Learning Objectives

• What is physiological sensing? What types of signals can be extracted and how?
• What kind of application areas there currently are physiological sensing?
• What is photoplethysmography?
• What are currently the main issues in physiological sensing systems?
• What are BANs and how they relate to physiological sensing?
Physiological Sensing

- Physiological sensing deals with the analysis of different biological signals
  - Reflect body activity levels, but also certain psychological and cognitive states
- Smartwatches and wearable fitness trackers the dominant platform for mobile physiological sensing
  - Physiological signals often combined with other sensors, especially motion related ones
- Sensing principles originate from healthcare studies where high measurement accuracy crucial
  - Wearable devices less accurate, hence mainly used to compare relative changes instead of absolute values
  - Also sensitive to varies sources of noise
  - Multidevice (e.g., smartphone + smart watch) sensing can be used to reduce noise
Types of Physiological Signals

- Heart rate
  - Wearable belts, ear phones, wrist worn devices
- Oxymetry (blood oxygen)
  - Wrist worn devices, e.g., smartwatches
- Breathing rate
  - Audio signals from neck worn devices
- Skin conductance
  - Smart rings, smart textiles, smartwatches
- Skin temperature
Remote ambulatory monitoring one of the biggest areas for physiological sensing

- Wearable devices used to detect abnormal situations and to alert medical practitioners in case of need
- Medical monitoring devices have high accuracy requirements (need medical certification)

Examples of conditions that can be monitored:
- Cardiovascular conditions
- Diabetes (through blood glucose levels)
- Respiratory conditions
- Posture-related conditions
- Epilepsy, Parkinson’s disease
- Stress, psychopathy, and numerous other conditions
Application Areas: Fitness Tracking

• The main consumer oriented application area has been fitness tracking
  • Smartwatches, specialized standalone fitness trackers, and multi-device “kits” (e.g., Nike FuelPod)
• Main sensors and information types
  • Motion sensing (accelerometer, gyroscope, and GPS) forms the basis
  • Heart rate and skin conductivity often combined with motion sensing to estimate calorie consumption
• Consumer grade accuracy ➔ no specific requirements
  • Accuracy highly varying and better at estimating relative differences than absolute values
Heart Rate Monitoring

- Heart rate probably the most widely used physiological measurements
  - Traditionally has been done using chest worn straps
  - Recently non-invasive optical sensing emerged as popular alternative
- Fitness trackers
  - Heart rate essential for assessing effects of exercise, and for establishing calorie and metabolic consumption
- Health care
  - Heart rate monitoring used to identify cardiovascular abnormalities and conditions
- Gaming and social sensing
  - Biofeedback based games
  - Detection of nervousness, anxiety, etc.
Photoplethysmography (PPG)

- Basic principle: light absorption in tissue varies with blood content
- With each cardiac cycle, heart pumps blood into peripheral arteries
  - Medical monitoring uses fingertips or ear, smartwatches use wrist area (also earphones can be used)
- The change in volume caused by the cardiac cycle can be assessed from changes in light absorption
- PPG sensors consist of a light source (LED) and light detector (photo diode)
  - Transmission PPG: Detector directly across light source
  - Reflective PPG: Detector next to light source
Beer’s law: total light absorption at a given wavelength can be written as a sum of individual absorptions.

In particular, PPG absorption can be divided into subcomponents:

- **DC**: static absorption caused by veins, tissue, and other constant factors
  - However, motion causes fluctuations in the DC component
- **AC**: alternating signal caused by heartbeat
  - Source for heart rate
  - Bandpass filtering can be used to extract the AC component of the signal
  - Period of AC signal can be used to identify pulse
Photoplethysmography (PPG) – Pulse Oxiometry

- PPG can be used to extract also other types of information about blood circulation
- Blood oxygen most popular additional information:
  - Oxygen-rich hemoglobin absorbs more infrared than hemoglobin without oxygen
  - Oxygen without hemoglobin absorbs more red light than oxygen-rich hemoglobin
  - Blood oxygen level can be determined by comparing the relative rates of the two types of hemoglobin
Photoplethysmography (PPG)
Example: Apple Watch

- High sampling rate: green led emitted at 100Hz and reflection measured
- Low rate: infrared pulses every 10 minutes, absorption of light measured
Capacitive Coupling Electrocardiogram

- Electrocardiography traditional way to measure heart activity levels
  - Uses multiple electrodes to measure electrical activity of the heart (e.g., chest straps)
- Capacitive coupling
  - Potential of an electrode measured between human body and an electrode that is isolated from body
  - So-called contactless ECG as operates over clothing
- Also other possible techniques, e.g., based on UWB sensing
Blood Pressure Monitoring

- Blood pressure traditionally measured using inflatable cuff sensors
  - Not suited for continuous measuring, and may disrupt blood circulation if used excessively
- Pulse Transmit Time (PTT)
  - Non-invasive blood pressure monitoring technique that combines ECG and PPG
  - The speed at which a pulse travels between two locations can be used to estimate pressure
  - Accelerometers and gyroscopes needed to adjust for changes in hand position relative to heart
Electrodermal Activity

- Electrodermal activity (EDA) refers to variation in electrical characteristics of the skin
  - Also known as skin conductance level/response, electrodermal response and psychogalvanic reflex
- Basic principle: skin resistance varies with the state of sweat on the skin surface
  - EDA can be estimated by measuring change in electric conductance between two points over time
  - Ambulatory monitoring typically relies on measurements from fingers, palms or soles
    - Can be integrated into a “smart ring”
  - But can also be approximated on the wrist, as done by smartwatches
Electrodermal Activity: Applications

- Electrodermal activity seldom used in isolation, but considered complementary source to other sensors
  - Exertion level in fitness applications
    - Same exercise has different effect on different people → accelerometers and heart rate monitors can be combined with EDA to get more reliable metabolic estimates
  - Biofeedback and biological state in gaming
    - Heart rate and EDA can be used to determine the physiological state of the user and adapt gaming experience
  - Cognitive load
    - EDA can be used to assess concentration levels and cognitive load in certain potentially stressful situations
Other Types of Signals

- Smart textiles can provide additional signals and/or alternative means to measure signals
- Most of these signals have medical interest, examples include:
  - Heart rate: electrodes on chest
  - Heart sounds: phonocardiography, microphone on a vest or embedded into a shirt
  - Brain activity (electroencephalogram EEG): electrodes placed on the scalp
  - Blood pressure: integrated into cuffs of shirts
  - Blood glucose: optical (infrared) sensing
  - CO$_2$: respiratory sensors, worn on chest
Most physiological sensing applications operate using a BAN structure

- Traditionally separate sensing and processing units, e.g., smartphone and a sensor belt

- With smartwatches increasingly integrated into a single device, but also BAN cases remain common

- EDA and acceleration can be estimated more reliably from sensors integrated into shoes

- Earphones or rings more accurate in measuring PPG derived features

- “Stetoscopes” and electrocardiography on the chest more reliable at estimating heart rate
Networking Technologies for Physiological Sensing

- Operating in a BAN structure requires regular local area communications
- Key requirements:
  - Low energy: wearable sensors difficult to charge, should have low transmission cost
  - Low latency: during activities of interest, need fast setup and transmission support
  - “Suitable” bandwidth: sensing devices close to human body should minimize magnetic radiation, but also body (or water in it) blocks/shadows communications
  - Security: nature of exchanged data highly sensitive and personal, need to safeguard it
Networking Technologies: Bluetooth Low Energy

- Bluetooth Low Energy (BLE)
  - Part of Bluetooth standard since 2010, originally developed by Nokia (“Wibree”)
- “Simplified” Bluetooth
  - considerably lower energy consumption
  - simplified channel assignment, routing, processing etc.
  - lower latency
  - lower throughput rate
- Designed originally for wearable sensing scenarios
  - Bluetooth specification provides separate profiles for different healthcare and fitness tracking technologies
- Devices need to connect using a star/piconet topology
Networking Technologies: WiFi Direct

- WiFi Direct is a standard that enables peer-to-peer connections over WiFi
  - Devices that support WiFi direct embed a software access point that allow direct communication between two devices instead of separate router
    - Similar to WiFi protected standard, but in software
- Widely supported on high-end devices
  - Mobile phones, laptops, TVs, gaming consoles
- Together with Bluetooth (LE) main standard in general use, but less used in specialized wearable domains
  - High power drain
  - Potential interference, e.g., with medical equipment
  - Human body blocks WiFi signals
Network Technologies: ZigBee IEEE 802.15.4

- Low-cost and low-power networking technology
- Designed for short range (10-20 meters)
- Maximum transmission rate 250 kbps so only suited for low-data rate applications
  - I.e., where communications are intermittent
- Can operate on different bands, standardized by country/jurisdiction
  - Europe: 868 Mhz
  - USA: 915 Mhz
  - The lower the band, the lower maximum transmission rate
- Natively supports authentication, and two types of network topologies: tree and star
Network Technologies

Others

- Ultra Wideband (UWB)
  - Very low energy level for short-range, high-bandwidth applications
  - Operates in the 3.1 – 10.6 GhZ band
  - Less sensitive to interference from human body, also smaller magnetic energy footprint
- ANT and ANT+
  - Proprietary sensor network technologies that operate over the 2.4 GHz band
  - Has been widely used to transfer data from sensing units to controllers, e.g., between heart rate bands and wrist worn monitors
- Many other (mainly proprietary) technologies exist: Z-Wave, Insteon, Sensium, RuBee, Zarlink,…
Research Directions

- New measurement technologies
  - Non-invasive sensing technologies continually being developed as alternatives to laboratory monitoring
  - Accuracy of techniques a concern, often long clinical trials required to validate the techniques
- Multi-device and/or cloud infrastructures
  - Optimal sensing schedules and distribution of computations to maximize operational time
- Security and privacy measures
  - Physiological information highly sensitive in nature, wireless communications insecure by nature
  - Need for new countermeasure techniques to safeguard data confidentiality
Summary

- Physiological sensing an emerging domain
  - Fitness trackers and smartwatches provide possibilities for more continuous monitoring than before
  - But accuracy of measurements remains an issue
- Common signal types include
  - Heart rate, measured using PPG (light reflectance and/or absorption)
  - Electrodermal activity (EDA), measured using changes in electrical conductance between two points
- Most physiological sensing applications operate using a body area network structure
  - Low-power and error reliance key requirements, also low-latency and high-bandwidth often required
  - But do not require long range
  - Bluetooth / BLE, WiFi direct, Zigbee, UWB, different proprietary technologies
References