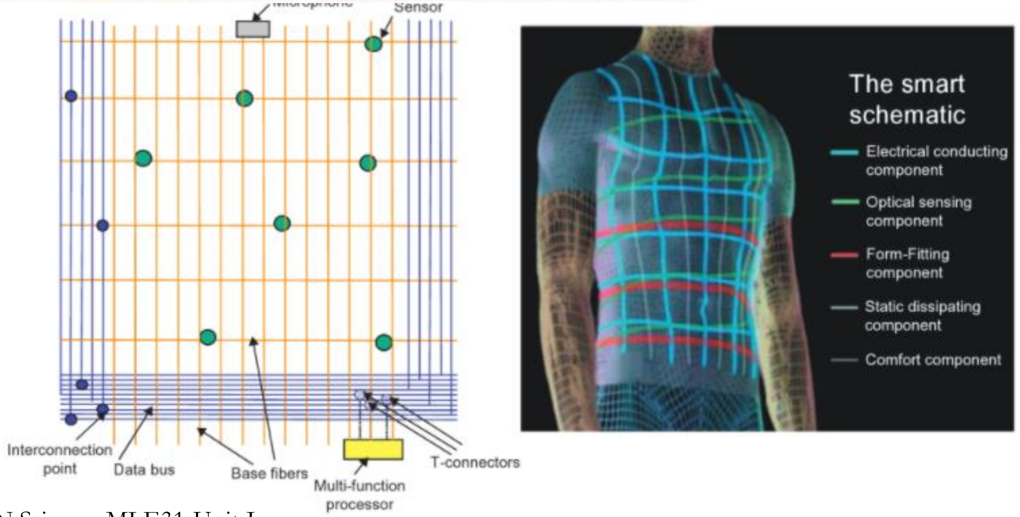


FIGURE 8 Wearable motherboard architecture.

THE WEARABLE MOTHERBOARD A USER-CENTRIC APPROACH TO THE DESIGN OF WEARABLES

Beginning in late 1996, Jayaraman and co-workers took a fundamentally different approach to the field of wearables and developed the concept of a wearable motherboard. Driven by the needs of soldiers - the end user - to be monitored in real- time in the battlefield so that they would receive medical care in the event of being shot, they developed fabric-based wearable technology to monitor the vital signs of soldiers in an unobtrusive manner and also to detect any shrapnel penetration when shot. This concept was called the wearable motherboard as it is conceptually analogous to a computer motherboard. The computer motherboard provides a physical information infrastructure with data paths into which chips (memory, microprocessor, graphics, etc.) can be plugged in to meet performance requirements for specific end uses such as gaming, image processing, highperformance computing,

FIGURE 9 Wearables in the twin continuum of life and activities.

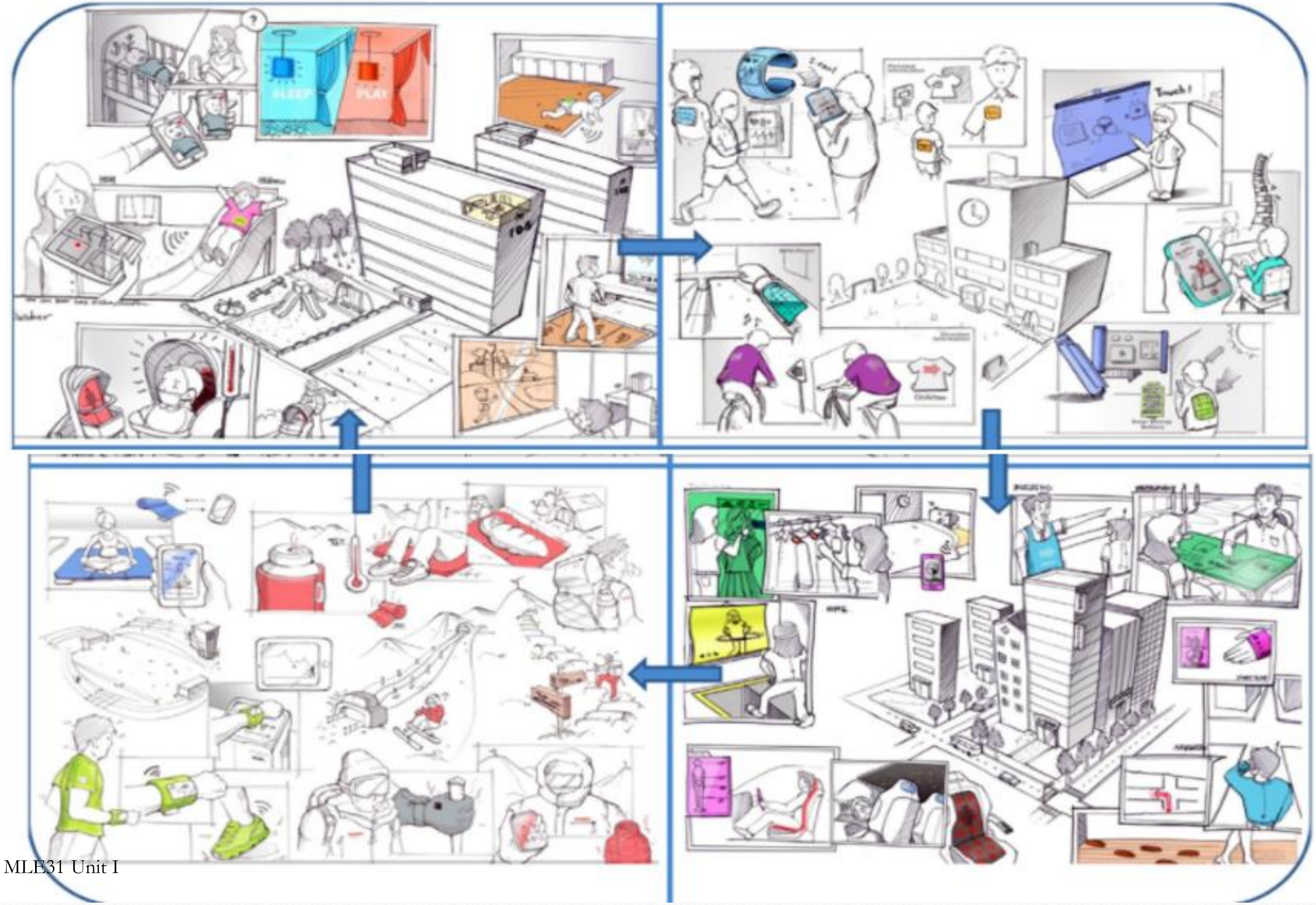


TABLE 1 Applications of Wearables

Sports Application: Coyle et al. have developed a wearable sensing system that integrates a textile-based fluid handling system for sample collection and transport with a number of sensors including sodium, conductivity, and pH sensors [41]. Together with sensors for sweat rate, EKG, respiration, and blood oxygenation, they were able to successfully monitor a number of physiological parameters together with sweat composition in real-time.
Public Safety (Protection) Application: The ProeTEX project, funded by the European Commission, has developed a wearable system for the protection of first responders [42]. It monitors the health of the users (heart rate, breathing rate, body temperature, blood oxygen saturation, position, activity, and posture) and environmental variables (external temperature, presence of toxic gases, and heat flux passing through the garments) and transmits the information to the coordination center to ensure the safety of the personnel.
Entertainment Application: The Philips Lighting project for the Black Eyed Peas group created a wearable system for the singers with organic light-emitting diodes (OLED) and LEDs that light up during the performance and provide a new experience for the audience and the entertainers [43].

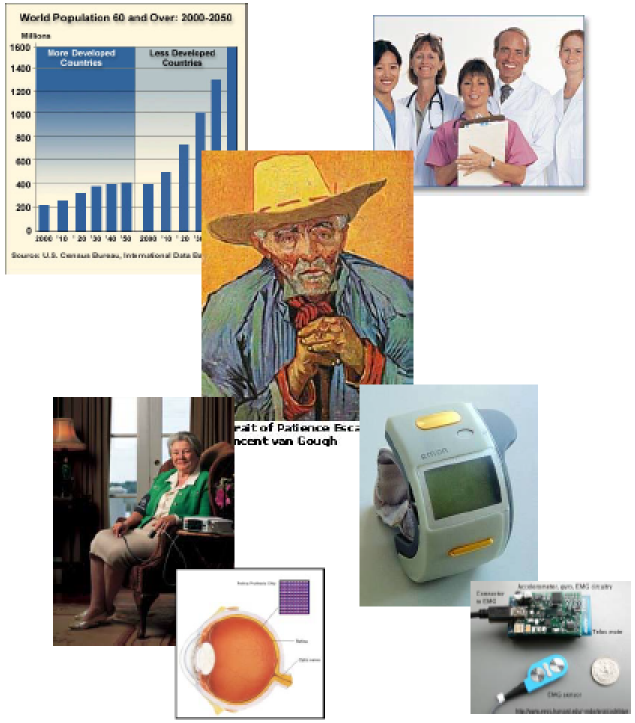
Wearable Physiological Monitoring Systems

Recent Developments

Happy BIRTHDAY!
JULY 1ST
WALKMAN
Sony co-founder Masaru Ibuka told Sony's R&D team to develop a lightweight portable cassette player with headphones to take on trips.
1979
The history-making first model TPS-L2 began the portable audio craze.
1981
Sony's Walkman II came with a belt clip and stylized buttons.
1983
Fitted with a heavy duty case, this splash-resistant unit also had radio.
1986
This WM-55 was the first one to come in pink, it also had radio.
1988
The D-20 Discman marked the arrival of Compact Discs.
2000
Sony's NW-MS9 Network Walkman with Memory Stick is as small as a keychain.
1999
Sony began using flash memory with NW-MS7.
1996
MZ-E50 marked the birth of the slimmest, smallest, and lightest audio player.
1992
Sony introduced the MiniDisc (MD) as its new audio format & this MZ-1 MD-Walkman.
2004
Sony's flagship MP3 Walkman NW-HD1 came with 20 GB of storage & 30 hrs of playback.
2009
Very compact, this NWZ-E Series Walkman MP3 player offered a battery life of up to 28 hours.
2011
The NWZ-W262 wearable Walkman MP3 player is water-resistant and came in many stylish colors.
Hi-Res AUDIO
2014
The NWZ-A17 Walkman Hi-Res Digital Music Player sets a new benchmark in sound and style.
Hi-Res AUDIO
2015
Walkman is redefined with the 128 GB Walkman Hi-Res Digital Music Player NW-ZX2 which can reproduce master quality recordings just as the artists originally intended.
SONY
WALKMAN

Healthcare Need for Point of Care Diagnosis and Treatment

- **Motivation**
  - By 2050 over 20% of population will be above 65. (US Department of Health)
  - Possible Consequences:
    - Acute shortage of medical professionals.
    - Decline in quality of medical care.
    - Increase in medical costs.
  - Automated & continuous monitoring of patients can reveal problems at an early stage leading to better control.
- **Challenges**
  - Integration of diverse technologies (micro – macro computing entities), for health monitoring.
  - Health management systems should be safe, dependable, secure and scalable system.



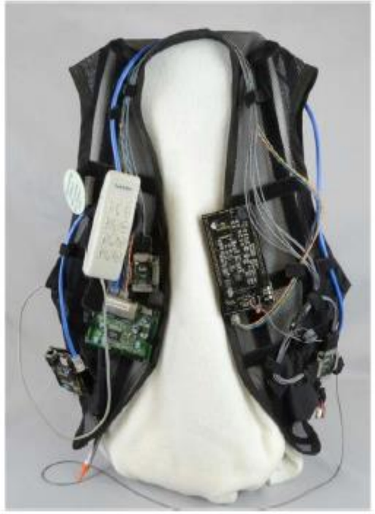
Healthcare Requirements

- **Mobility**
  - "Around the Clock" coverage and monitoring of a patient's medical condition
  - No longer the patients to be confined to hospital /bed
- **Preventative Medicine**
  - Proactive/Preventive Approach
- **Real-time Access**
  - Doctors and nurses to monitor the status of their patient's medical data (Patient is carrying out his normal routine activities)

Wearable Physiological Monitoring System – International Scenario

- Georgia Tech Wearable Motherboard
- Vivometrics - Lifeshirt
- AMON
- Stanford University
- Wealthy
- MyHeart
- Virginia Commonwealth University
- ……..

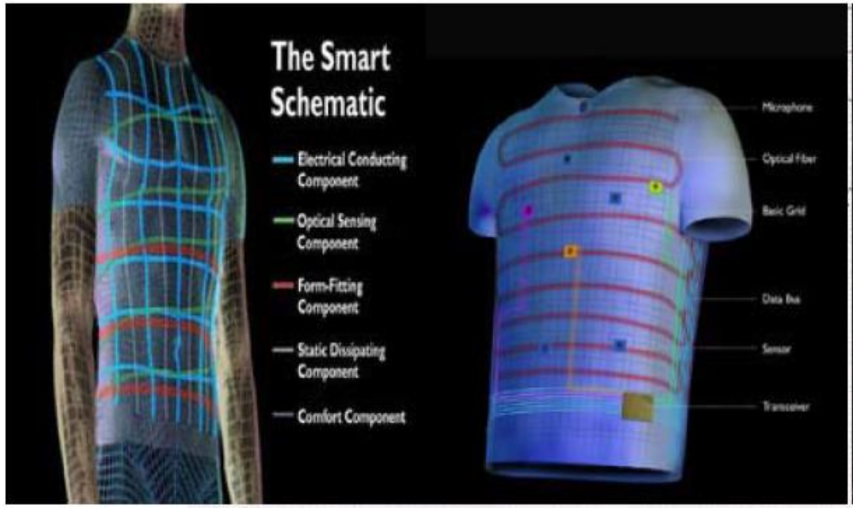
MIThril, the next generation research platform for context aware wearable computing



- The MIThril hardware platform combines in a clothing-integrated design
  - Body-worn computation
  - Sensing
  - Networking
- The MIThril software platform is a combination of user interface elements and machine learning tools built on the Linux operating system.

Georgia Tech. University

"Sensate Liner"

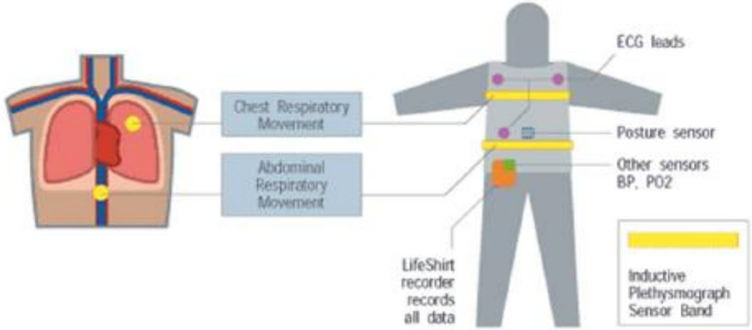


ECG
Heart Rate
Temperature
Respiratory Rate
Noisy ECG Signals
No Blood Pressure

Funded by DARPA

Bullet Penetration detection & localization
(Proof of concept only)

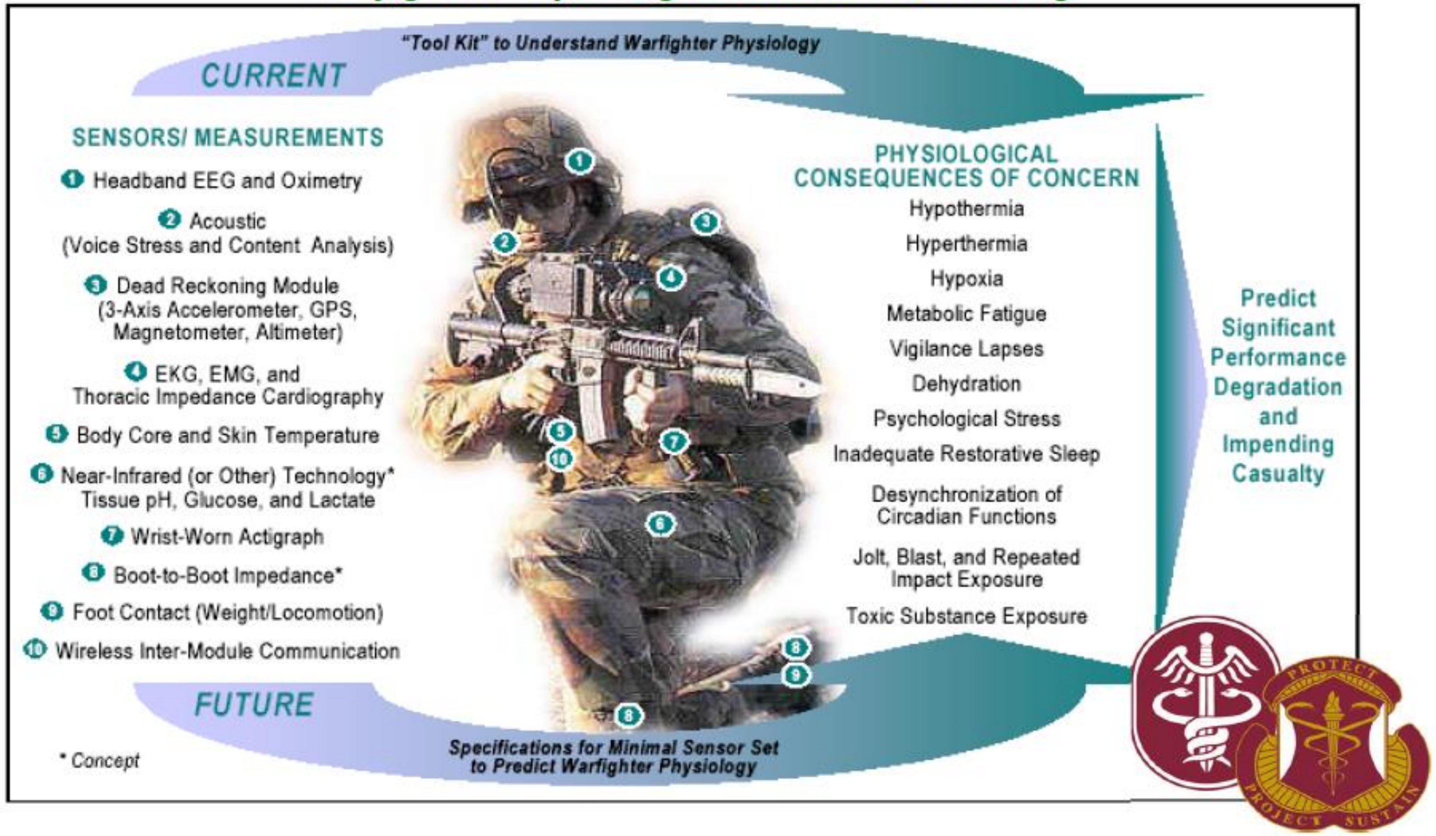
Vivometrics – Life Shirt



- **Physiological Parameters**
  - ECG
  - Position Sensor
  - Respiratory Parameters
  - Blood Pressure
  - PO2
  - Inductive Plethysmograph

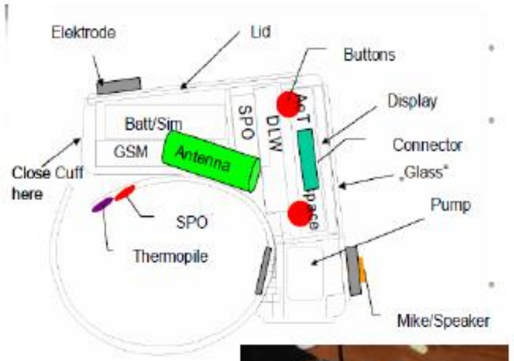
US ARMY

Warfighter Physiological Status Monitoring



AMON – Wrist Worn Multi-parameter Medical Monitoring Device

- Wrist Worn Device to Monitor
  - Single Lead ECG Signal
  - Heart Rate
  - Systolic and Diastolic Blood Pressure
  - Skin Temperature
  - Pulse Oxymetry
  - GPRS data transmission

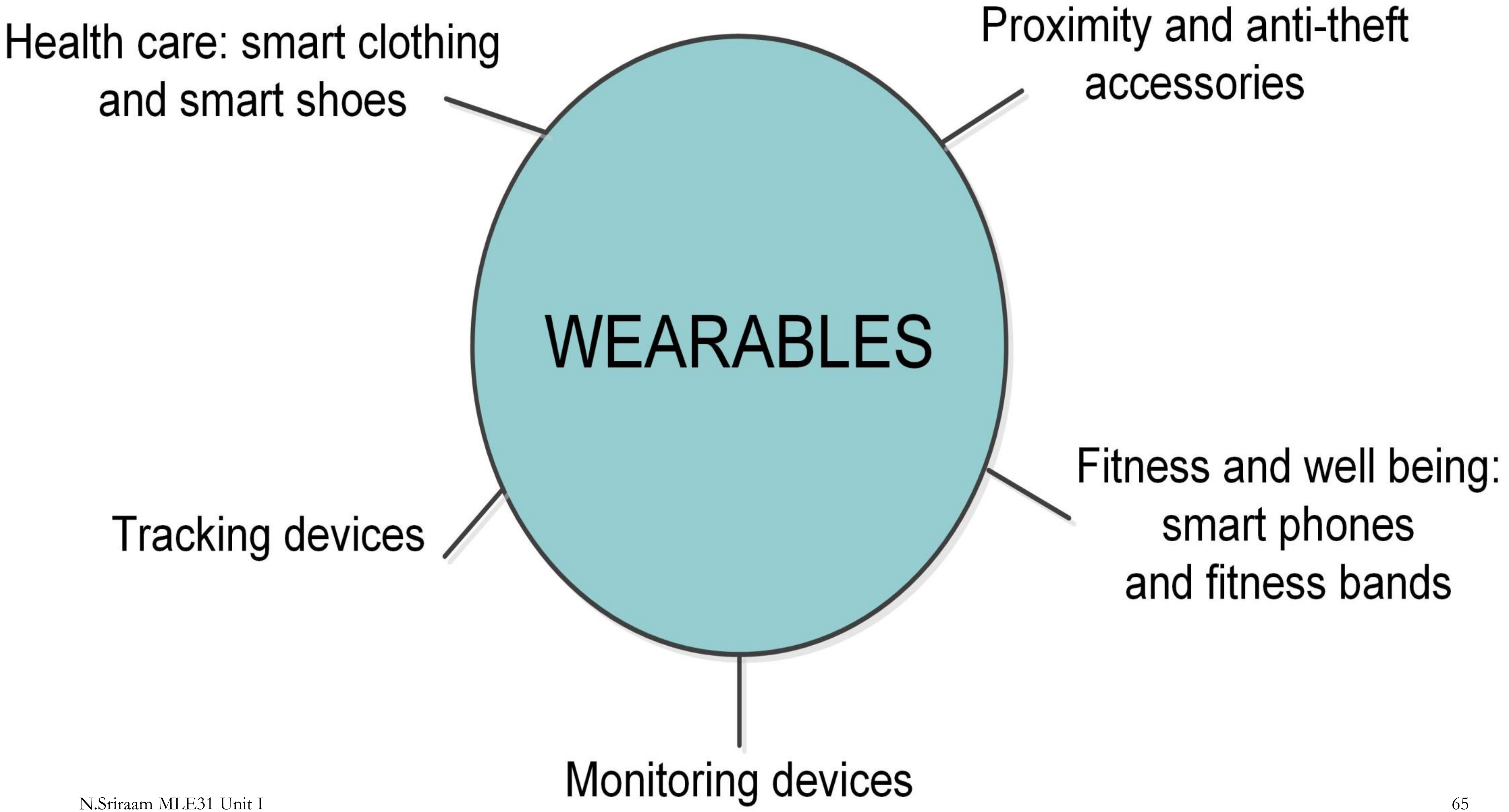


- Noisy ECG Signal
- Data affected by movement artifact
- Inconsistent Data

Types of wearables

- Watches.
- Fitness trackers.
- Hearables.
- Smart clothing.
- Glasses.
- Smart jewelry.
- Wearable cameras.
- Body sensors.


IBERDROLA
Types of wearables
01 Glasses
02 Bracelet
03 Belt
04 Socks
05 Earphones
06 T-shirt
07 Watch
08 Sneakers

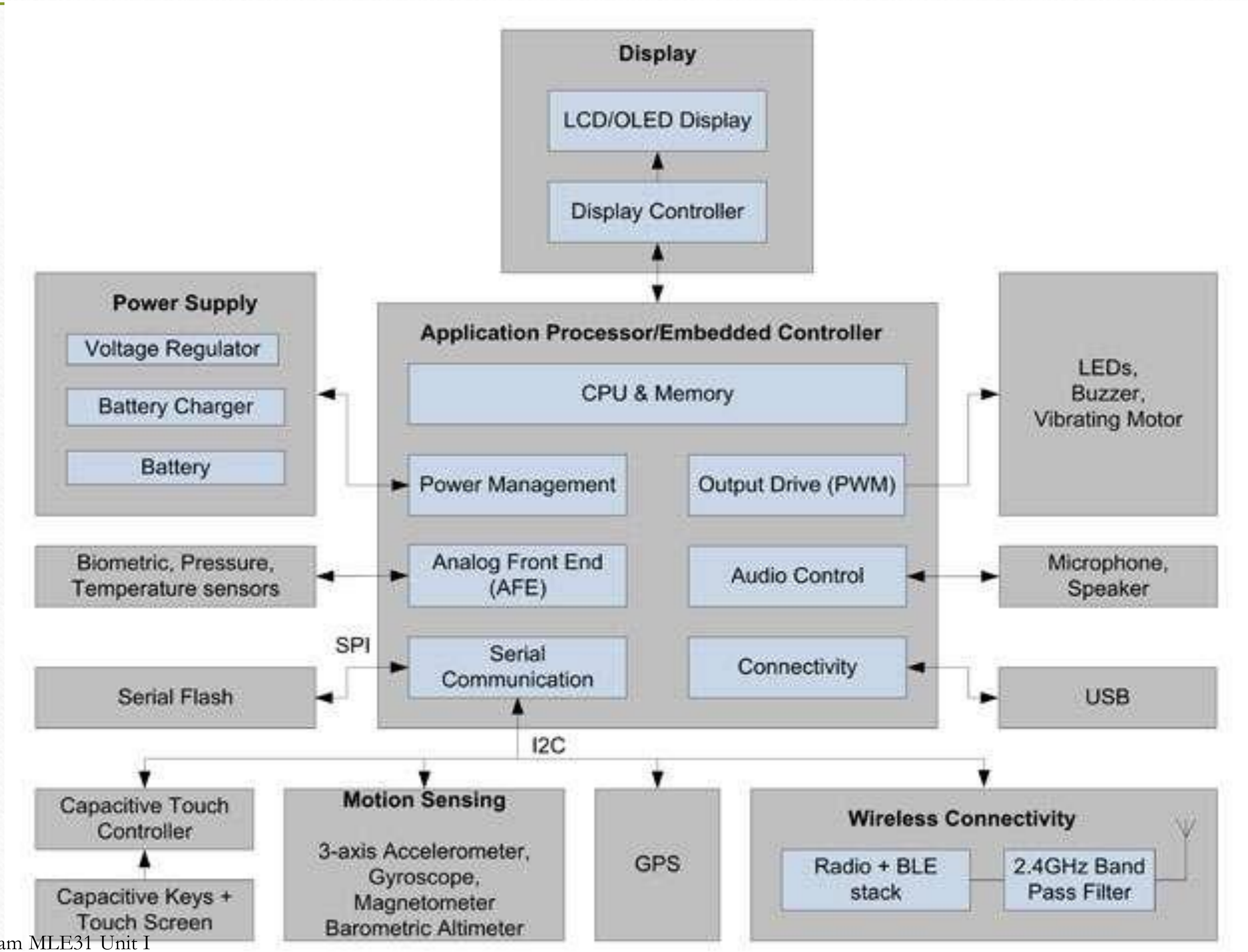

Health care: smart clothing and smart shoes
Proximity and anti-theft accessories
WEARABLES
Tracking devices
Fitness and well being: smart phones and fitness bands
Monitoring devices

Components of Wearable Systems

- Components play a key role in one of the fastest-growing fields of tech solutions: Wearable technology.
- As the name implies, wearable technology is technology that is worn on the body, either as a device, as clothing, or even implanted under the skin. The use of wearable has expanded greatly in recent years and is only going to become more common as more and more people begin to understand its benefits.

Components of Wearable Systems

- Wearable is based on three layers:
- *First Layer* – This layer is the sensor(s). The sensors are placed closest to the body. The sensors monitor elements such as temperature, movement and pulse.
- *Second Layer* – This layer is the connectivity and control layer. The Bluetooth Low Energy (BLE) protocol is the most commonly used to connect wearable devices to a smartphone or home network.
- *Third Layer* – This layer is the cloud where the wearable supplies and reads data.



Display
LCD/OLED Display
Display Controller
Power Supply
Voltage Regulator
Battery Charger
Battery
Application Processor/Embedded Controller
CPU & Memory
Power Management
Output Drive (PWM)
Analog Front End (AFE)
Audio Control
Serial Communication
Connectivity
LEDs, Buzzer, Vibrating Motor
Biometric, Pressure, Temperature sensors
Microphone, Speaker
SPI
Serial Flash
USB
I2C
Capacitive Touch Controller
Capacitive Keys + Touch Screen
Motion Sensing
3-axis Accelerometer, Gyroscope, Magnetometer Barometric Altimeter
GPS
Wireless Connectivity
Radio + BLE stack
2.4GHz Band Pass Filter

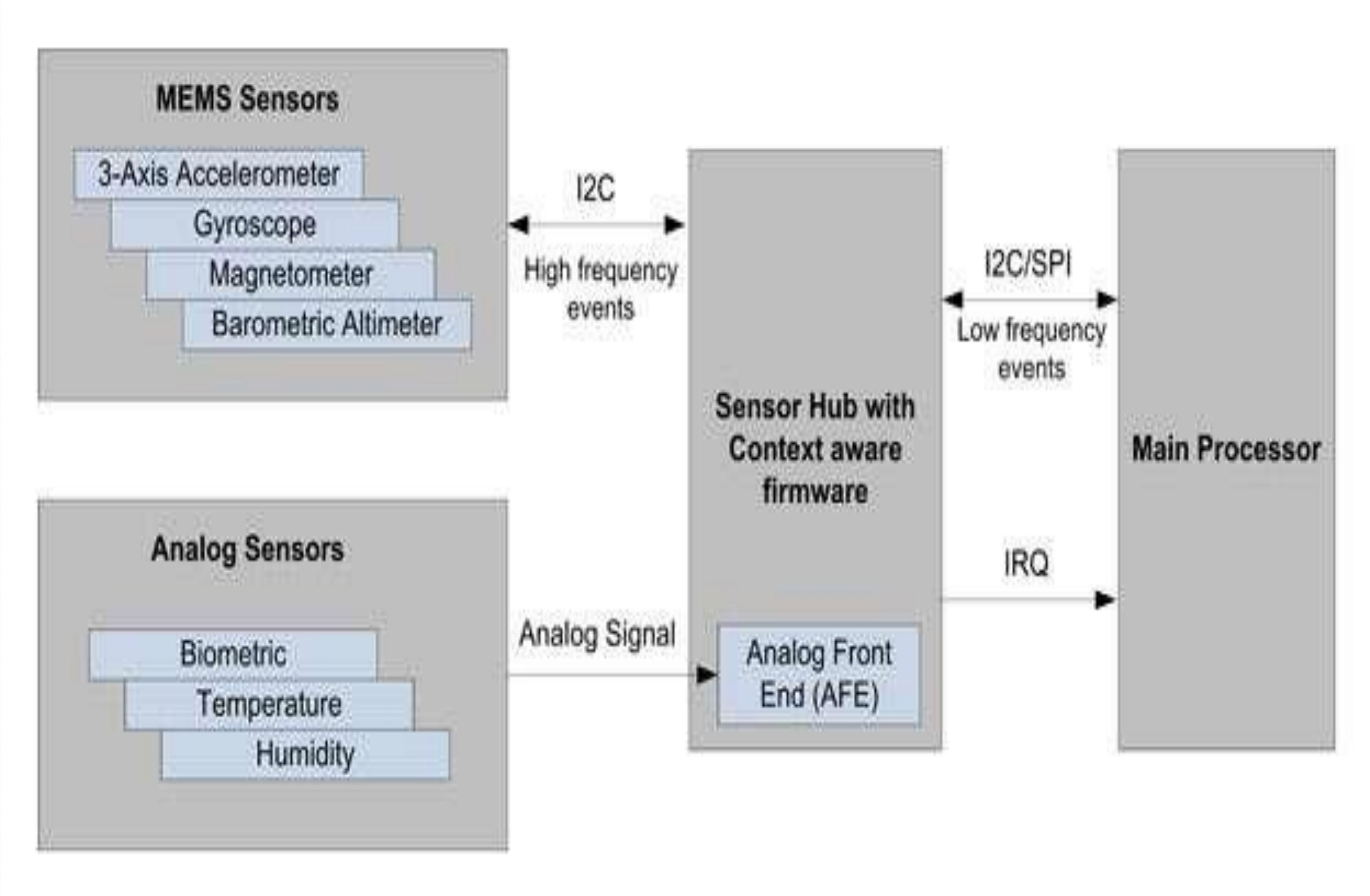
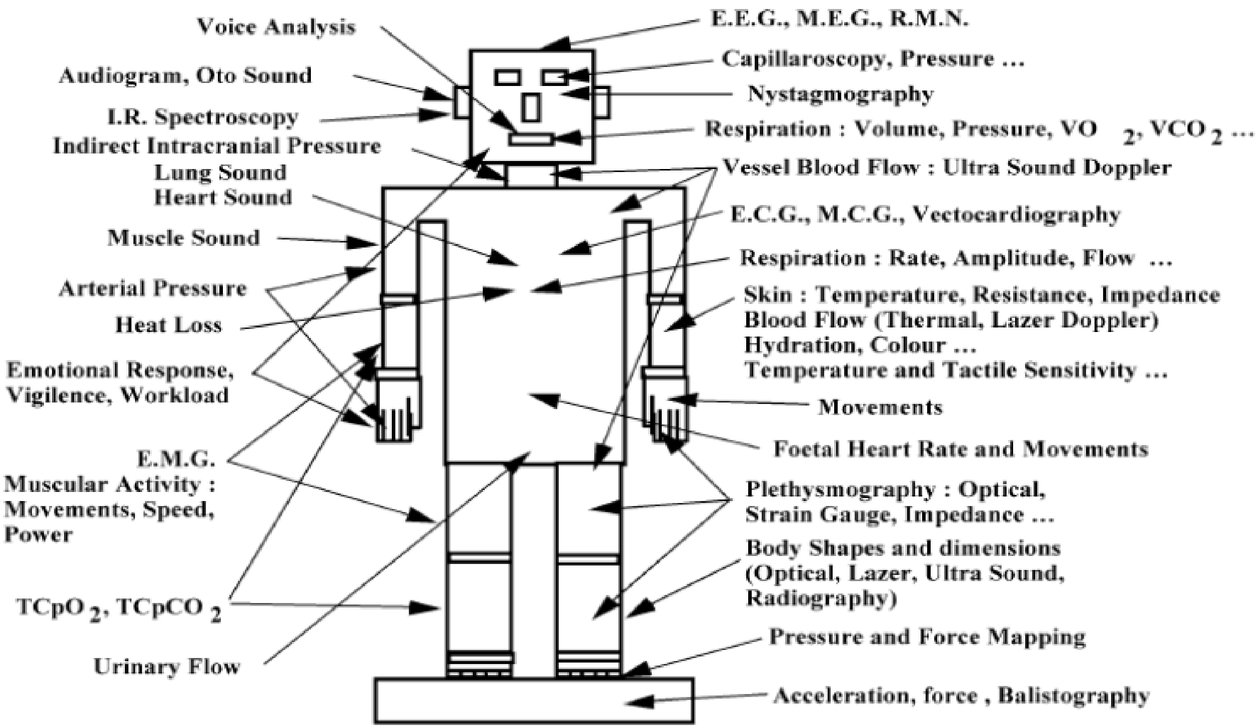


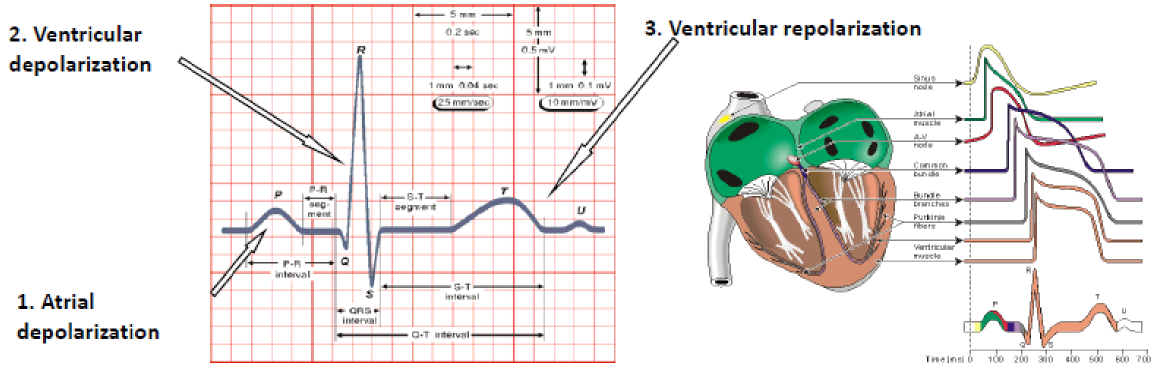
Figure 1: Role of sensor hub in a wearable system

Non-Invasive Physiological Signal Measurements in Humans

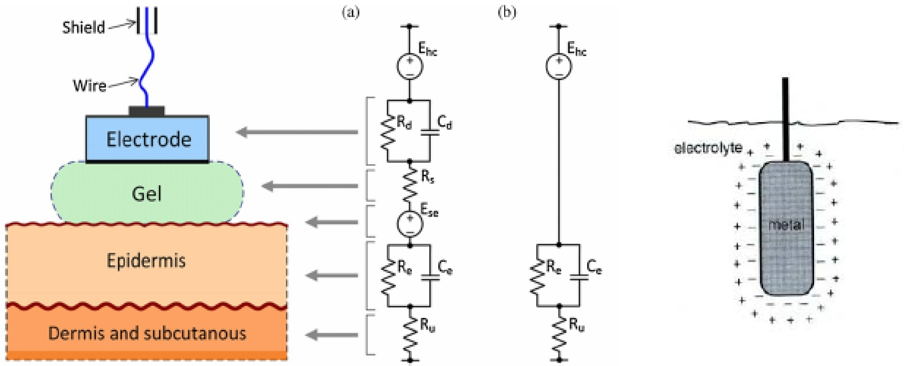


What physiological parameters are to be monitored?

ECG signals

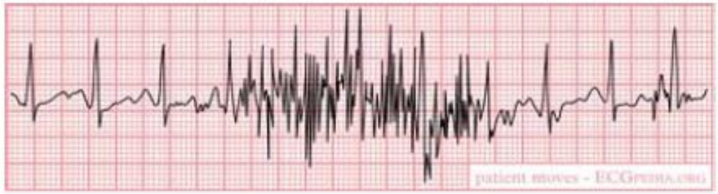


2. Ventricular depolarization
3. Ventricular repolarization
1. Atrial depolarization
R
P
Q
S
T
U
P-R segment
S-T segment
P-R interval
S-T interval
QRS interval
Q-T interval
5 mm
0.2 sec
0.5 mV
1 mm 0.04 sec
1 mm 0.1 mV
25 mm/sec
10 mm/mV



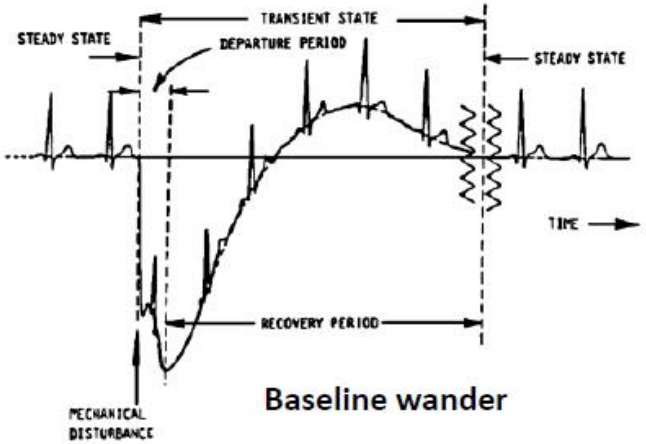
Shield
Wire
Electrode
Gel
Epidermis
Dermis and subcutanous
(a)
(b)
electrolyte
metal

Typical Noises in ECG Signals

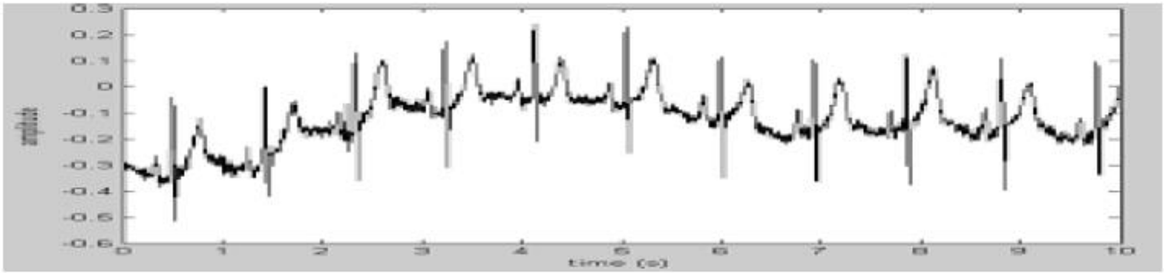


Tremor

Baseline wander



Baseline wander



Baseline Wander and Tremor