Health and Emotions

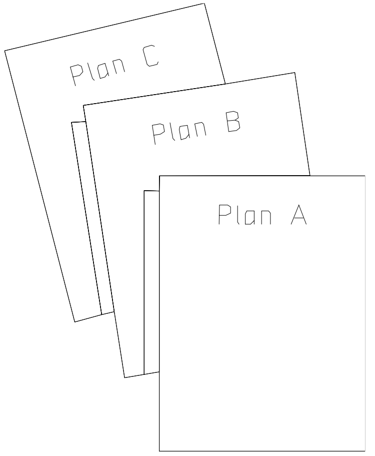
If everyone is moving forward together,
then success takes care of itself.

Henry Ford

Overview

- Objective
  - To understand the opportunities for pervasive healthcare and techniques to capture various health-related metrics

- Content
  - Pervasive healthcare: Overview and opportunities
  - Heart monitoring: PPG and ECG
  - Other physiological sensing techniques
  - Sleep monitoring



- After this module, you should be able to
  - Understand the opportunities for pervasive healthcare
  - Understand physiological sensing techniques

Pervasive Healthcare

Making healthcare available everywhere, anytime, and to anyone

Clinical Applications (used in hospital)	Daily Wellness (used in daily life)
• RFID for patient tracking • Robot-aided surgery • DNN-aided diagnosis	• Telemedicine • Activity tracking • Stress monitor • Home language therapy

Opportunities (1/4)

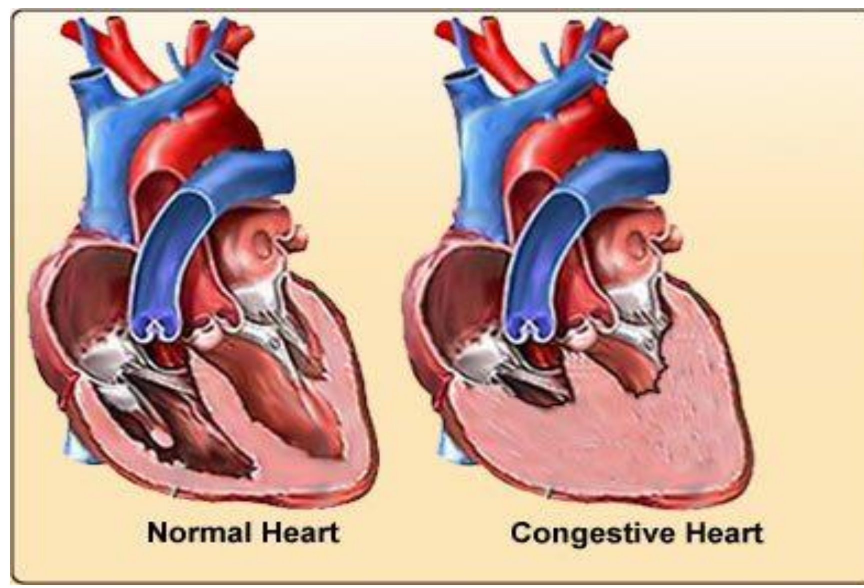
- No reach of doctors

Opportunities (2/4)

- Daily well-being and preventive healthcare

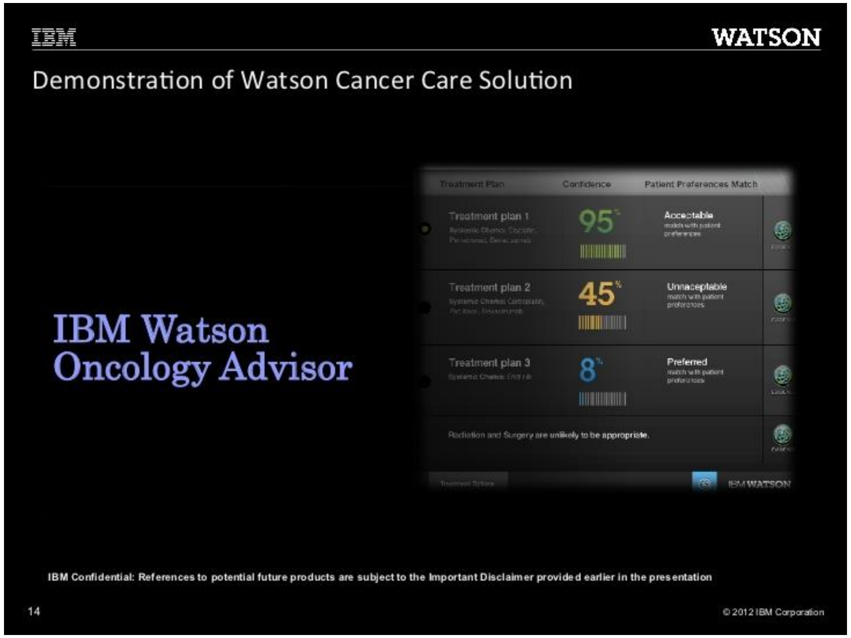
Opportunities (3/4)

- Non-life threatening but life-impacting issues
- Chronic diseases (e.g., diabetes, arrhythmia, fatty heart)
- Children with autism or ADHD (Attention deficit hyperactivity disorder)



Opportunities (4/4)

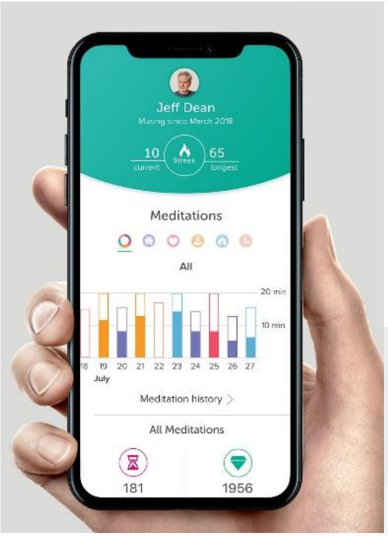
- Corner cases that doctors hardly see
- Lack of human resources and inefficient operations in hospitals



Wearable and IoT Devices

- Wearable and IoT devices are emerging to measure different physiological signals such as
  - cardiac rhythms, breathing, sweat, brain waves, gestures, muscular contractions, eye movements
- Health sensors will be integrated into clothing, jewelry, and many other accessories.
- Many new health-related applications are emerging using these devices.

Example Devices



Physiological Sensing:

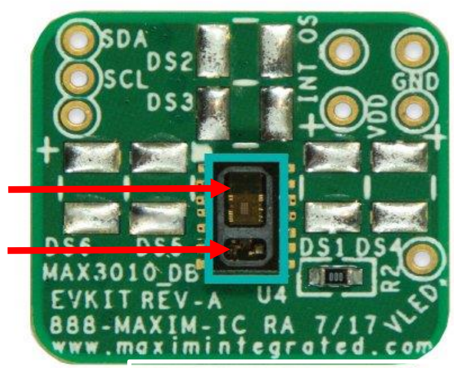
Heart Monitoring with PPG and ECG

PhotoPlethysmoGraphy (PPG)

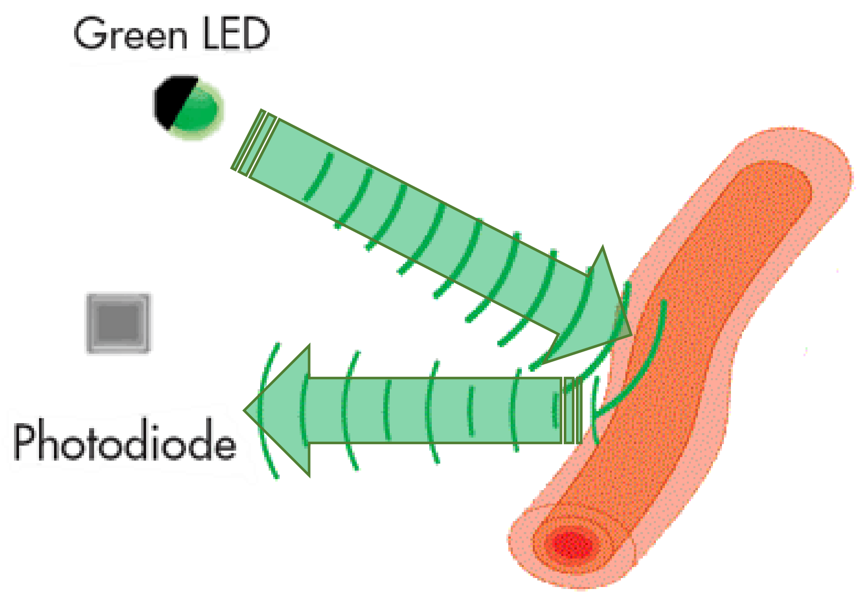
- PPG is a non-invasive technique for measuring blood volume changes in the blood vessels close to the skin.
- PPG has become a popular method for extracting heart rate and oxygen saturation (left figure).
- PPG can be measured using a built-in cellphone camera without any additional hardware (right figure).

Basic Operation of PPG

- Uses green LED light emissions and a photodiode capturing reflected light levels from the skin.
- Detects heartrate by measuring the differences in light absorption from the skin.



PPG Sensor

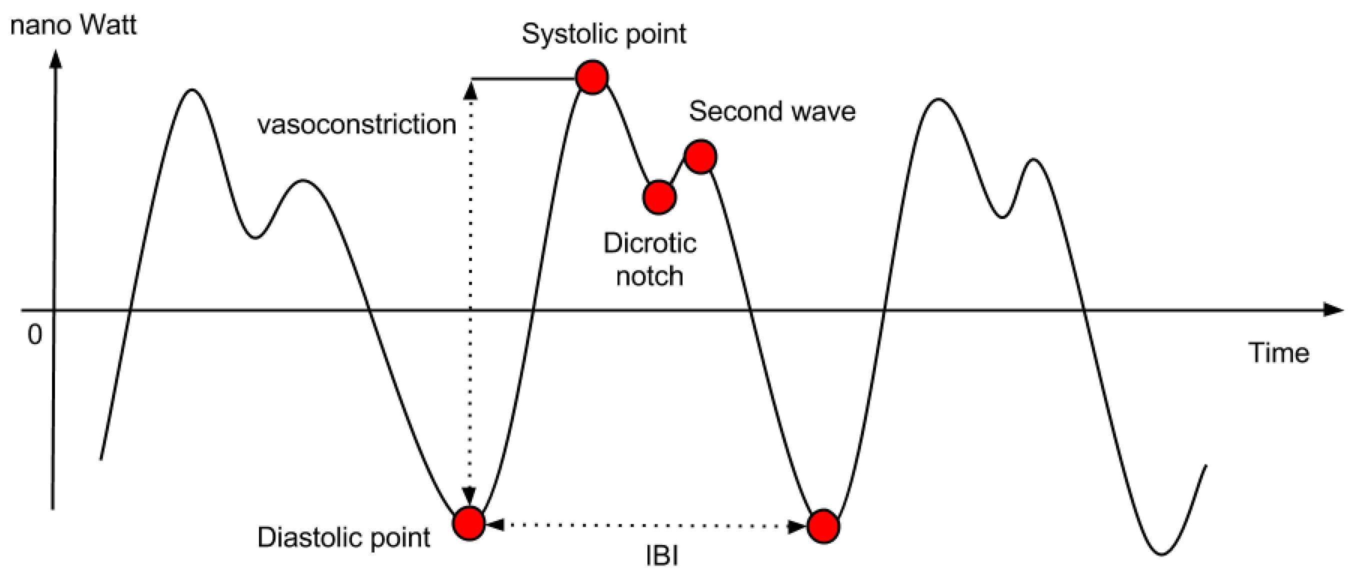


PPG with Smartwatches/bands

PPG with Smartphones

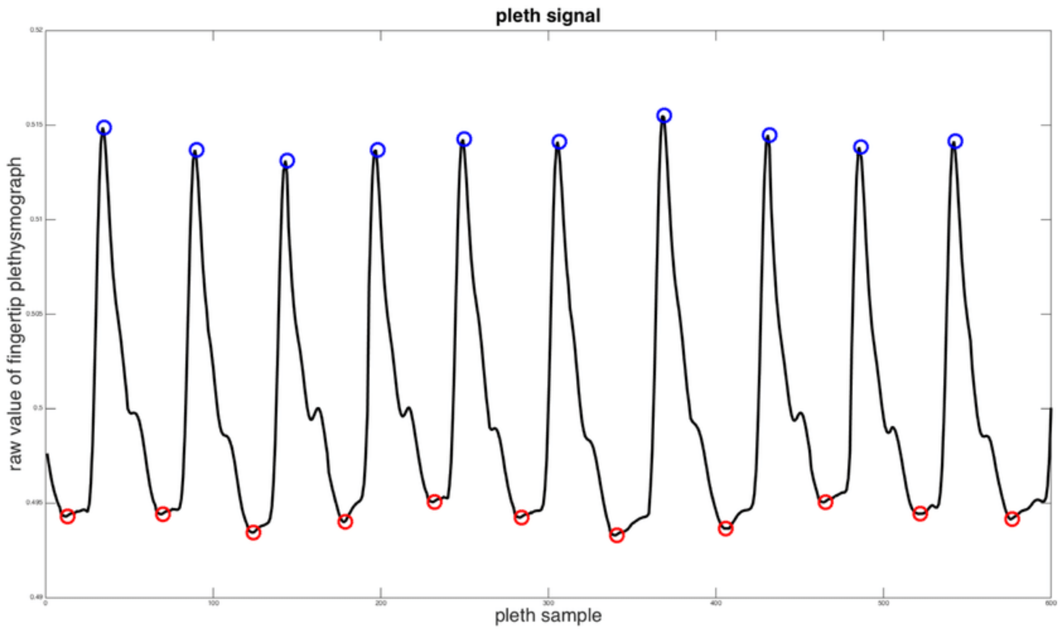
Detecting Heartrate from PPG

- The green intensity in the PPG signal forms peaks corresponding to cardiac pulse.



Heartrate Calculation Method

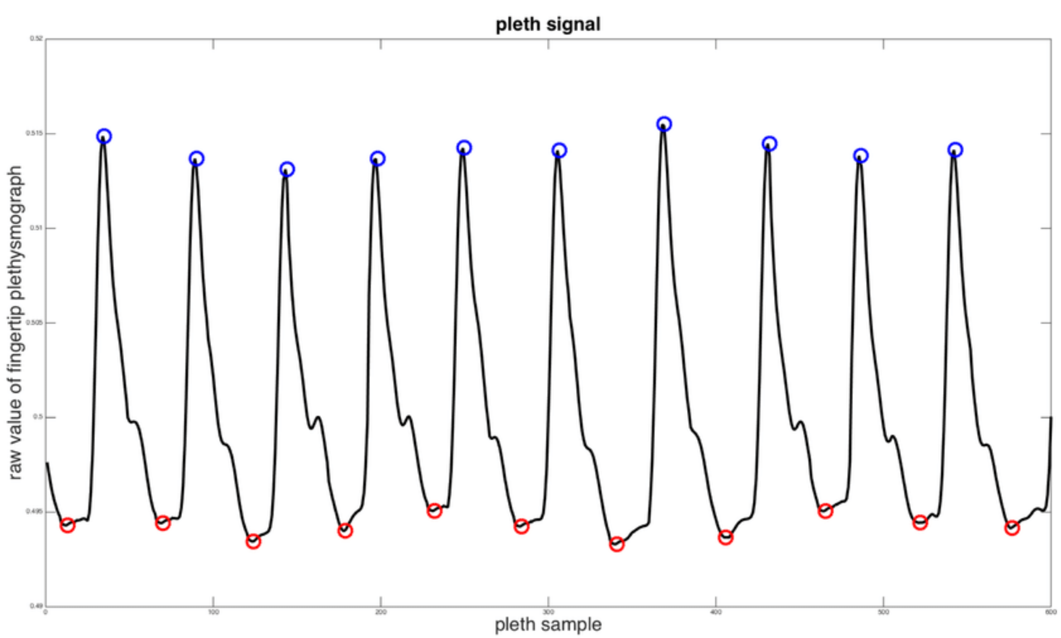
- Step 1: Get the average green intensity per frame.
- Step 2: Use a peak detection algorithm to find all the cardiac peaks in the signal.
  - A peak: the highest average green intensity in a fixed window (~0.7 seconds).



Acknowledgement: Prof. Deepak Ganesan's Lecture Note

Heartrate Calculation Method

- Step 3: The time difference between consecutive peaks is computed. This time difference is known as R-R interval (RRI) or Inter-Beat Interval (IBI).
- Step 4: HR is estimated from the RR Interval: HR = 60 / RRI



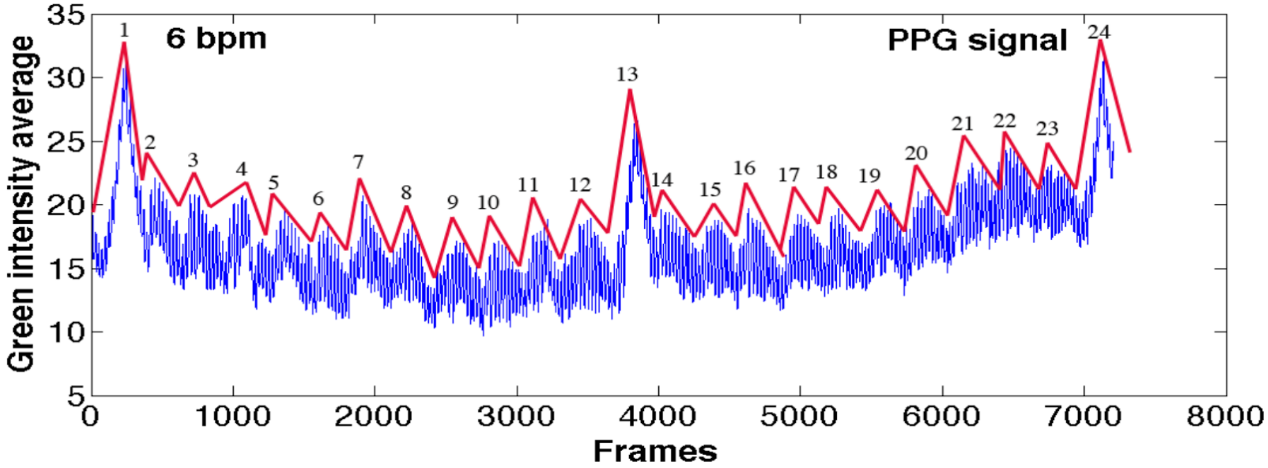
Acknowledgement: Prof. Deepak Ganesan's Lecture Note

Breathing Rate from PPG

- The PPG signal can be used for extracting not just the heart rate but also the breathing rate of the individual.
- Respiratory sinus arrhythmia (RSA): a naturally occurring variation in heart rate that occurs during a breathing cycle.
- Heart rate increases during inspiration and decreases during expiration!

Example PPG Signal

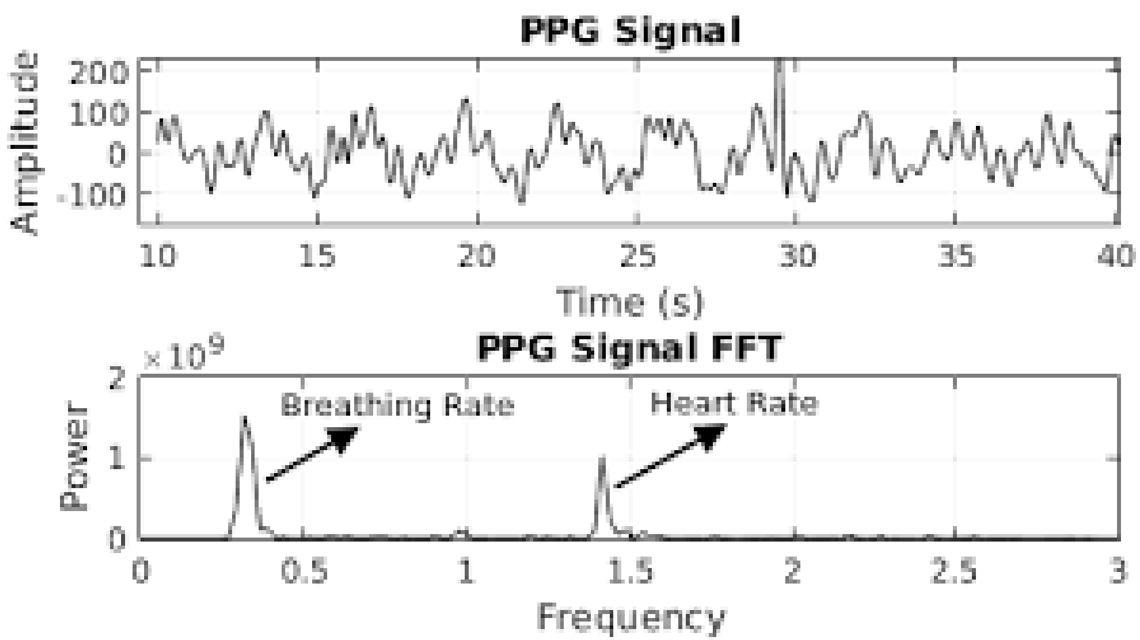
- The blue curve plots the average green intensity per frame.
- The green intensity goes up and down for each heartbeat.
- There is another pattern where the green intensity spikes every few heartbeat.
  - R-R interval on an ECG is shortened during inhalation and prolonged during exhalation



Average green intensity per image frame

Calculation of Breathing Rate

- Step 1: Get the average green intensity per frame.
- Step 2: Perform an FFT.
- Step 3: The second dominant frequency will match to the respiration rate.

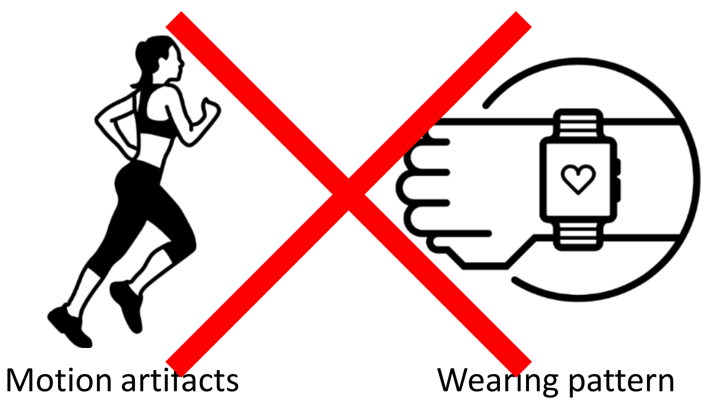


Problems with Daily PPG Sensing

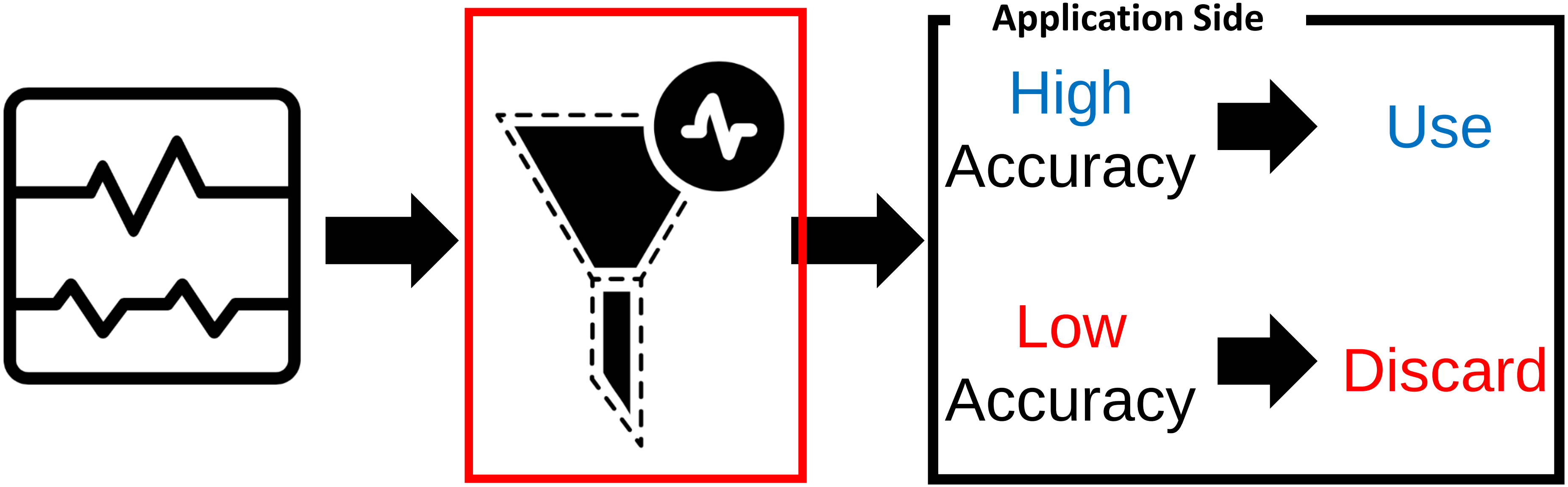
I am a Smart watch, Smart Enough to Know the Accuracy of My Own Heart Rate Sensor [HotMobile '17]

- Inaccurate readings can negatively impact the healthcare application's implications on the user's health status.
  - Asthma attacks, stroke, heart attack, …

- Smartwatch vendors admit that the accuracy of heart rate readings may not be high.



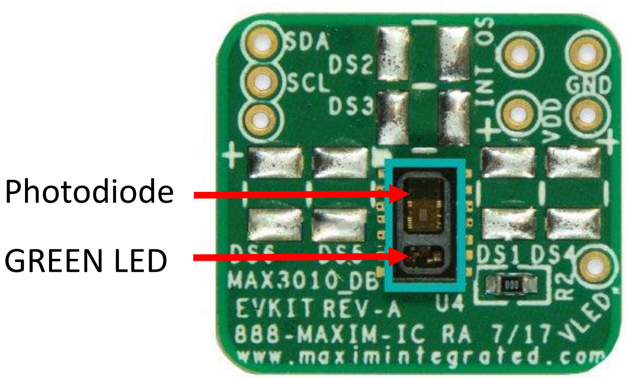
Making the Smartwatch Sensors Reliable!



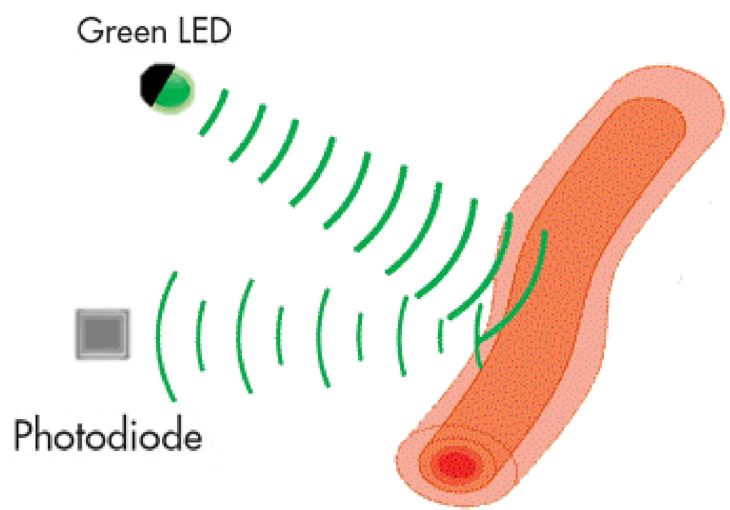
- If smartwatches can predict the accuracy of the heart rate sensor itself, applications can selectively use the measurement according to the accuracy.

Factors Impacting Accuracy

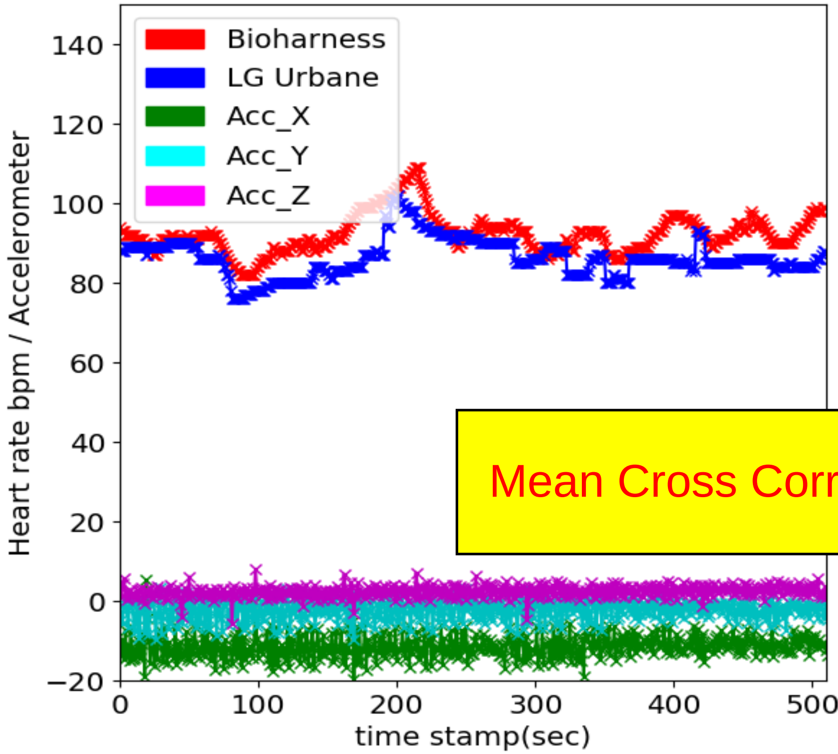
- If the PPG Sensor vibrates by motion artifacts, the photodiode cannot read the reflected light from the skin properly
- This causes irregular light intensity readings at the photodiode.



PPG Sensor

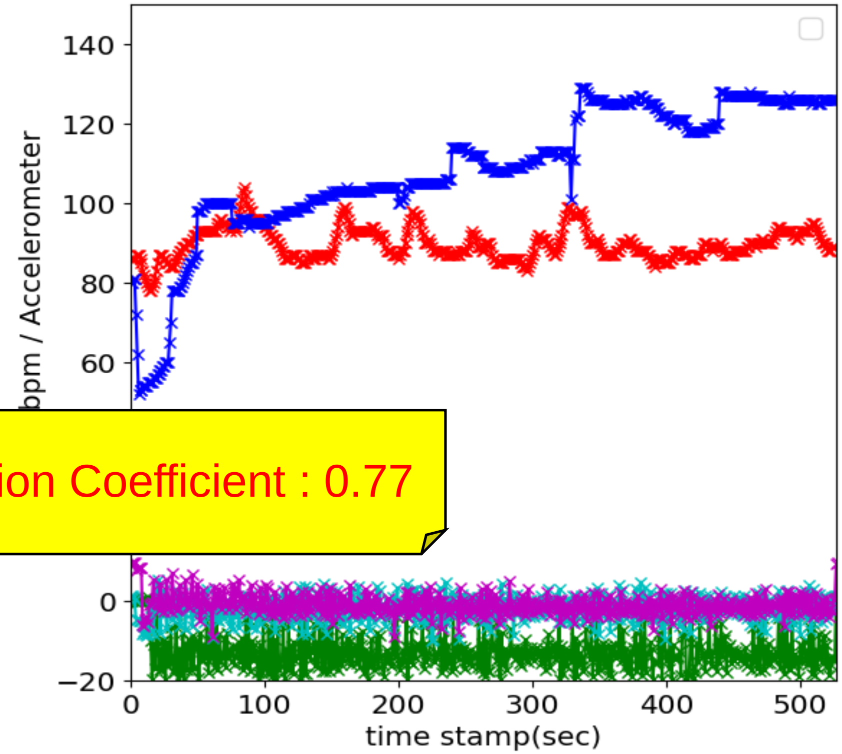


Idea 1: Use Accelerometer



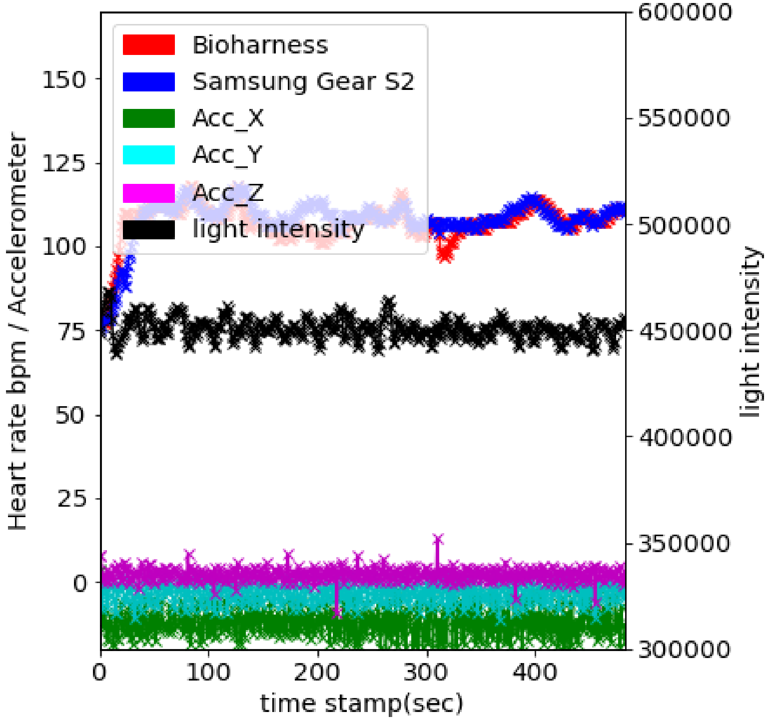
Watch worn tightly– LG Urbane

Mean Cross Correlation Coefficient : 0.77

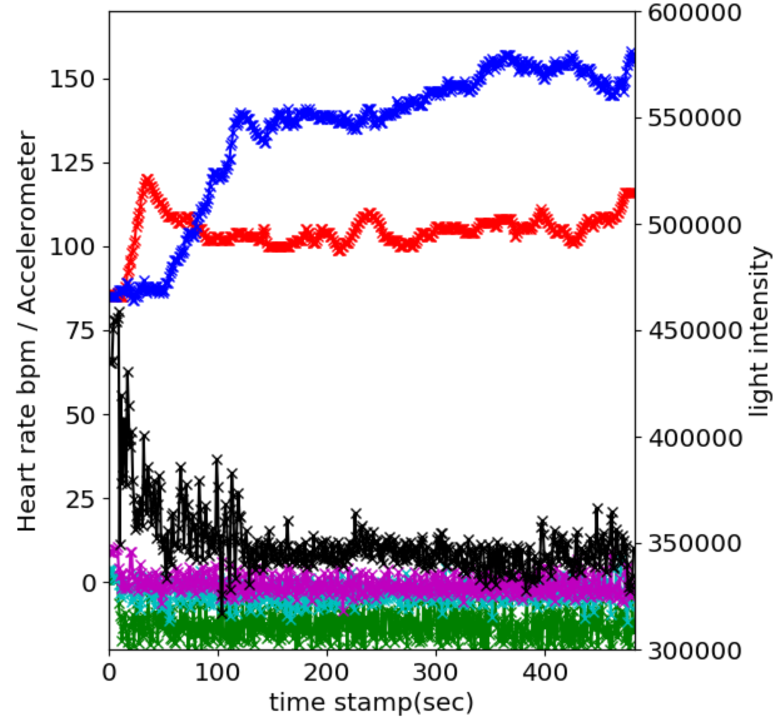


Watch worn loosely– LG Urbane

Idea 2: Use Light Intensity



Samsung Gear S2 worn tightly



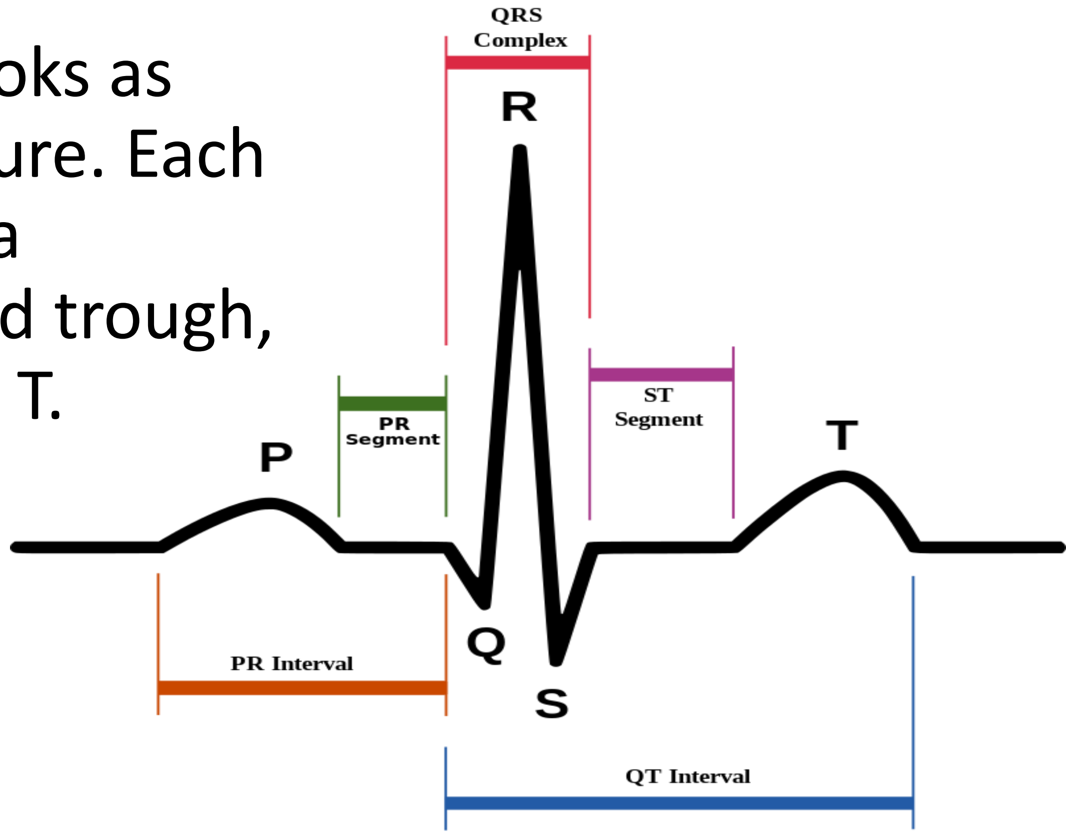
Samsung Gear S2 worn loosely

ElectroCardioGram (ECG)

- ECG is a recording of the electrical activity of the heart.
- With each heartbeat, an electrical signal spreads from the top of the heart to the bottom.
  - As it travels, the signal causes the heart to contract and pump blood. The process repeats with each new heartbeat.
- ECG shows how fast your heart beats, the rhythm of your heartbeat (steady vs irregular), and the strength and timing of the electrical signals as they pass through each part of the heart.

ECG Signal

- A typical ECG wave looks as shown in the right figure. Each heartbeat comprises a sequence of peaks and trough, labeled P, Q, R, S, and T.



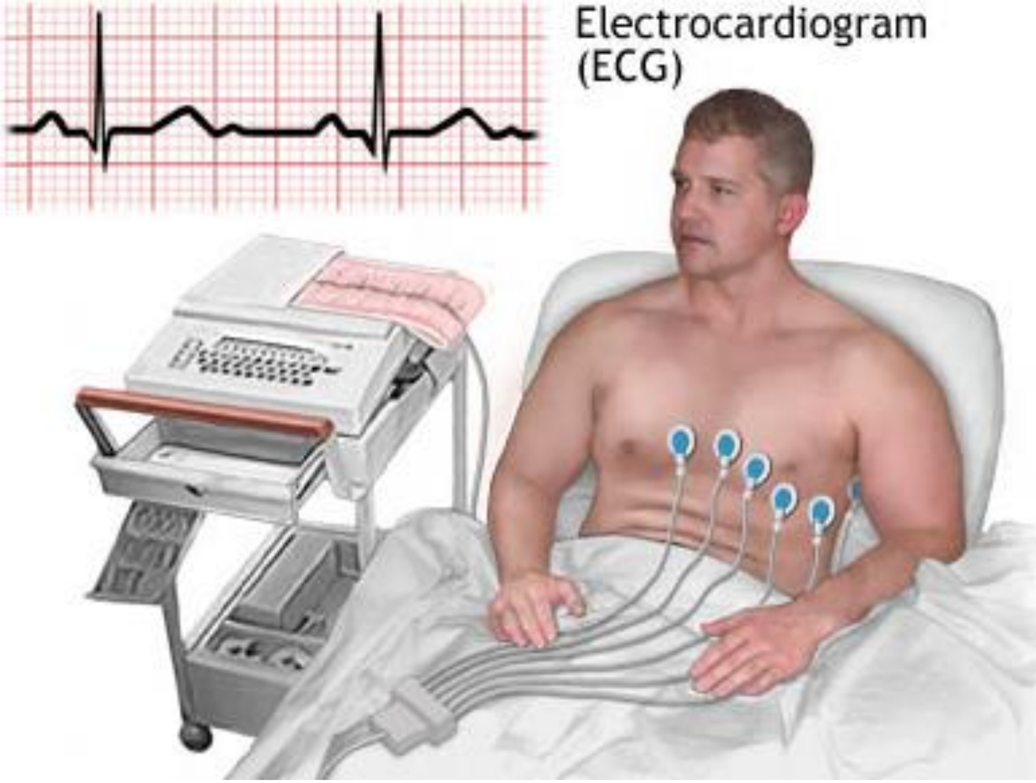
Applications of ECG

Diagnosing Cardiac Disease

- Arrhythmia
- Cardiac Malformation
- Cardiac Valve disease
- Cardiac Muscle disease

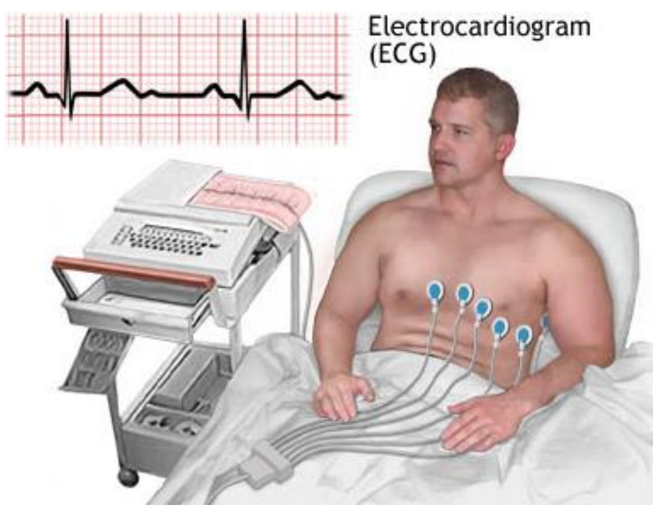
Monitoring Autonomous Nervous System (ANS)

- Stress Management
- Sleep Analysis
- Affect Recognition



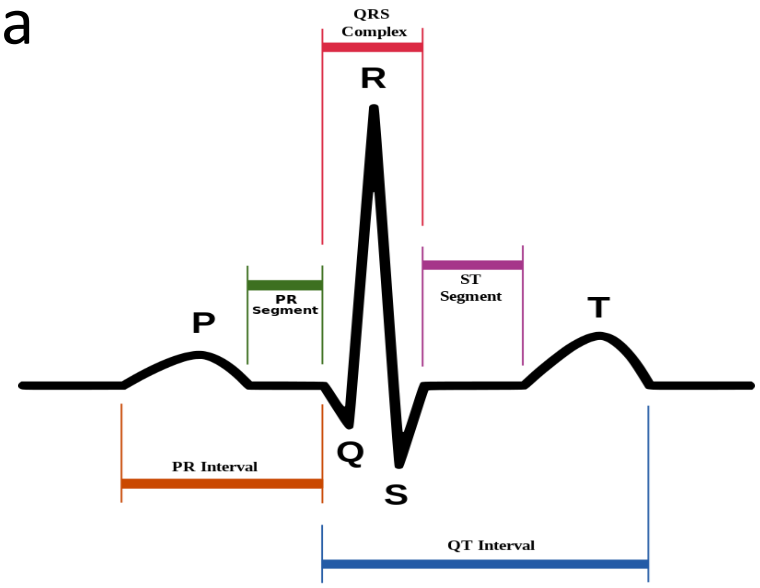
How Do We Measure ECG?

- Use two or more electrodes at different points on the chest (or on two opposite body parts from the chest), and measuring the electrical activity between these electrodes.



Detecting Peaks from ECG

- A good starting point: A step detector that we studied in Week 2.
- As in step detection, you look for a change in the slope from positive to negative (peak) or negative to positive (trough).
- You then look at the sequence information to label the appropriate peaks (P, Q, R, S, T).



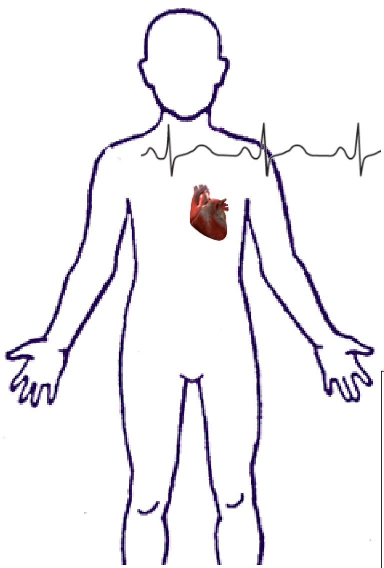
Heartrate Calculation from ECG

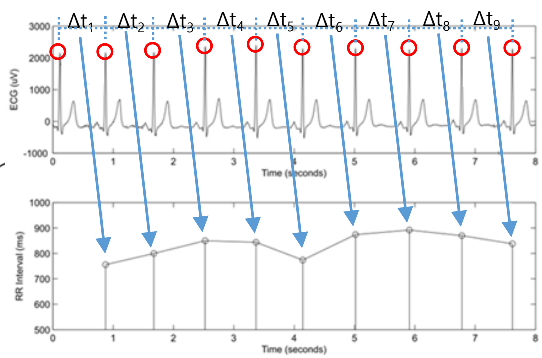
- Obtaining heart rate from ECG is straightforward.
  - Each RR interval corresponds to the time between two s uccessive heartbeats
  - HR = 60 / RR Interval

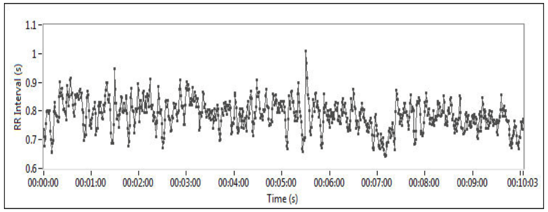
- The time differences between different peaks are known to be useful features.
  - E.g.) RR interval, PR interval, the QRS interval, the QT interval, the ST interval
  - Look at how these intervals vary to detect abnormalities in the heart.

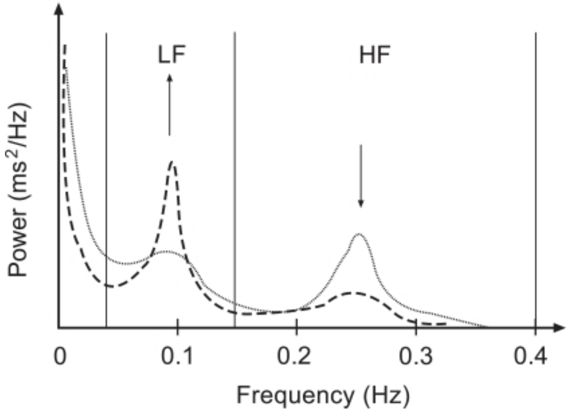
Detecting Stress from ECG

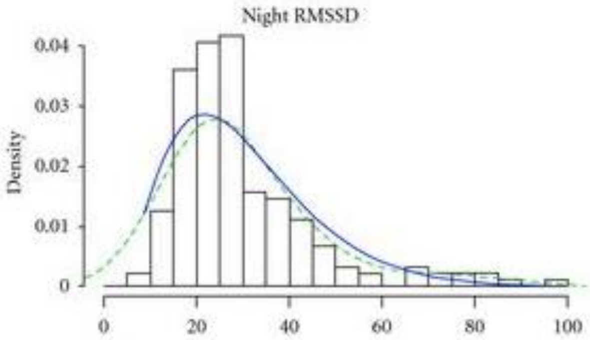
ECG Sensing | **Heartbeat Detection** | **LF / HF features** | **Stress Analytics**



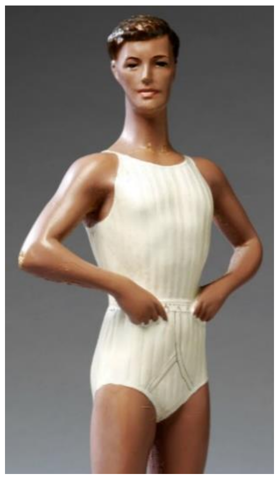


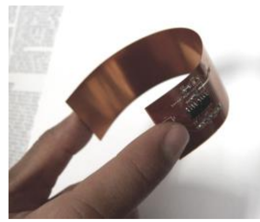


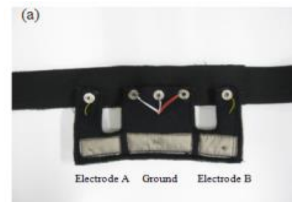


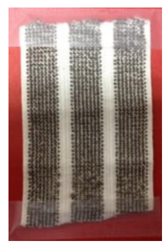


Daily ECG Monitoring



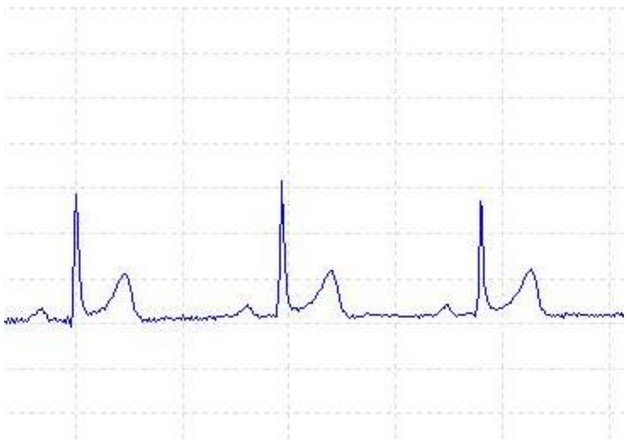






Clothes or Accessories + Flexible Sensors → Wearable Sensors

Limitations of Wearables



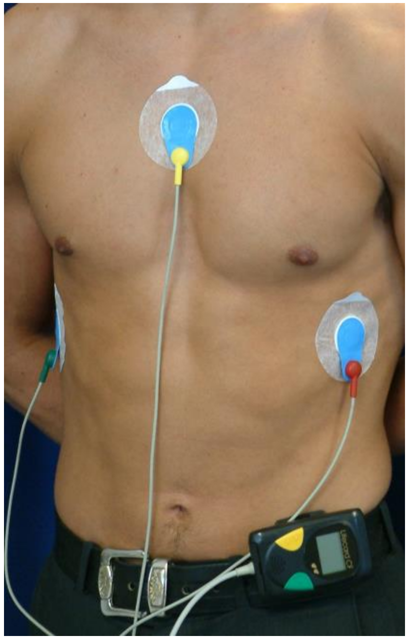
Reliability of sensing

Motion
Artifect

Washing
durability

Limitations of Wearables

- Skin contacted sensor required
- Burden to wear and measure continuously

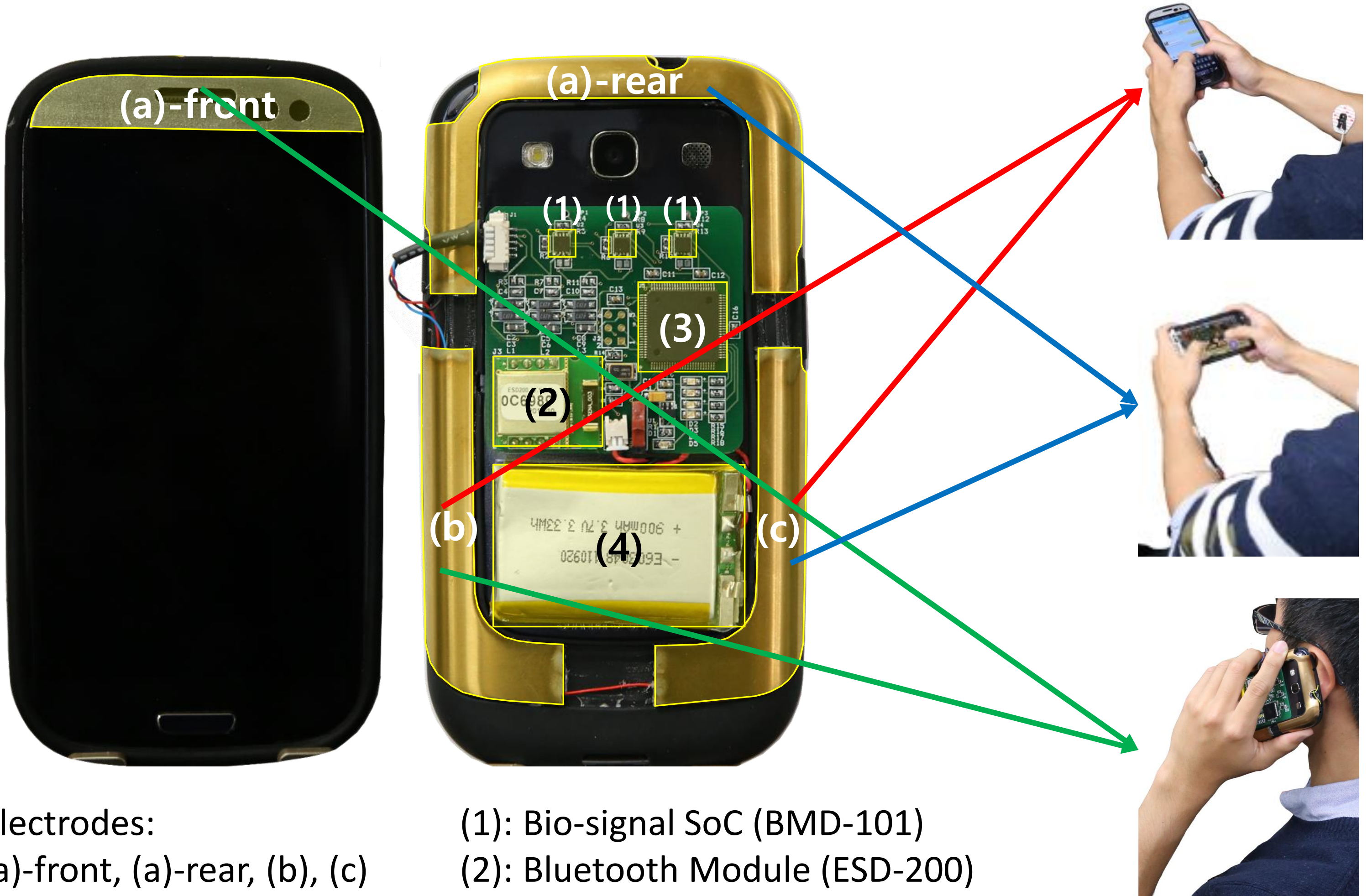


Smarthome-Integrated Sensing

- Embed sensors in daily living space
- The requirements for “skin contact” and “metallic electros” make reliable sensing challenging.



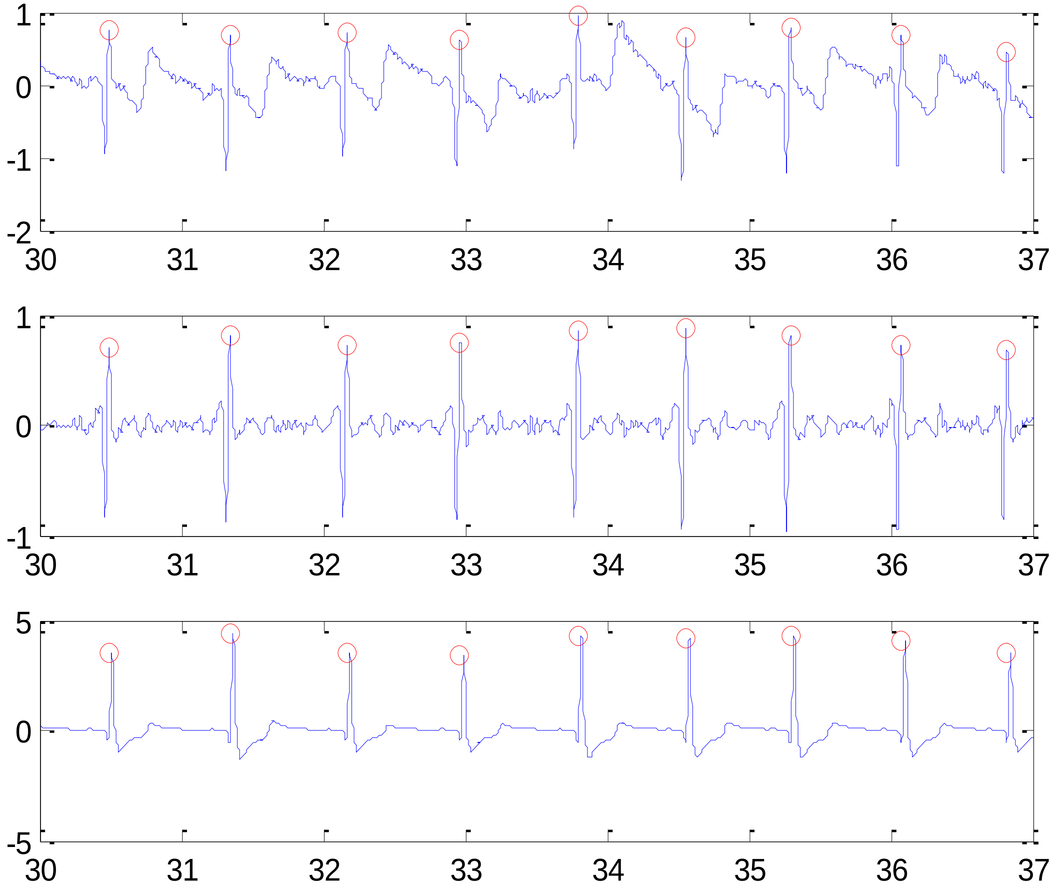
Sinabro Sensing System [HotMobile '14]



Electrodes:
(a)-front, (a)-rear, (b), (c)

(1): Bio-signal SoC (BMD-101)
(2): Bluetooth Module (ESD-200)
(3): MCU (ATMEGA2560)
(4): Battery

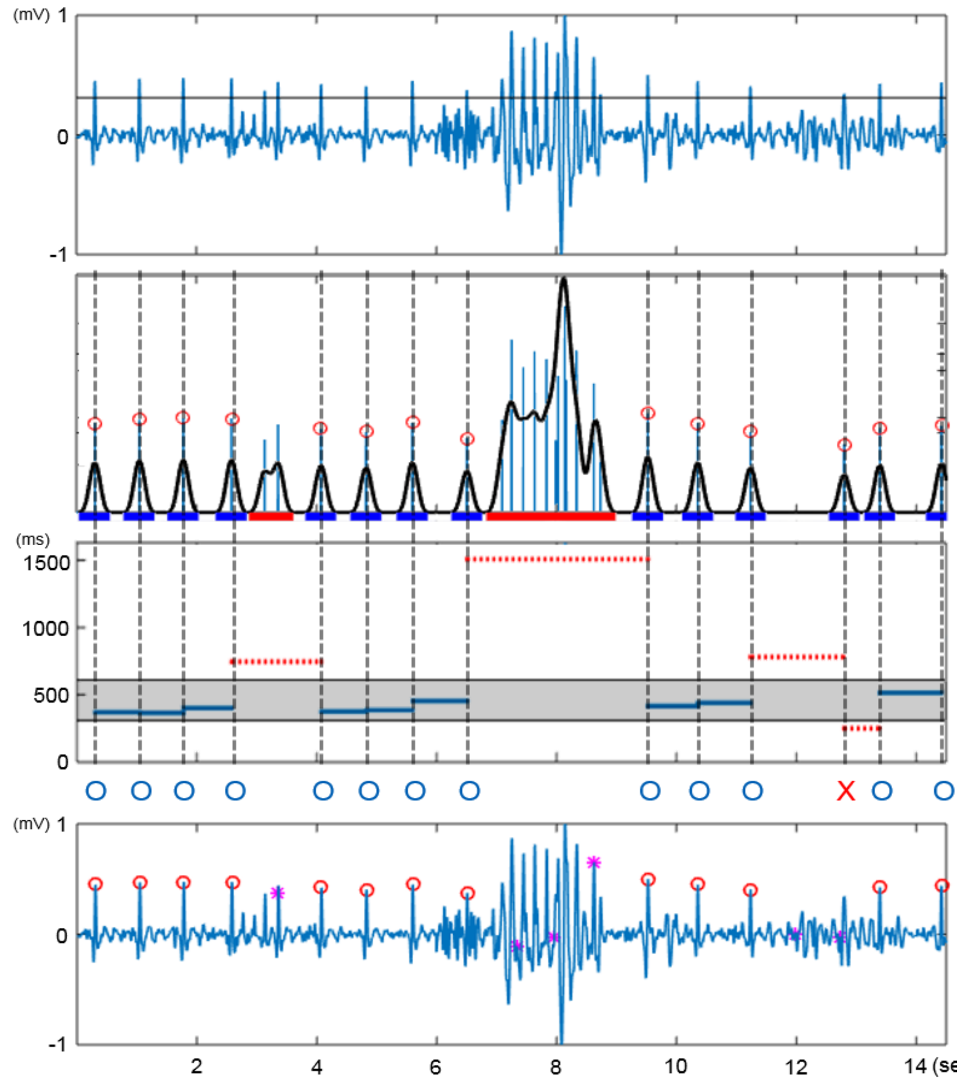
Sensor Signals Example



- Raw Signal
- Processed Signal
- Reference Signal

Heartrate Variability (HRV) Extraction

1. Filter out non-contact signals
2. Detect noisy section
3. Drop a time window hard to correct
4. Detect RR intervals
5. Correct QRS peaks
6. Interpolate missed QRS peaks



Other Physiological Sensors

Electrodermal Activity (EDA)

- Electrodermal activity refers to electrical changes measured at the surface of the skin.

- When people experience emotional arousal, increased cognitive workload or physical exertion, the brain sends signals to the skin to increase the level of sweating.

- The person may not feel any sweat, but the electrical conductance increases in a measurably significant way as the pores begin to fill below the surface.

- EDA can be used to examine implicit emotional responses that may occur without conscious awareness or are beyond cognitive intent.

Main Components of EDA

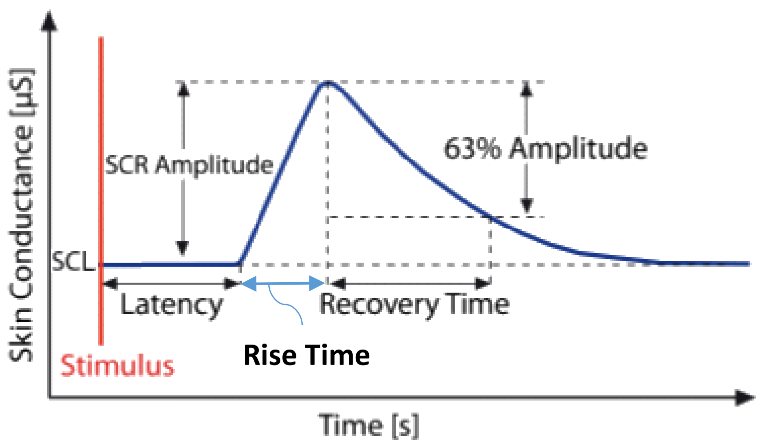
- Skin Conductance Level (SCL)
  - Slow declinations and claiming over time (changes over the course of minutes)
  - Reflects general chances in autonomic arousal

- Skin Conductance Response (SCR)
  - Phasic component
  - Faster changing elements of the signal (changes over the course of seconds)
  - Corresponds to sudden events (e.g., startled)

SCR Features

- Several useful SCR features can be extracted for classification.

- **Latency**, which is the amount of time between the stimulus and the rise of the wave.
- **Rise time**, how long it takes for the skin conductance to shoot up to it's peak.
- **Amplitude** is the height of the SCR.
- **Recovery time** is the amount of time it takes for the wave to fall back to a certain level of it's amplitude.

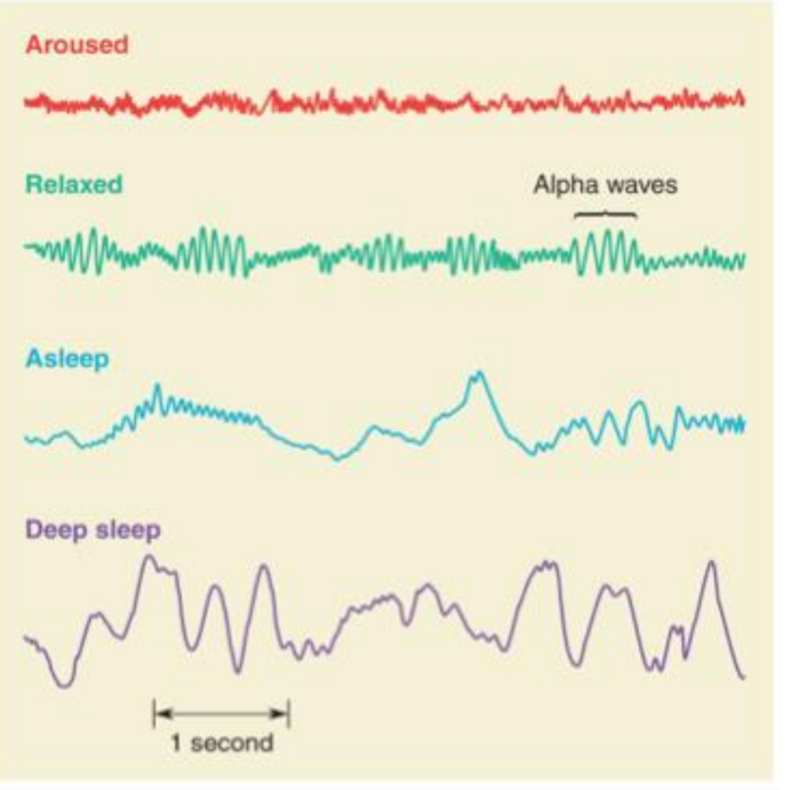


ElectroEncephaloGraphy (EEG)

- EEG signals are recordings of brain signals.
- Traditionally captured by a huge array of electrodes on the scalp (head).
- Recent EEG headbands with fewer electrodes to capture a subset of EEG signal.

Electroencephalography (EEG)

- Many useful EEG-driven applications are emerging.
- They classify various states (e.g, aroused, relaxed, asleep, etc.) of a person using various time-domain and frequency-domain features.



EEG signals when an individual is aroused, relaxed, asleep and in deep sleep state.

ElectroMyoGraphy (EMG)

- Captures the electrical signal produced by skeletal muscles.
- Useful applications of this measure.
  - An armband can detect various gestures from your fingers.
  - It can enable gesture-based interaction with computers and video games, or perhaps light bulbs.

Summary

- There are a wide range of physiological signals that can be measured using wearable sensors.
  - PPG, ECG, EDA, EEG, EMG, etc.
- Physiological sensors are becoming commonplace, and our ability to continuously measure physiological signals has significantly grown.
- This is opening up huge opportunities to enable useful pervasive healthcare applications.

Sleep Sensing

Importance of Sleep

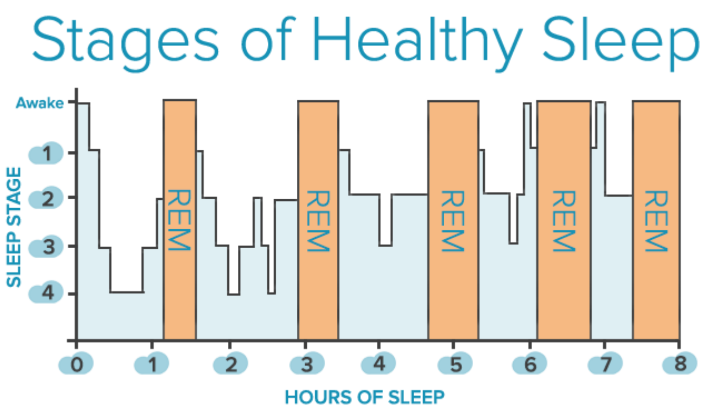
- Sleep is increasingly recognized as important to public health.
- Sleep insufficiency causes vehicle crashes, industrial disasters, and medical and other occupational errors.
- Persons experiencing sleep insufficiency are also more likely to suffer from chronic diseases such as hypertension, diabetes, depression, and obesity, as well as from cancer, increased mortality, and reduced quality of life and productivity.

Polysomnography

- An intensive high-fidelity approach to quantify sleep.
- It typically requires more than 20 wires to be hooked up to the test subject to measure brain activity, eye movement, leg movement, breathing rate and heart rate.
- Done in a controlled lab.
  - Not the same sleep condition
    - Lots of wires, unfamiliar environments
  - Highly cumbersome to measure

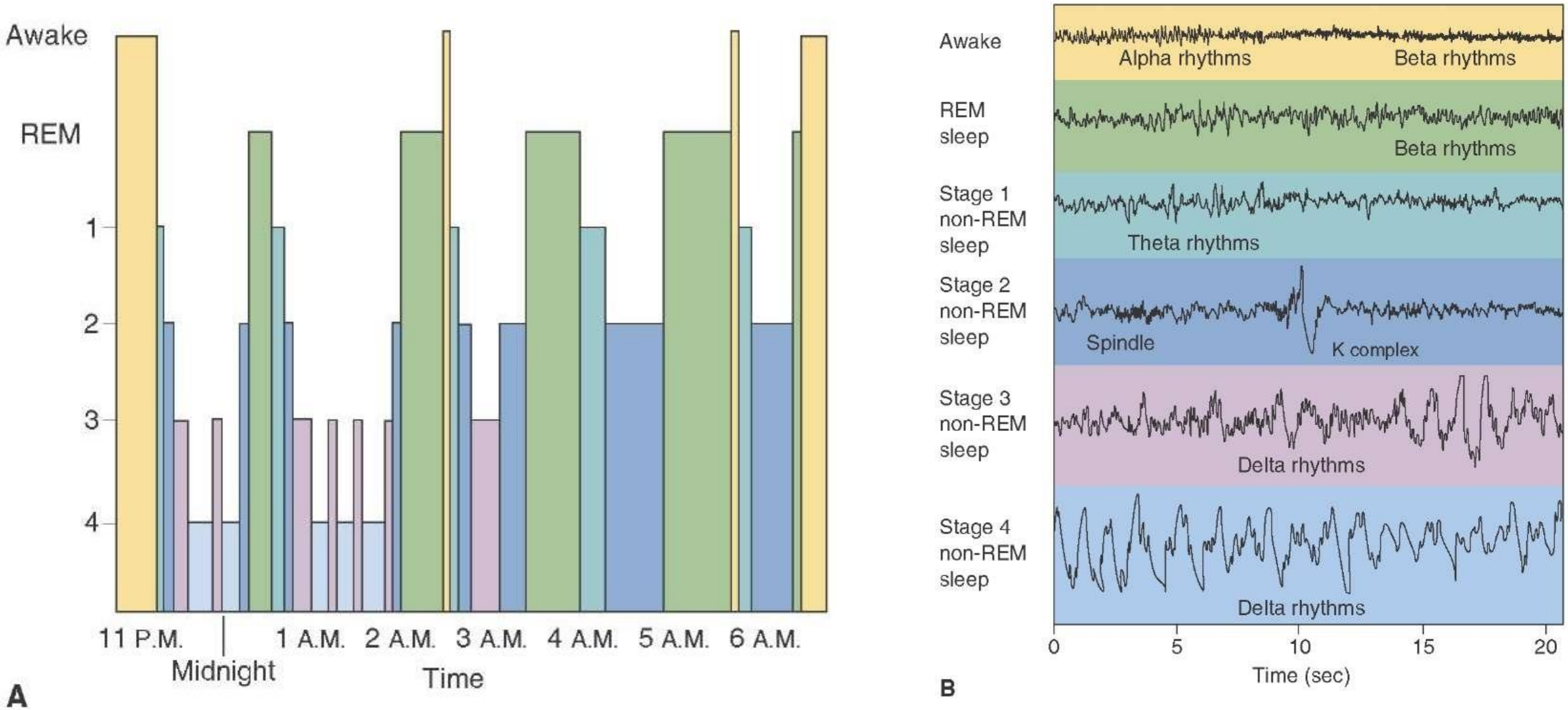
Sleep Stages

- Four sleep stages as an individual goes from light to deep sleep.
- These sleep stages are interspersed with REM sleep, where the brain is alert and one has vivid dreams.
- The role of all the sleep stages is not entirely clear, but it is considered that they aid physical and mental recovery, and memory consolidation.
- REM sleep is considered to aid in creative thinking and making new connections between neurons.



EEG and Sleep Stages

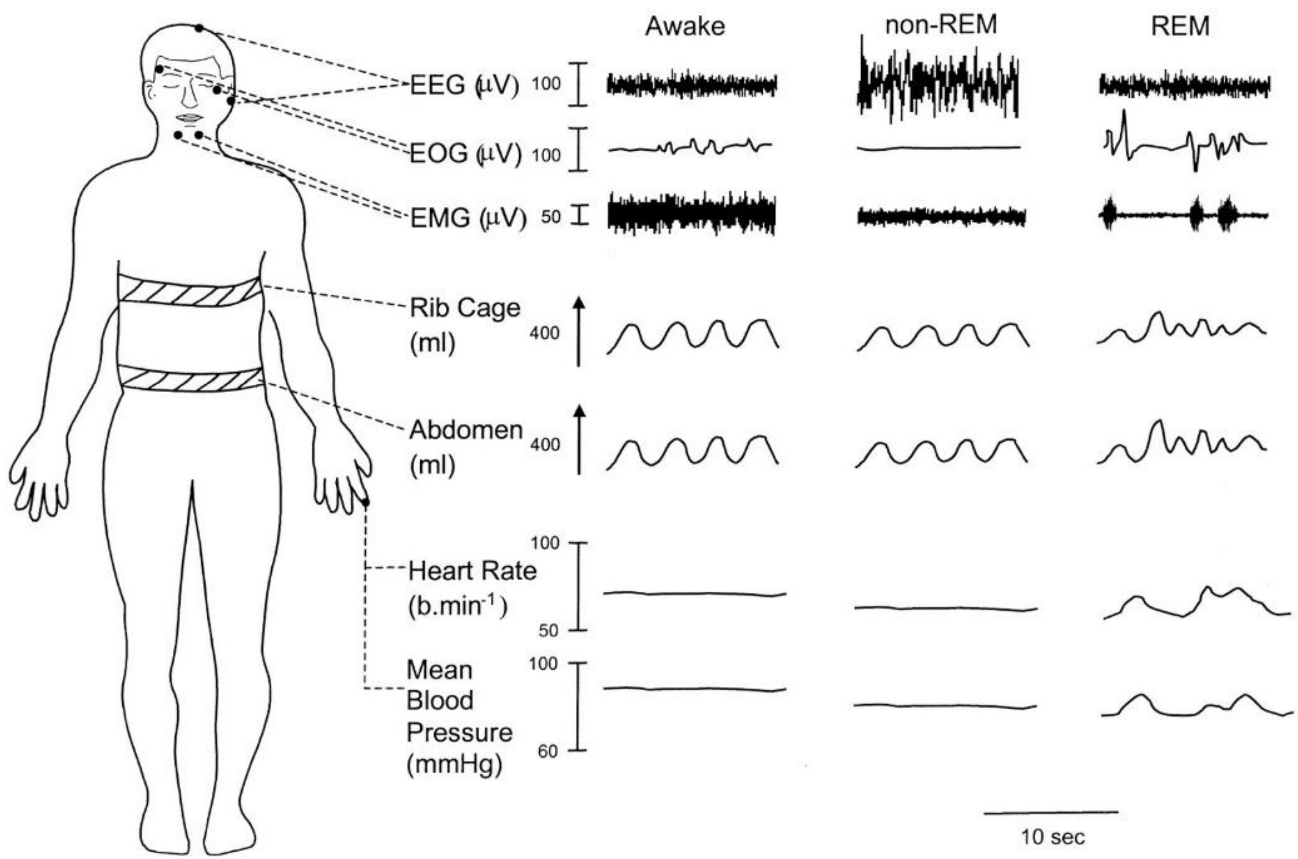
- The most common way of measuring sleep.



Example EEG signals for different sleep stages of a person

Other Sensing Modalities?

- Sensor modalities used in polysomnography

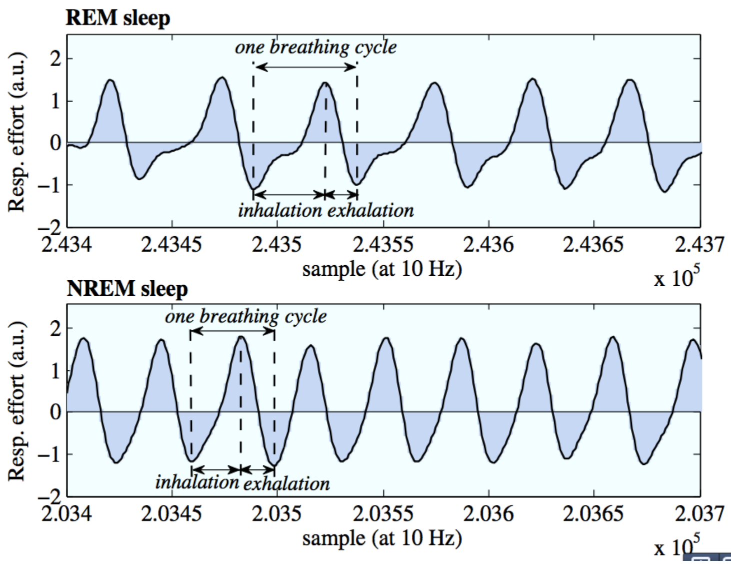


Respiration-based Sleep Sensing

- Intuition: Your breathing become slower and more controlled when you sleep. Many datasets on sleeping suggest this.

- REM sleep: More irregularity, longer inhalations

- NREM sleep : uniform respiration



Activity-based Sleep Sensing

- Can we measure sleep parameters using our trusty accelerometer?
  - Not very obvious to measure sleep quality using accelerometers.

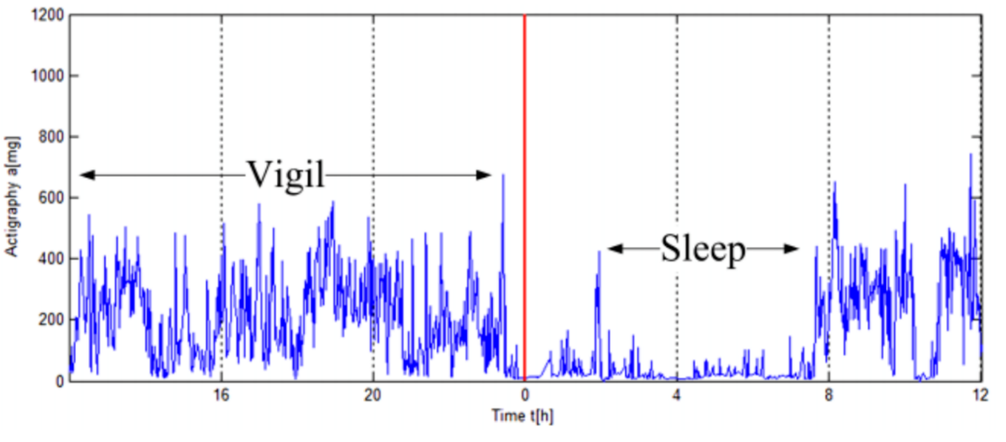
- Consumer sleep tracking devices:
  - Using smartphone-embedded accelerometers.
  - Using wrist-worn accelerometers (fitbit, Microsoft band, jawbone up, etc).
  - Custom-designed measurement pad beneath the mattress.

- These apps usually combine light levels, environmental noises (affecting sleep) to measure sleep quality.

Classifying Asleep vs. Awake

- People tend to move more when awake then when asleep

- Possible processing steps:
  - Segment data into short time windows (30-60 seconds)
  - Extract the peak acceleration, average acceleration, number of movements, etc.
  - Feed these features to a classifier to decide awake vs. asleep.



overall accelerometer activity (energy) during a vigilant phase vs. while sleeping.

Handling Confounding States

- Not moving does not always mean sleeping.
- A few filtering mechanisms.
  - Use accelerometers on a wristband.
  - There usually are small hand movements when a person is not sleeping (even though the body does not move)
- It is not an easy problem to cover all the corner cases.

Classifying Sleep Stages

- It is difficult to reliably classify sleep stages using just an accelerometer, but people have tried!
- Intuition: some jerky motions when you are about to slip into a deep sleep mode. The idea is to sense this pattern to detect your current sleep stage.
- This is a difficult problem that research or commercial systems haven't solved yet. (Many claim to identify sleep stage, but results tend to be quite unreliable).

EDA-Based Sleep Sensing

- EDA provides a measure of sympathetic nervous system (SNS) activity, a main branch of the autonomic nervous system.

- Recent wrist-worn devices (e.g., Microsoft Band, Empatica) come equipped with Galvanic Skin Response sensors which measures EDA activity, which can be used for sleep sensing.

EDA-Based Sleep Sensing

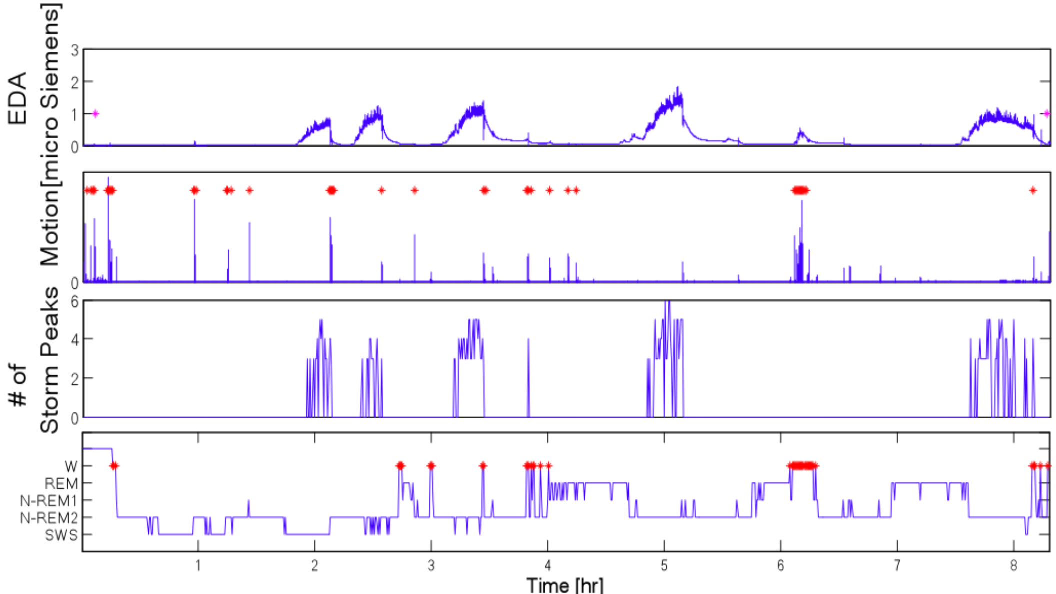
- Studies on EDA have shown that EDA is more likely to appear elevated with high frequency “storm” patterns during deep sleep

- An EDA “storm” region refers to a region of EDA with a burst of high frequency peaks.

- For instance, a storm can be defined as a minimum of five galvanic skin responses (GSRs)/min for at least ten consecutive minutes of sleep, but different studies use slightly different thresholds.

EDA-Based Sleep Sensing

- EDA storms can distinguish wake and sleep, and also REM sleep and NREM sleep.
- Features: the number of peaks in storms, durations of storms, peak frequency, amplitude and onset time of the first storm.
- While promising, this is an area with lacking evidences.



RF/Ultrasound-Based Sensing

- There have also been studies that have attempted to use passive methods to sense sleep.
- Use Doppler effect to sense chest movements and thereby detect the respiration and heart-rate patterns, from which information can be gleaned about sleep.
- The chest makes two movements of interest
  - Tiny movements from ballistic movements of the chest every time the heart pumps
  - Larger movements corresponding to respiration cycles.
- This certainly early work and needs more validation in real-world settings.

Summary

- Measuring quality and sleep cycles has long been an important research topic.

- It is a widely-researched area to provide unobtrusive and accurate sleep monitoring solutions.

- Many works are still in an early stage, requiring more evaluations and improvements.