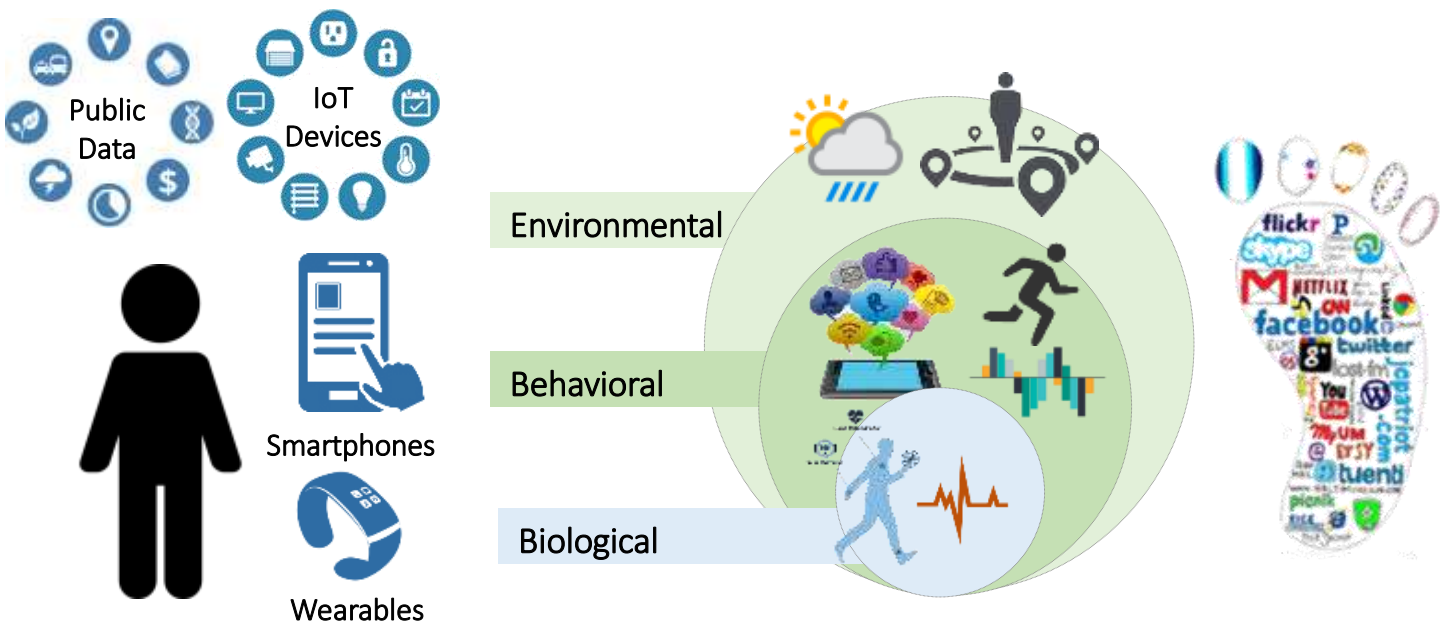
# Sensor Data Collection

Youngtae Noh

# Mobile & Wearable Sensing

Digital phenotype - Personal digital footprints of biological, behavioral, and environmental data, captured either consciously or unconsciously by smart devices and wearables (Nature Biotechnology, 2015)




***Intelligent Positive Computing with Mobile, Wearable, and IoT Devices**: Literature Review and Research Directions, Uichin Lee Kyungsik Han, Hyunsung Cho, Kyong-Mee Chung, Hwajung Hong, Sung-Ju Lee, Youngtae Noh, Sooyoung Park, John M. Carroll, Ad Hoc Networks Journal (Elsevier), 2019*

# Sensor Data Collection – Overview

- Ground truth labeling
  - Elicitation : recording sensors data for a given stimulus (=ground truth)
  - Natural setting: asking a user to self-label (in-situ: ESM, or review/recall)
  - Observation : 3rd person labeling (in-situ or video reviewing)
- Smartphone sensors
  - Android programming basics
  - Android sensors
    - Motion sensors (accel, compass, gyro), light, pressure, temperature, activity, GPS
    - Digital behavior sensing (app usage, key typing)
- Wearable sensors
  - Sensors
    - Empatica E4 (EDA/PPG/Temp), Samsung Watch 3 (PPG/SpO2/ECG)
    - Polar H10 (ECG) Polar OH1 (PPG)
    - OpenBCI, NeuroSky, Emotiv (EEG)
    - Glass: jins-meme (EOG)
  - Sensing
    - EDA (Electro-Dermal Activity)
    - ECG (Electro-Cardio-Gram)
    - PPG (Photo-Plethysmo-Gram) / $SpO_2$
    - EEG (Electro-Encephalo-Graphy)
    - EOG (Electro-Oculo-Gram)

# Ground Truth Labeling

# Ground Truth Labeling

- Activity
  - Elicitation : asking users to follow a predetermined scenarios
  - Natural : in-situ labeling – asking people to label a current activity whenever there's a change of activity
  - Observation : real-time following (observer) or video recording with post-hoc labeling
- Emotion
  - Elicitation : watch "emotional" videos or doing some tasks that can "elicit" specific emotional states
  - Natural : experience sampling – randomly asking a user to label a current emotion state
  - Observation : 3rd person judges a user's emotion (e.g., watch facial videos and label emotion)

# Activity Recognition (Bao & Instille 2004)

- Wearing 5 biaxial accelerometers
- Semi-Naturalistic, User-Driven Data Collection
  - Detailed tasks involving a series of activities are listed in a worksheet
  - Example: “use the web to find out what the world’s largest city in terms of population is”
  - No researcher supervision while subjects performed those tasks


TI ADXL210E
biaxial accelerometer
(time synced among
devices)

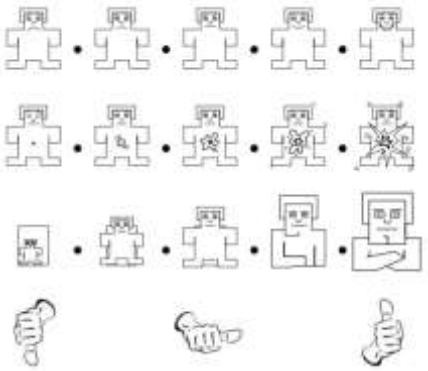
Activity Recognition from User-Annotated Acceleration Data, Ling Bao, Stephen S. Intille, Pervasive 2004

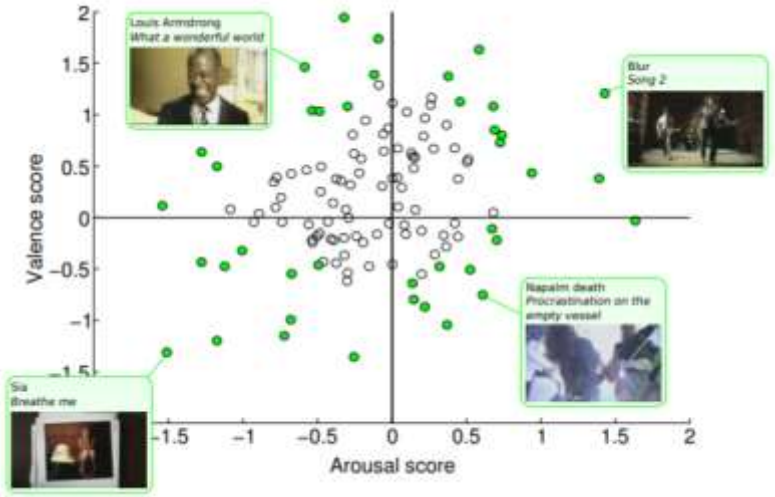
# Emotion - DEAP

- Elicitation – Stimuli w/ specific emotion (EEG)
  - Watch one-min video and then rate current emotion

Video
(40 videos)

Rating






https://www.eecs.qmul.ac.uk/mmv/datasets/deap/

# Experience Sampling Method (ESM)

- Experience Sampling Method (ESM)
  - Also known as EMA (Ecological momentary assessment)
- Parameters to consider
  - Notification schedule
    - Random: e.g., max 10 times a day
    - Interval: e.g., every hour
    - Event: e.g., incoming calls, app use
  - Notification expiry (lifetime) (e.g., must be answered in 3 minutes)
  - Inter-notification time (e.g., min time in between notifications)
  - Inquiry limits (max # of ESM notifications per day)
  - Study duration (how long?)



More Info: The Experience Sampling Method on Mobile Devices, CUSR 2017

# Sensor Data Collection

- Smartphone sensors
  - Android programming basics
  - Android sensors
    - Motion sensors (accel, compass, gyro), light, pressure, temperature, activity, GPS
    - Digital behavior sensing (app usage, key typing)
- Wearable sensors
  - Sensors
    - Empatica E4 (EDA/PPG/Temp), Samsung Watch 3 (PPG/SpO2/ECG)
    - Polar H10 (ECG) Polar OH1 (PPG)
    - OpenBCI, NeuroSky, Emotiv (EEG)
    - Glass: jins-meme  (EOG)
  - Sensing
    - EDA (Electro-Dermal Activity)
    - ECG (Electro-Cardio-Gram)
    - PPG (Photo-Plethysmo-Gram) / $SpO_2$
    - EEG (Electro-Encephalo-Graphy)
    - EOG (Electro-Oculo-Gram)

# Smartphone Sensors (Android)

# Galaxy S20 Sensors


| |
|---|
| **Accelerometer** |
| **Magnetometer (Compass)** |
| **Gyroscope** |
| **Ambient Light** |
| **Proximity** |
| **Camera** |
| **Voice** |
| **Pressure (Barometer)** |
| **NFC** |
| **Heart Rate** |
| **Fingerprint scanner** |

# SensorManager

- SensorManager & LocationManager
  - Obtain pointer to android service using

    **`Context.getSystemService(name)`**
  - For name, use constant defined by Context class
    - SENSOR_SERVICE for SensorManager
    - LOCATION_SERVICE for LocationManager
- Check for available sensors using

  **`List<Sensor> getSensorList(int type)`**
  - Type constants provided in Sensor class documentation

# SensorManager

- Use getDefaultSensor(int type) to get a pointer to the default sensor for a particular type

```
Sensor accel = sensorManager.getDefaultSensor(
  Sensor.TYPE_ACCELEROMETER);
```

- Register for updates of sensor values using `registerListener(SensorEventListener, Sensor, rate)`
  - Rate is an int, using one of the following 4 constants
    - SENSOR_DELAY_NORMAL (delay: 200ms)
    - SENSOR_DELAY_UI (delay: 60ms)
    - SENSOR_DELAY_GAME (delay: 20ms)
    - SENSOR_DELAY_FASTEST (delay: 0ms)
  - Or, the desired delay between events in microseconds (as of Android 2.3)
  - Use the lowest rate necessary to reduce power usage
- Registration will power up sensor:

```
mSensorService.enableSensor(l, name, handle, delay);
```

# SensorManager

- Unregister for sensor events using

```
unregisterListener(SensorEventListener, Sensor)
        or
unregisterListener(SensorEventListener)
```

- Undregistering will power down sensors:

```
mSensorService.enableSensor(1, name, handle,
  SENSOR_DISABLE)
```

- Perform **register in OnResume()** and **unregister in OnPause()** to prevent using resources while your activity is not visible

# SensorEventListener

- Must implement two methods

```
onAccuracyChanged(Sensor sensor, int accuracy)
onSensorChanged(SensorEvent event)
```

- SensorEvent
  - int accuracy
  - Sensor sensor
  - long timestamp
    - Time in nanoseconds at which event happened
  - float[] values
    - Length and content of values depends on sensor type

# API – Setup

```
public class MainActivity extends Activity implements SensorEventListener {
..
    private SensorManager sm = null;
    …
    public void onCreate(Bundle savedInstanceState) {
    ..
        sm = (SensorManager) getSystemService(SENSOR_SERVICE);
    }
    protected void onResume() {
        ..
        List<Sensor> typedSensors =
        sm.getSensorList(Sensor.TYPE_ACCELEROMETER);
        // also: TYPE_ALL
        if (typedSensors == null || typedSensors.size() <= 0) … error…
        sm.registerListener(this, typedSensors.get(0),
            SensorManager.SENSOR_DELAY_GAME);
        // Rates: SENSOR_DELAY_FASTEST, SENSOR_DELAY_GAME,
        // SENSOR_DELAY_NORMAL, SENSOR_DELAY_UI
    }
}
```

# API – Processing Events

```
public class MainActivity extends Activity implements SensorEventListener {
    ..
    private float currentValue;
    private long lastUpdate;
    …
    public void onSensorChanged(SensorEvent event) {
        currentValue = event.values[0];
        lastUpdate = event.timestamp;
    }
    ..
}
```

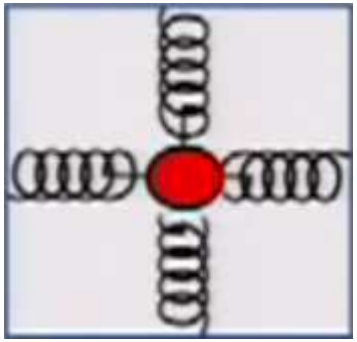
It is recommended not to update UI directly!

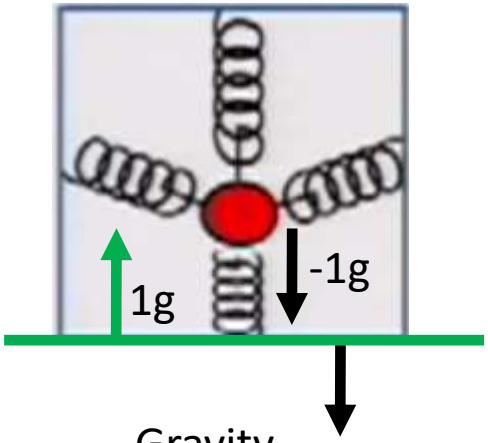
# API – Cleanup

```
public class MainActivity extends Activity implements SensorEventListener {
…
    protected void onPause() {
        …
        sm.unregisterListener(this);
    }
…
    protected void onStop() {
        …
        sm.unregisterListener(this);
    }
    ..
}
```

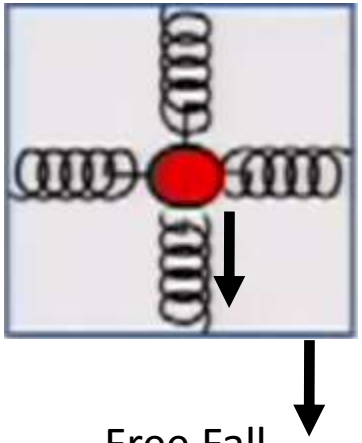
# Accelerometer

Mass on spring

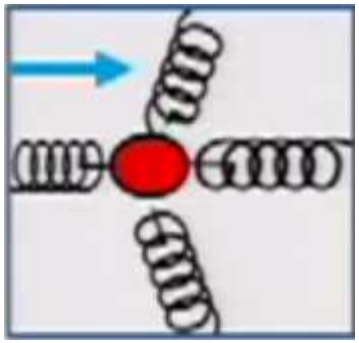




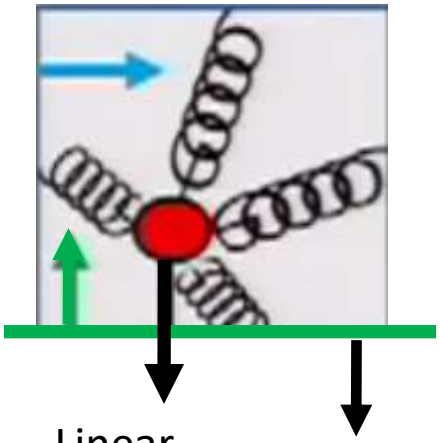

Gravity



Free Fall



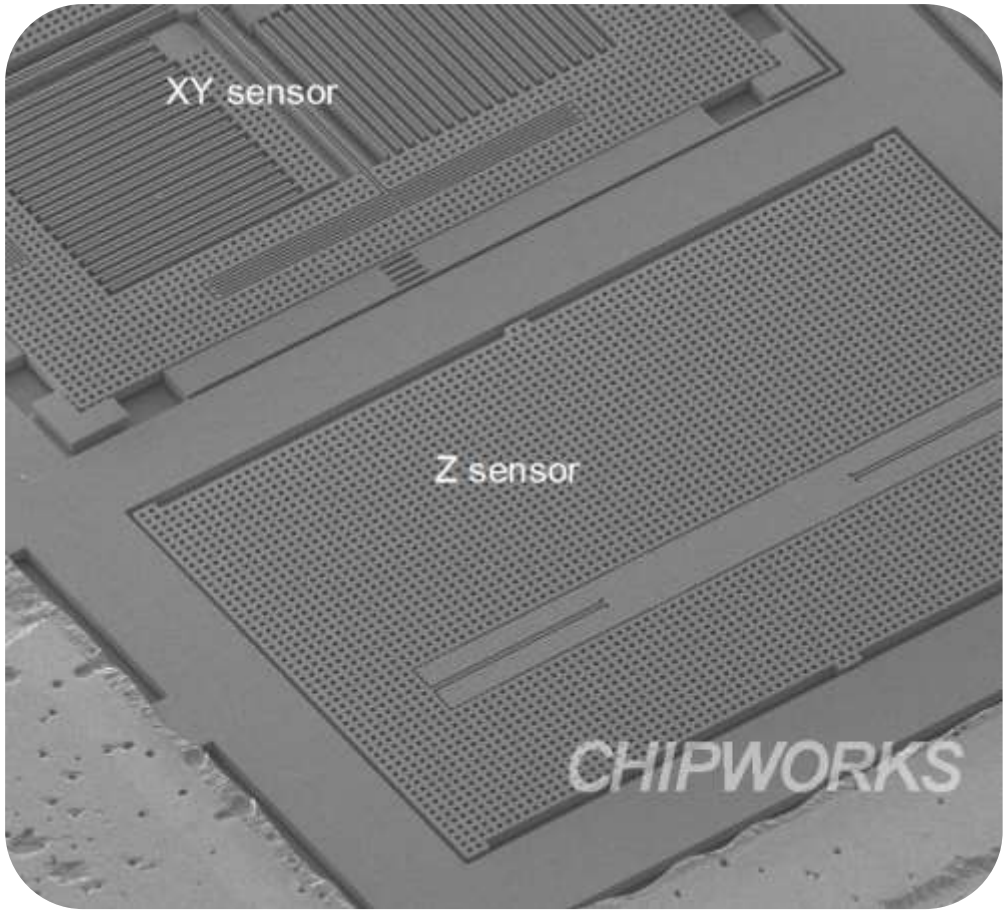
Linear Acceleration



Linear Acceleration plus gravity

$1g = 9.8 m/s^2$

# Accelerometer




STMicroelectronics STM331DLH three-axis accelerometer (iPhone4)

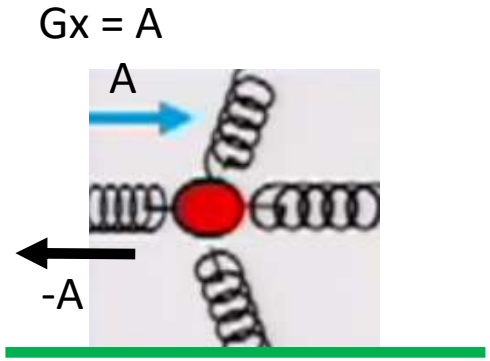
# Accelerometer

- Sensor.TYPE_ACCELEROMETER
- Values[3] = $m/s^2$, measure the acceleration applied to the phone minus the force of gravity
  - Values[0]: minus gx on the x-axis
  - Values[1]: minus gy on the y-axis
  - Values[2]: minus gz on the z-axis

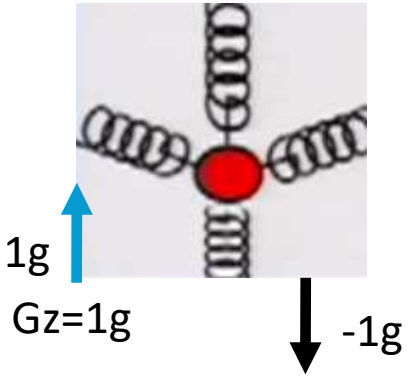
- SensorManager's constants
  - GRAVITY_EARTH (=STANDARD_GRAVITY)
  - GRAVITY_MOON ….

# Accelerometer

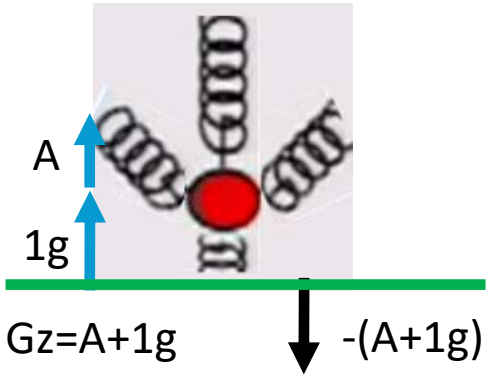
- When the device lies flat on a table and is pushed on its left side toward the right, the X acceleration value is positive




- When the device lies flat on a table, the acceleration value is +9.81
  - acceleration of the device (0 m/s^2) minus force of gravity (-9.81 m/s^2)

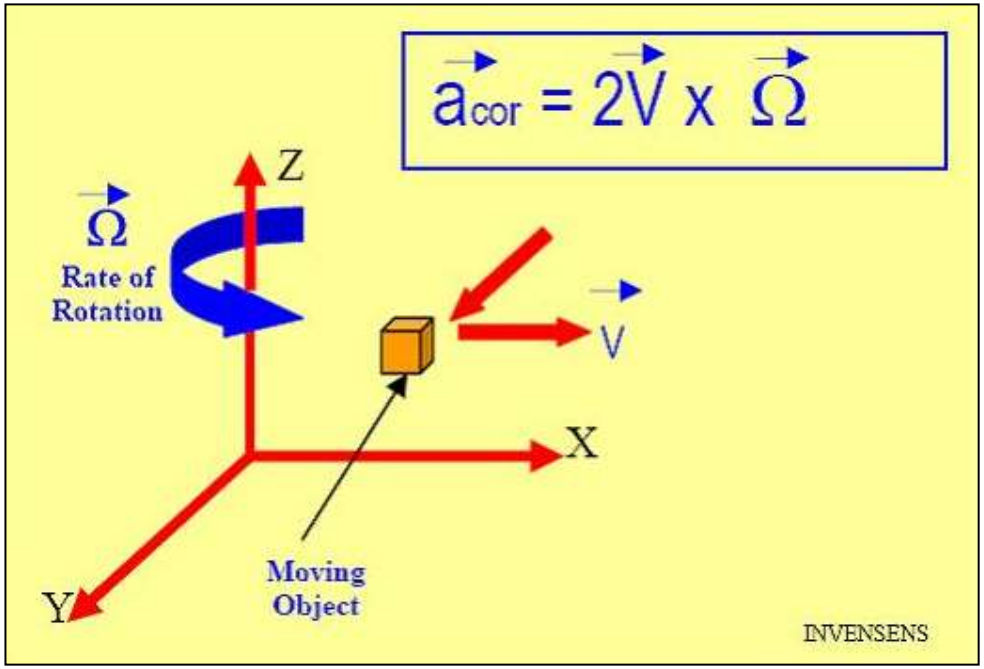



- When the device lies flat on a table and is pushed toward the sky with an acceleration of A m/s^2, the acceleration value is equal to A+9.81
  - acceleration of the device (+A m/s^2) minus force of gravity (-9.81 m/s^2)



# Gyroscope

- Angular velocity sensor
  - Coriolis effect – “inertial force” that acts upon a freely moving object as observed from a rotating frame of reference



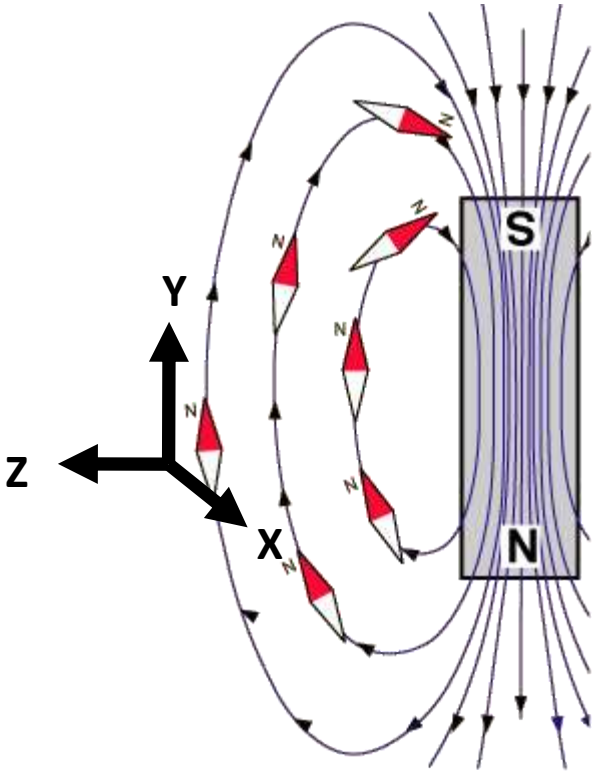

https://www.youtube.com/watch?v=ti4HEgd4Fgo

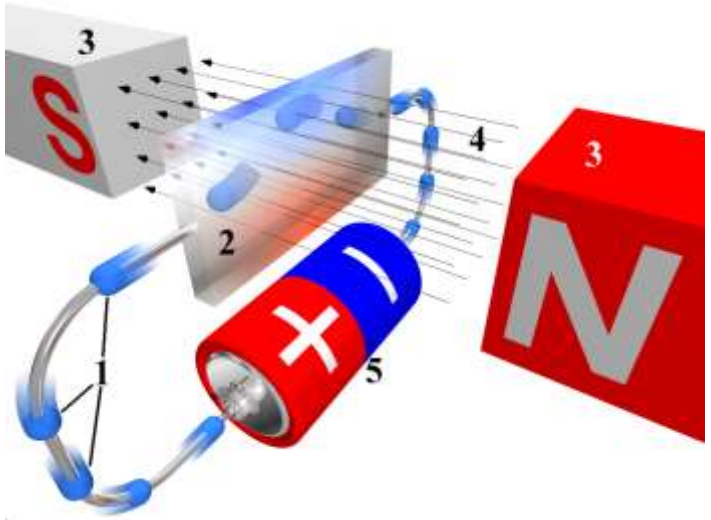
# Gyroscope

- Sensor.TYPE_GRYOSCOPE
- values[3] = all values are in radians/second and measure the rate of rotation around the device's local X, Y and Z axis
  - values[0]: Angular speed around the x-axis
  - values[1]: Angular speed around the y-axis
  - values[2]: Angular speed around the z-axis

# Compass

- Magnetic field sensor (magnetometer)




Hall Effect

# Compass

- Sensor.TYPE_MAGNETIC_FIELD
- values[3] = in micro-Tesla (uT), magnetic field in the X, Y and Z axis
- SensorManager’s constants
  - MAGNETIC_FIELD_EARTH_MAX: 60.0
  - MAGNETIC_FIELD_EARTH_MIN: 30.0


https://www.youtube.com/watch?v=eqZgxR6eRjo
https://howtomechatronics.com/how-it-works/electrical-engineering/mems-accelerometer-gyrocope-magnetometer-arduino

# Light sensor

- Sensor.TYPE_LIGHT
- values[0] = ambient light level in SI lux unit
- SensorManager's constants
  - LIGHT_NO_MOON: 0.001
  - LIGHT_FULLMOON: 0.25
  - LIGHT_CLOUDY: 100
  - LIGHT_SUNRISE: 400.0
  - LIGHT_OVERCAST: 10000.0 (cloudy)
  - LIGHT_SHADE: 20000.0
  - LIGHT_SUNLIGHT: 110000.0
  - LIGHT_SUNLIGHT_MAX: 120000.0

# Pressure sensor (barometer)

- Sensor.TYPE_PRESSURE
- values[0] = pressure
- SensorManager's constant
  - PRESSURE_STANDARD_ATMOSPHERE = 1013.25 milibar (mbar) or hPa
- Primary used for determining altitude in places where the device cannot get a GPS fix (e.g., indoors)
  - SensorManager.getAltitude(float p0, float p)
    - p0 = pressure at sea level (standard atmosphere value)
    - p = atmospheric pressure (measured value)
  - E.g., getAltitude(SensorManager.PRESSURE_STANDARD_ATMOSPHERE, pressure_at_point1);
  - Cf) 10m change ⇔ 1.2 mbar

# Proximity sensor

- Sensor.TYPE_PROXIMITY
- values[0]: Proximity sensor distance measured in centimeters (typically around 5 cm, but it is sometimes binary, i.e., near-far)
  - Should check this using: getMaximumRange()
- Proximity sensor:
  - weak infrared LED (light-emitting diode) next to a photodetector
  - When something comes close enough to the sensor, photodetector detects the reflected infrared light

# Temperature Sensor

- Sensor. TYPE_AMBIENT_TEMPERATURE
  - TYPE_TEMPERATURE was deprecated in Android 4.0 (API Level 14).
- values[0]: ambient (room) temperature in degree Celsius.

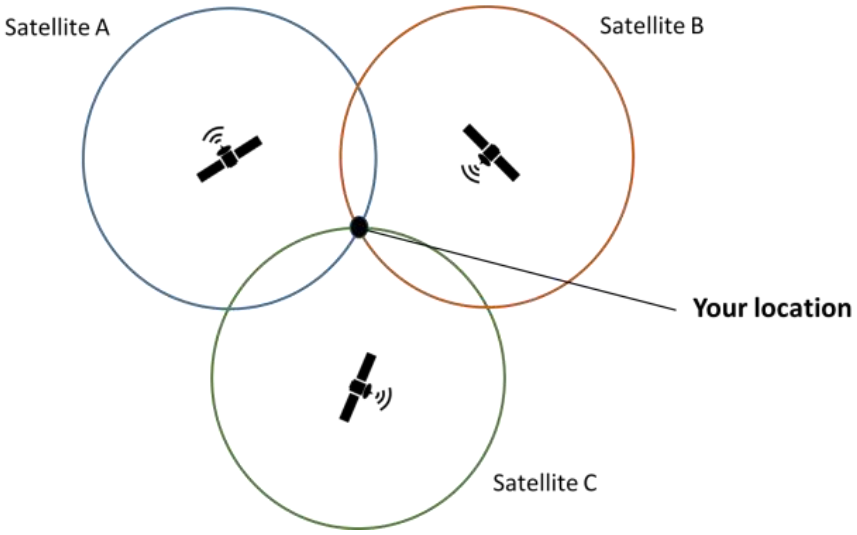
# Activity Sensor

- ActivityType
  - IN_VEHICLE – The device is in a vehicle, such as a car
  - ON_BICYCLE – The device is on a bicycle
  - ON_FOOT – The device is on a user who is walking or running
  - RUNNING – The device is on a user who is running
  - STILL – The device is still (not moving)
  - TILTING – The device angle relative to gravity changed significantly
  - WALKING – The device is on a user who is walking
  - UNKNOWN – Unable to detect the current activity
- Confidence value
  - Range: 0 – 100, indicating how likely it is that the user is performing this activity.

https://developers.google.com/android/reference/com/google/android/gms/location/ActivityRecognitionClient

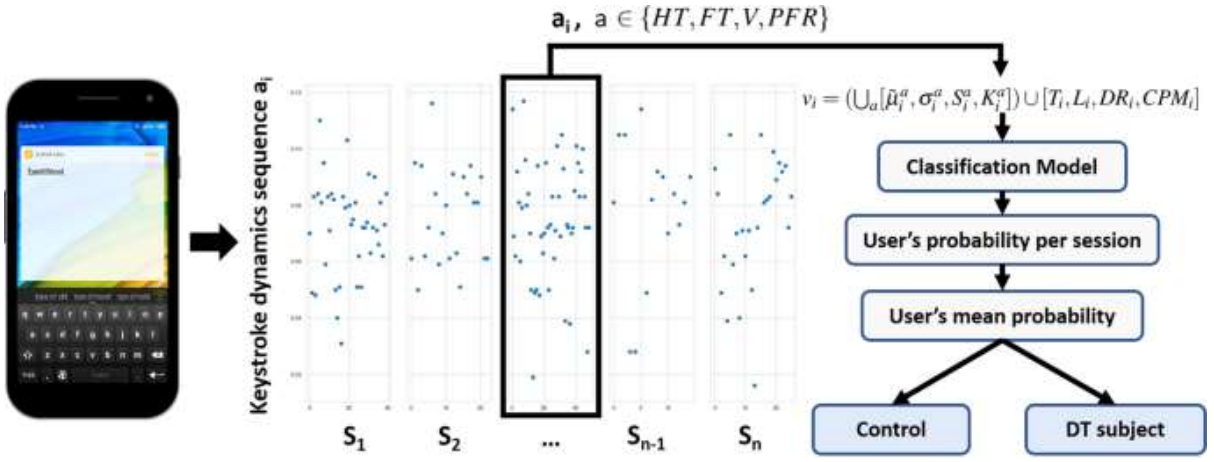
# GPS

- Algorithm
  - Satellites transmit their local time in the signal
  - Receivers compute their difference in time-of-arrival
  - Receivers estimate their position (longitude, latitude, elevation), using (at least) 4 satellites
- GPS receiver requires clock synchronization (w/ satellites)
- Accuracy is about 5 meters
- Differential GPS provides extra accuracy approx. 2 meters



# Digital Behaviors

- App Usage: app categories, app switching
- Notification handling behaviors
- Keyboard typing: flight time/distance




Touchscreen typing pattern analysis for remote detection of the depressive tendency, Scientific Reports 2019 https://www.nature.com/articles/s41598-019-50002-9

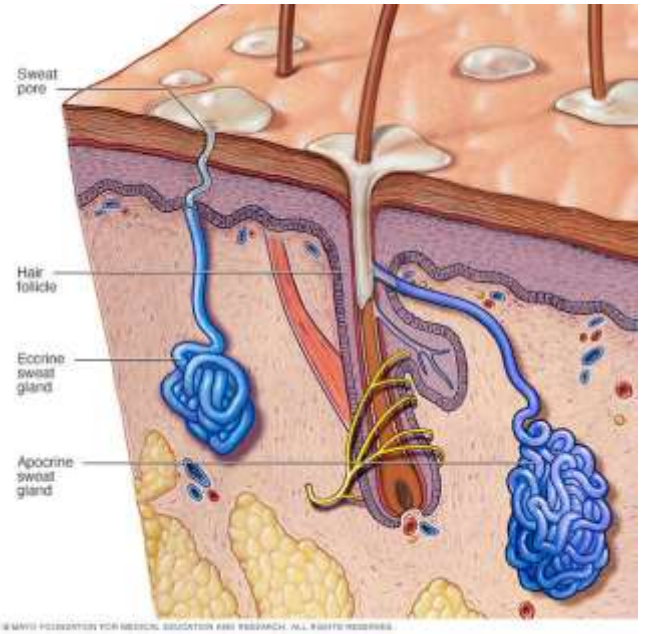
# Wearable Sensors

# Wearable Sensors

- Sensors
  - Empatica E4 (EDA/PPG/Temp), Samsung Watch 3 (PPG/$SpO_2$/ECG)
  - Polar H10 (ECG) Polar OH1 (PPG)
  - OpenBCI, NeuroSky, Emotiv (EEG)
  - Glass: jins-meme  (EOG)
- Sensing
  - EDA (Electro-Dermal Activity)
  - ECG (Electro-Cardio-Gram)
  - PPG (Photo-Plethysmo-Gram) / $SpO_2$
  - EEG (Electro-Encephalo-Graphy)
  - EOG (Electro-Oculo-Gram)

# Electrodermal activity (EDA)

- Féré (1888) discovered that the skin momentarily becomes a better conductor of electricity when external stimuli are presented
- Why? Eccrine sweat glands
  - Highest density of eccrine sweat glands on hand/feet
  - If the sympathetic branch of the autonomic nervous system is highly **aroused**, then **sweat** gland activity also increases, which in turn increases skin conductance
  - Skin conductance can be used as an indicator of emotional arousal
  - Responsive to psychologically significant stimuli than to thermal stimuli




Electrodermal activity (EDA)
=Galvanic Skin Response (GSR)
=Electrodermal Response (EDR)
=Psychogalvanic Reflex (PGR)
=Skin Conductance Response (SCR)

http://www.ledalab.de/download/Analysis%20of%20EDA%20data%20using%20Ledalab.pdf

Noldus

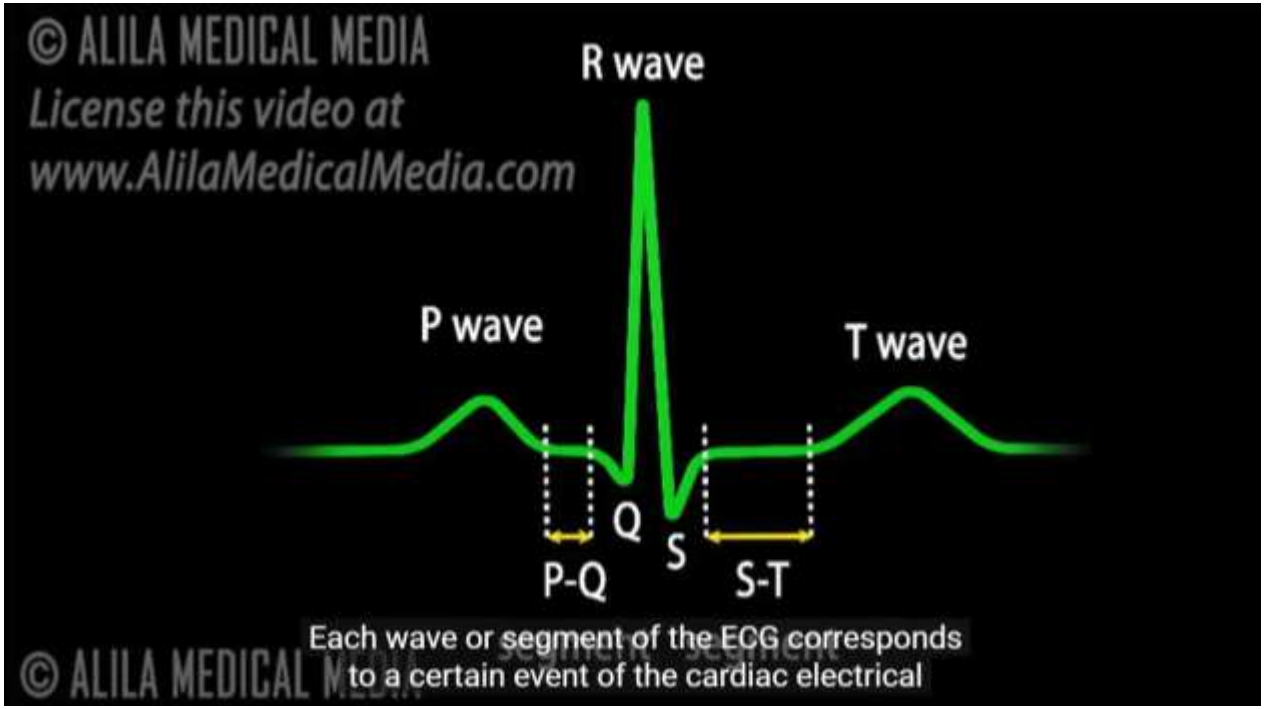
# Skin conductance

## Eccrine sweat glands

- Eccrine sweat glands have predominantly sympathetic innervation
- High correlation between sympathetic nerve activity (⇨ 'fight-flight' response) and skin conductance responses
- Skin conductance can be used as an indicator of emotional arousal

https://www.youtube.com/watch?v=-KupdgJERng

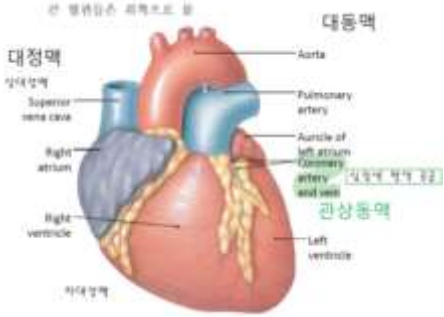
# ECG – Electro-Cardio-Gram




ECG 심전도
Depolarization 탈분극

Sinoatrial node (SA) 동방결절
Atrioventricular node (AV) 방실결절
B, bundle of His 방실속
Purkinje fiber 푸르키니에 섬유
Superior Vena Cava 대정맥

Atrium (심방)
Ventricle (심실)
Myocardium (심근)
Systole (수축기), Diastole (이완기)

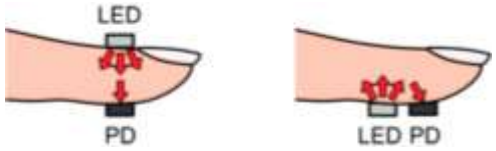

https://www.youtube.com/watch?v=RYZ4daFwMa8

ECG = EKG (Elektro-Kardio-Gramm / German)

# PPG (Photo-plethysmo-gram)

# PPG (Photo-plethysmo-gram)

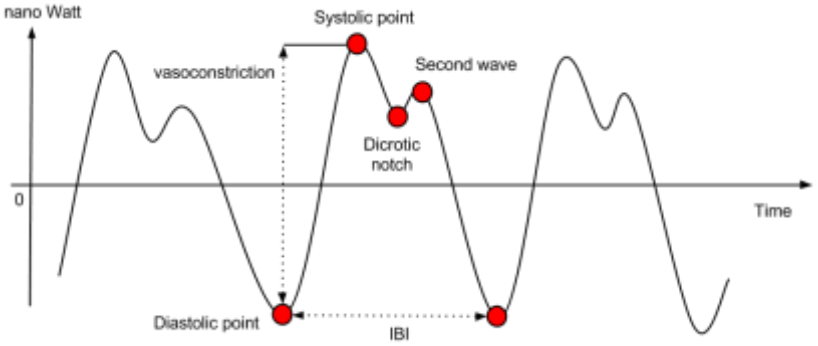
- PPG sensor output - BVP (Blood Volume Pulse)
- Multi-wavelength PPG (different depth)

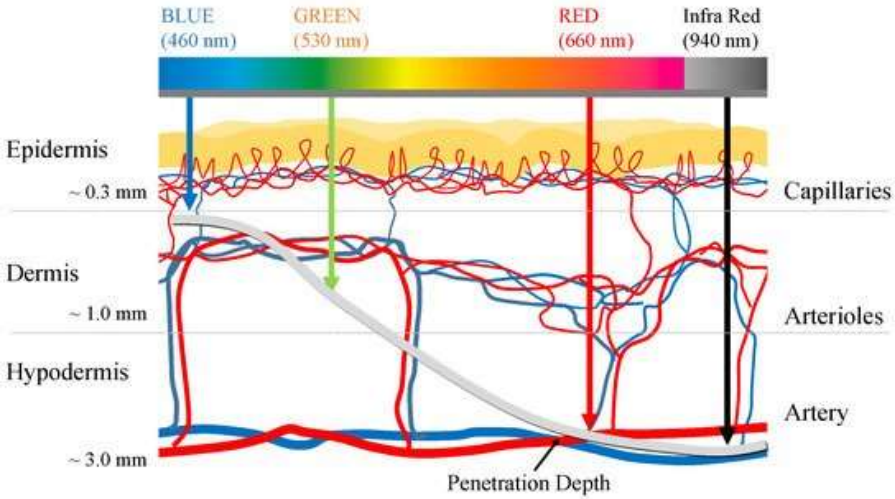






PD: Photo-detector

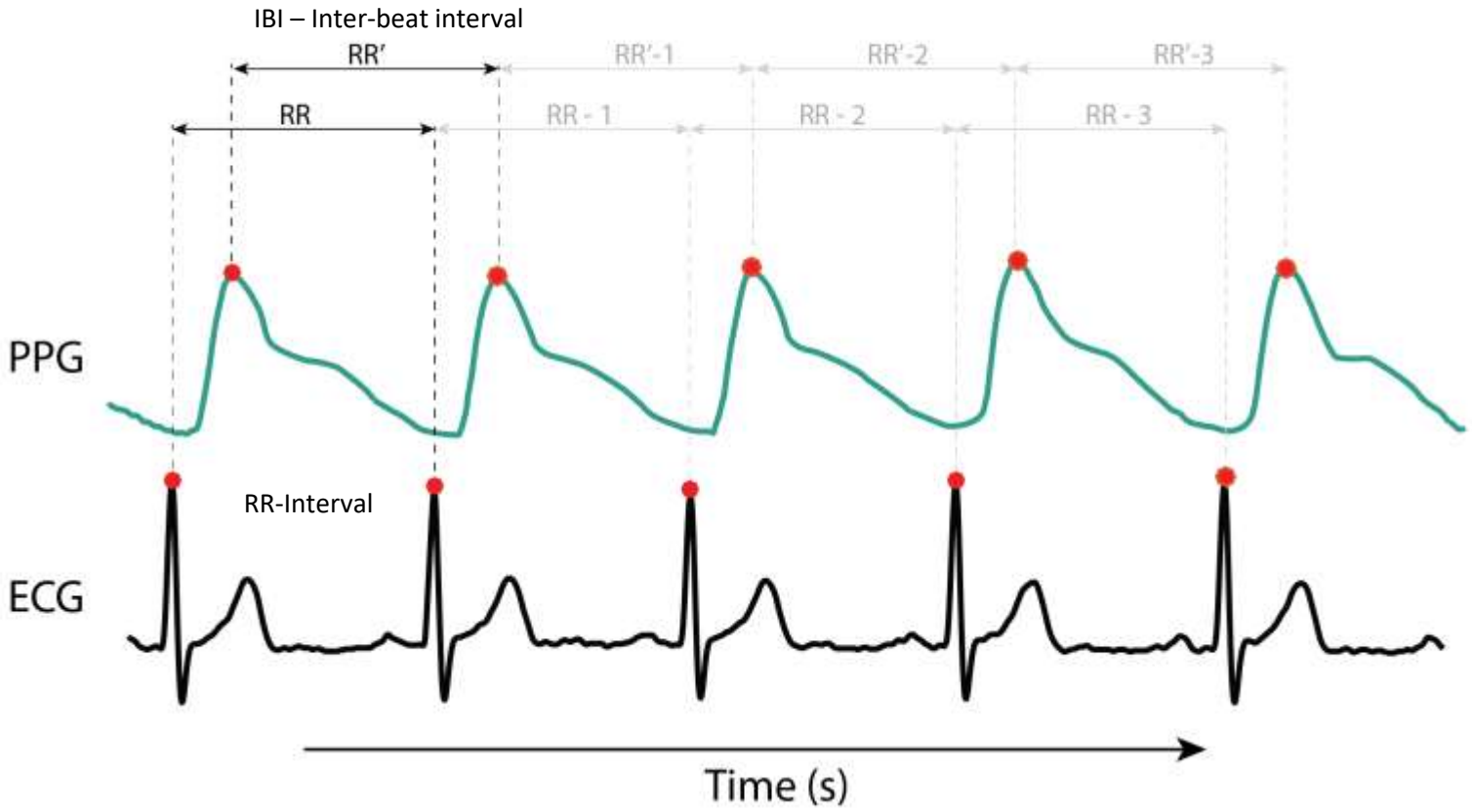



https://support.empatica.com/hc/en-us/articles/360029719792-E4-data-BVP-expected-signal

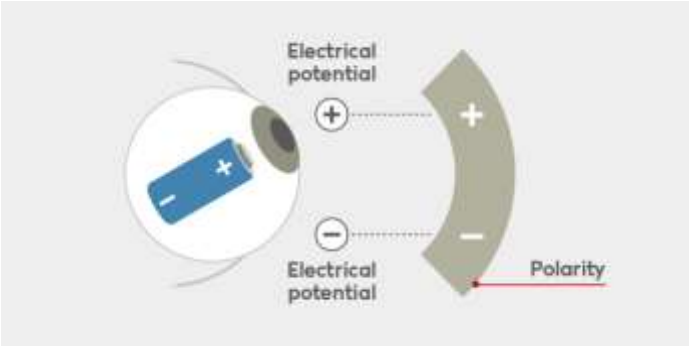
https://www.mdpi.com/1424-8220/19/24/5441/htm

# PPG vs. ECG

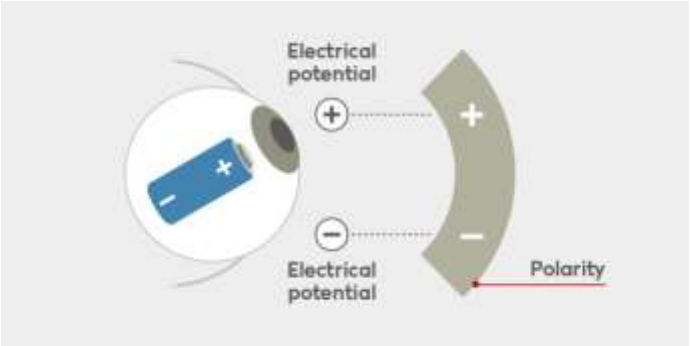


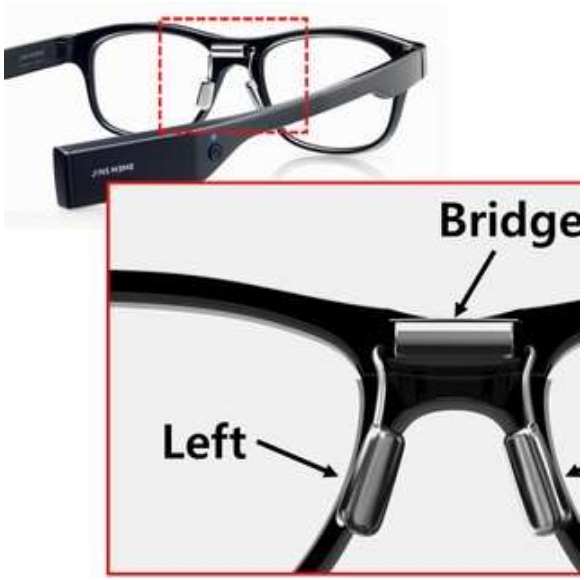

https://www.fibricheck.com/fibricheck-beat-to-beat-accuracy-compared-with-wearable-ecg-in-broad-dynamic-range

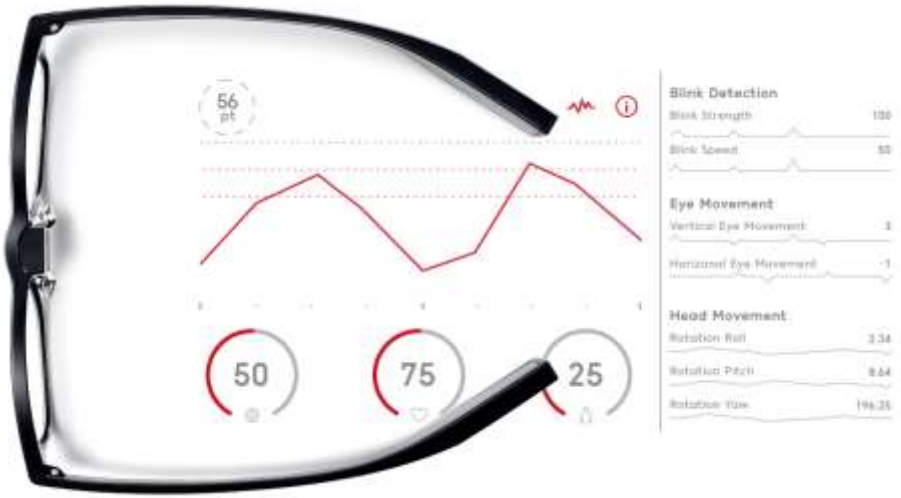
# EOG –
# Electro Oculo Gram




# EOG –
# Electro Oculo Gram




https://jins-meme.com/en

# Eye Tracking with Camera

# Polar H10 – HR Sensor



- Connectivity – Bluetooth Low Energy (BLE) & ANT+
- Coin battery (last about a week)
- Sensor Values
  - Heart rate as beats per minute.
  - RR Interval in ms and 1/1024 format.
  - Electrocardiography (ECG) data in µV.
  - Accelerometer data with sample rates of 25Hz, 50Hz, 100Hz and 200Hz, and range of 2G, 4G and 8G
- Polar SDK (released in 2019): https://github.com/polarofficial

https://www.polar.com/en/about_polar/press_room/polar_releases_polar_sdk_and_team_pro_api_allowing_developers_to_tap_into_its_proprietary_heart_rate

# Polar OH1 – HR Sensor (PPG)


https://www.hatfieldswimmingclub.org/product/polar-oh1/

- Connectivity – Bluetooth Low Energy (BLE) & ANT+
- Rechargeable battery
- Sensor Values
  - Heart rate as beats per minute
  - Photoplethysmograpy (PPG) values
  - PP interval (milliseconds) representing cardiac pulse-to-pulse interval extracted from PPG signal
  - Accelerometer data with sample rate of 50Hz and range of 8G
- Polar SDK (released in 2019): https://github.com/polarofficial

# Empatica E3/E4 Wristband

E3

E4


https://store.empatica.com/products/e4-wristband?variant=17719039950953

# Empatica E4 Wristband

## E4 sensors

**PPG Sensor**
Measures Blood Volume Pulse (BVP), from which heart rate variability can be derived

**3-axis Accelerometer**
Captures motion-based activity

**Event Mark Button**
Tags events and link them to physiological signals

**EDA Sensor (GSR Sensor)**
Measures the constantly fluctuating changes in certain electrical properties of the skin

**Infrared Thermopile**
Reads peripheral skin temperature

**Internal Real-Time Clock**
5ppm high accuracy time reference

# Samsung Watch 3



- Accelerometer, Gyro Sensor, Barometer
- Electrical Heart Sensor (ECG)
- Optical Heart Rate Sensor (HRM)
- Light Sensor, GPS


ECG/SpO2 data can be accessed through Samsung Health :
https://developer.samsung.com/health/android/data/guide/health-data-type.html

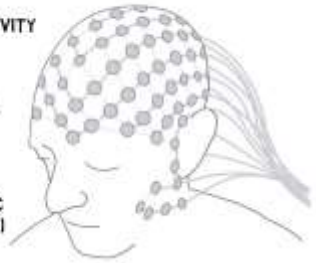
# EEG (Electro-Encephalo-Graphy)

2-MINUTE NEUROSCIENCE:

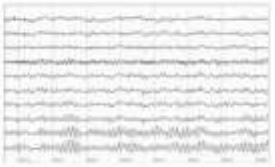
## ELECTROENCEPHALOGRAPHY (EEG)

### ELECTROENCEPHALOGRAPHY (EEG)

- USED TO MEASURE ELECTRICAL ACTIVITY OF THE BRAIN
- DETECTS ACTIVITY OF LARGE GROUPS OF NEURONS THAT ARE ACTIVE AT THE SAME TIME
- PRIMARILY MEASURES POSTSYNAPTIC POTENTIALS (NOT ACTION POTENTIALS)



### EEG

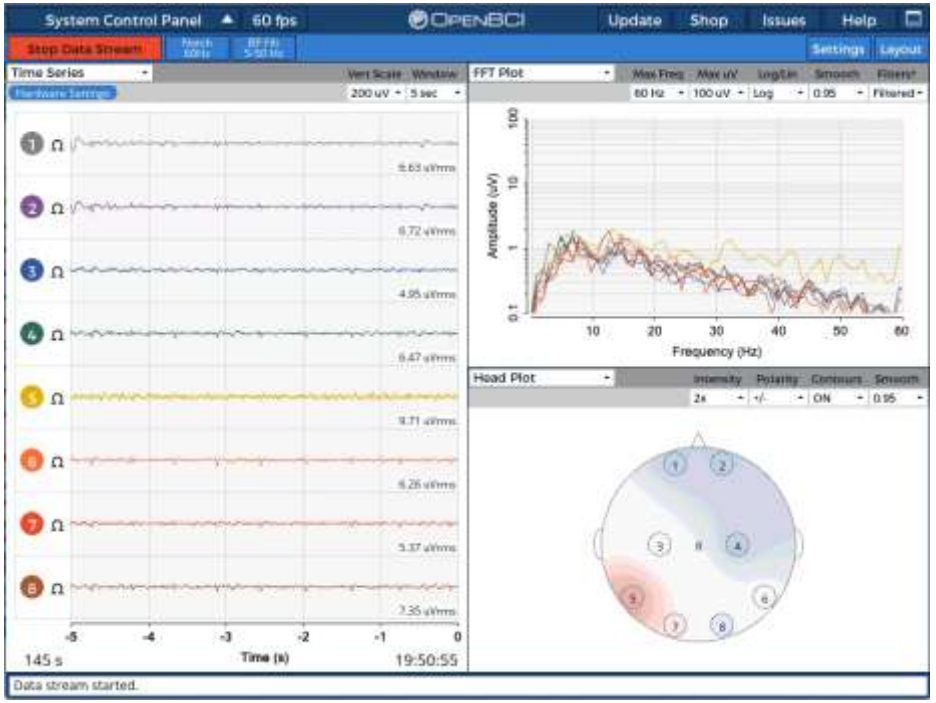


- CAN BE USED TO MEASURE BRAIN ACTIVITY THAT OCCURS DURING AN EVENT, OR TO MEASURE SPONTANEOUS BRAIN ACTIVITY
- ACTIVITY THAT OCCURS IN ASSOCIATION WITH AN EVENT IS SOMETIMES CALLED THE EVENT-RELATED POTENTIAL
- VARIETY OF CLINICAL APPLICATIONS

https://www.youtube.com/watch?v=tZcKT4l_JZk

# EEG (Electro-Encephalo-Graphy)


OpenBCI



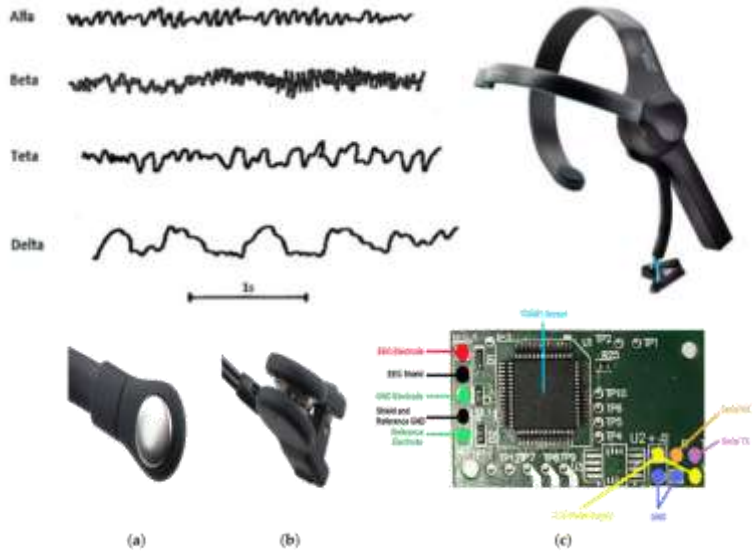

OpenBCI – Raw Data Access

# EEG

**EMOTIV Insight 5 Channel Mobile Brainwear**
https://www.emotiv.com/product/emotiv-insight-5-channel-mobile-eeg

- EEG signals: 120 Hz per channel
  - 5 channels: AF3, AF4, T7, T8, Pz
- Motion signals (ICM-20948): 64Hz, Acc/Gyro/Mag
- Lithium Polymer Battery
- Price - $299 USD
- SDK requires licensing (about $1000 per year)

https://doi.org/10.3390/brainsci10060403




**NeuroSky Mindwave** Mobile system main parts. (a) Dry Electrode. (b) Reference and Ground Electrodes. (c) EEG biosensor TGAM1 with Communication Module

**NeuroSky MindWave Mobile 1, 2**
https://github.com/pwittchen/neurosky-android-sdk

- Single channel: 12 bit Raw-Brainwaves (3 - 100Hz) with Sampling rate at 512Hz, EEG power spectrums (Alpha, Beta, etc.)
- NeuroSky proprietary eSense meter such as Attention, Meditation, and other future meters
- Accuracy comparison: https://www.mdpi.com/1424-8220/19/12/2808/htm
- Price - $99 USD
- SDK freely available for development

# Sensor Data Collection – Review

- Ground truth labeling
  - Elicitation : recording sensors data for a given stimulus (=ground truth)
  - Natural setting: asking a user to self-label (in-situ: ESM, or review/recall)
  - Observation : 3rd person labeling (in-situ or video reviewing)
- Smartphone sensors
  - Android programming basics
  - Android sensors
    - Motion sensors (accel, compass, gyro), light, pressure, temperature, activity, GPS
    - Digital behavior sensing (app usage, key typing)
- Wearable sensors
  - Sensors
    - Empatica E4 (EDA/PPG/Temp), Samsung Watch 3 (PPG/SpO2/ECG)
    - Polar H10 (ECG) Polar OH1 (PPG)
    - OpenBCI, NeuroSky, Emotiv (EEG)
    - Glass: jins-meme (EOG)
  - Sensing
    - EDA (Electro-Dermal Activity)
    - ECG (Electro-Cardio-Gram)
    - PPG (Photo-Plethysmo-Gram) / $SpO_2$
    - EEG (Electro-Encephalo-Graphy)
    - EOG (Electro-Oculo-Gram)