Mobile Health

Photoplethysmography (PPG) and Mobile Health

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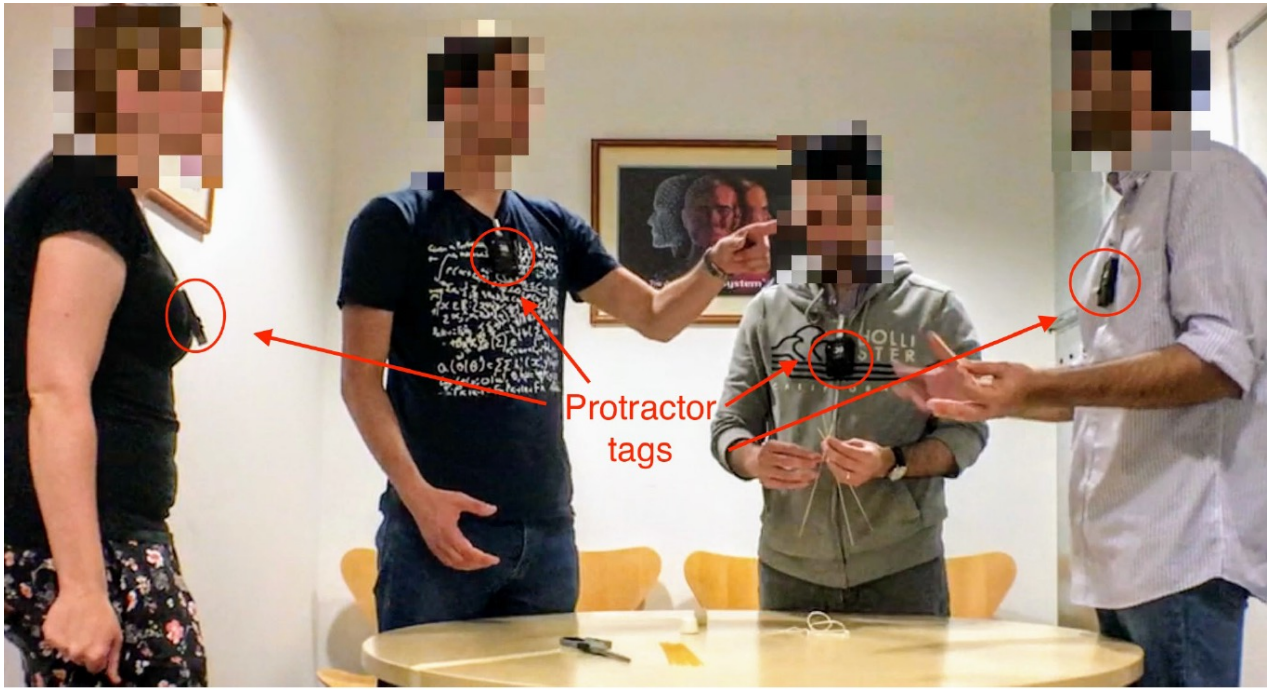
Light Sensing

- Wearable devices are being equipped with light sensors
  - These sensors are used to mainly detect heart rate features
- Other applications of light sensors exist
  - Detection of face to face contacts

Interaction Monitoring:
Angle of Interaction with light sensing



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Measuring Interaction Proxemics with Wearable Light Tags. A. Montanari, Z.Tian, E. Francu, B. Lucas, B. Jones, X. Zhou, C. Mascolo. In Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT). Volume 2, Issue 1. Presented at Ubicomp 2018. Singapore. October 2018.

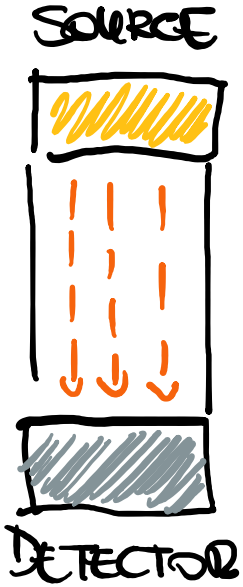
Essence of Photoplethysmography (PPG)

- It consists of a light emitting diode (LED) and a photodetector (PD).

- PPG signal measures the reflected (back-scattered) of the transmitted light through the region of tissues under examination. By looking at the intensity of the light at the PD, it is possible to detect variations in blood volume which occur with each heartbeat.

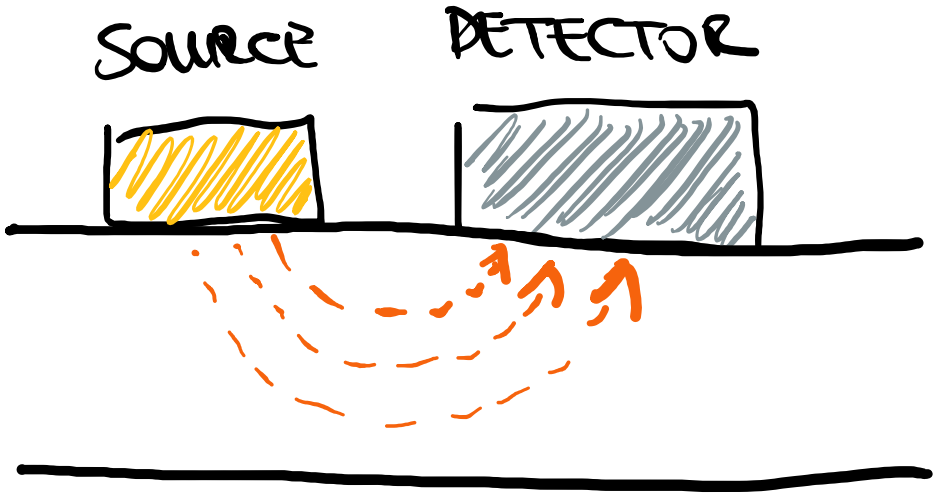
Classical PPG

- It measures the light through the tissue by placing the sensors on the opposite side.



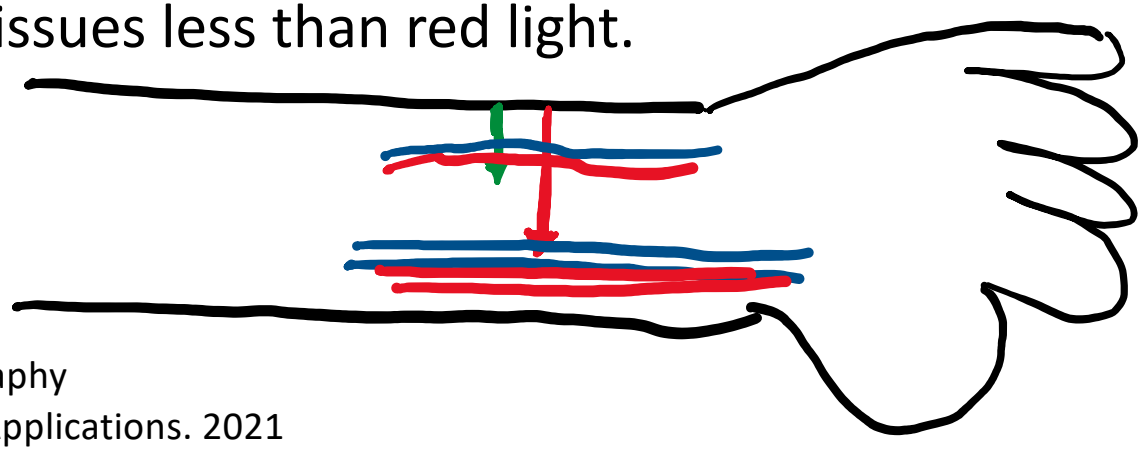
Reflective PPG

- Measures the reflective light: sensors are on the same side of the tissue



Light type

- The wavelength of the light used in PPG sensors typically ranges between 500nm (green colour) and 1100nm (infrared). Red and infrared (IR) lights are absorbed less by the water present in the human tissues compared to green light.
- Depending on the wavelength of the LED, the light is absorbed differently by the skin, achieving different depth in the tissue.
- Green light penetrates the tissues less than red light.



More details: Photoplethysmography
Technology, Signal Analysis and Applications. 2021

Wearable PPGs

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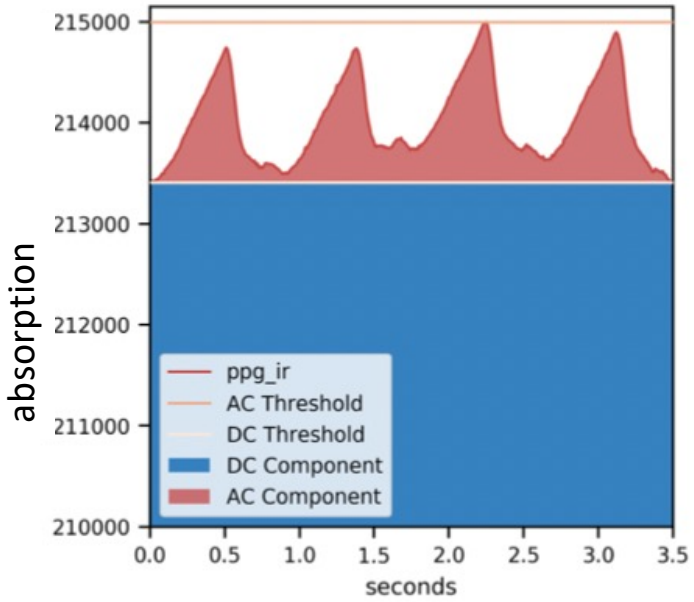
Working of Heart Sensing with PPG

- Light absorption goes up when systolic pumps blood in the body and then goes down
- Light absorbance of oxygenated hemoglobin is different from that of reduced hemoglobin.
- Absorbance have an oscillating (AC) component, due to volume change, normally from arterial blood, occurring between the emitter and the detector sensor.
- Non pulsatile component (DC) that results from light attenuated by skin, fingernails, tissue, bone, and static blood. The slow variation in the DC wave is also attributed to respiration, the sympathetic nervous system, blood pressure control, and thermoregulation.



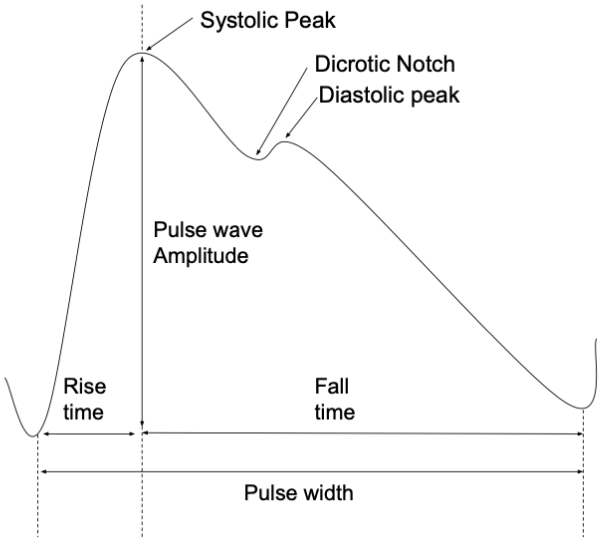
Cardiac Cycle

- A cardiac cycle consists of two stages:
- Systole: blood pumped out of the heart rushes throughout the body, including all the peripheral tissue sites.
- Diastole: the heart muscle relaxes and allows the chambers to fill with blood.

[See also audio lectures where this was introduced.]

Measuring Heart Signal from PPG

- The signal has two phases:
- First Phase: the rising edge of the pulse or **anacrotic phase** primarily relates with systole.
- Systolic peak (less light)
- Second Phase: the falling edge of the pulse or **catacrotic phase** which is associated with diastole.
- The dicrotic notch: marker of the end of aortic systole and the beginning of diastole.



PPG Signal Cleaning

- Signal cleaning examples
  - Band pass filters
    - Eg to isolate the AC component [0.4-4Hz]
  - Cutting out unacceptable segments
    - Various techniques to define this
  - Skewness (S), Kurtosis (K) & Shannon Entropy measure if the signal have noise (on time domain as well as frequency domain).
    - Skewness measures signal symmetry while Kurtosis measures the deviation from the mean of the signal data.

Measuring Heart Rate with PPG

- Provided the signal is clean…
- Find the systolic peaks: count them into a time interval and extrapolate beats per minute.

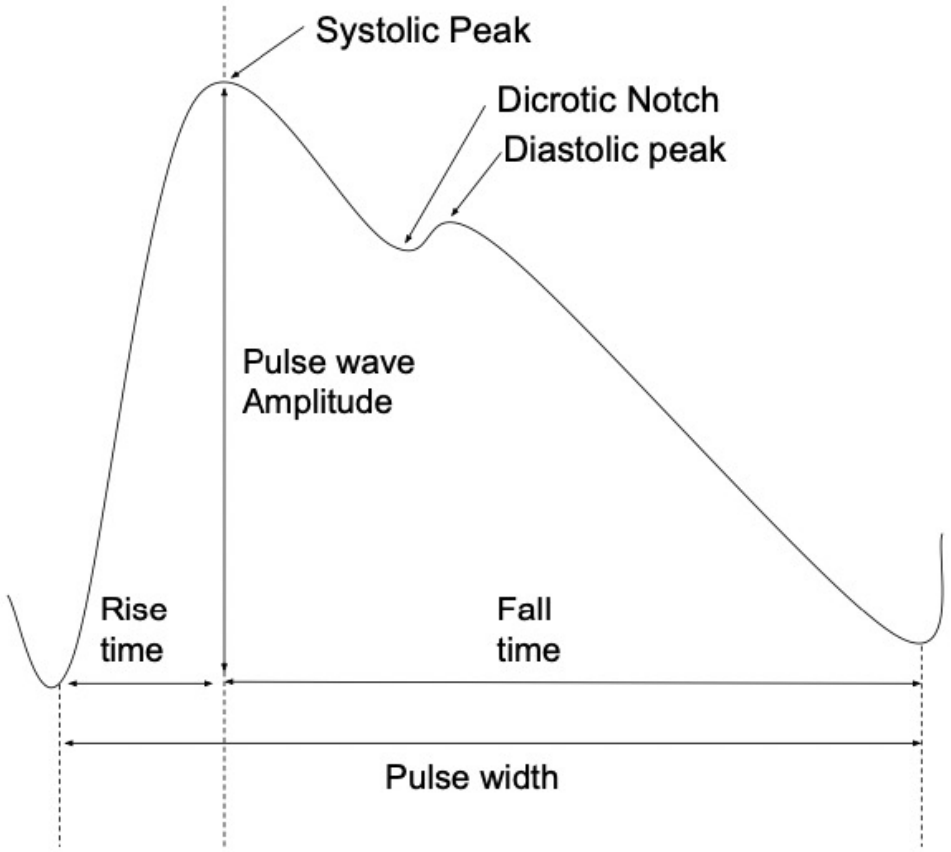
- What can influence the signal?
  - Breathing
  - Motion
  - Quality/fitting of the sensor

Interbeat-intervals (IBIs)

- the **interval between consecutive heartbeats** is used for applications such as arrhythmia identification and pulse rate variability.
- IBIs are extracted by measuring the time delay between occurrences of a particular fiducial point on consecutive pulse waves.
  - Fiduciary points could be the pulse onset, the systolic and diastolic peaks, and the dicrotic notch.
- Intervals between pulse onset seem to work well.

More details in Chapter 4 of Photoplethysmography Technology, Signal Analysis and Applications. 2021. Elsevier.

PPG: Time Domain Features



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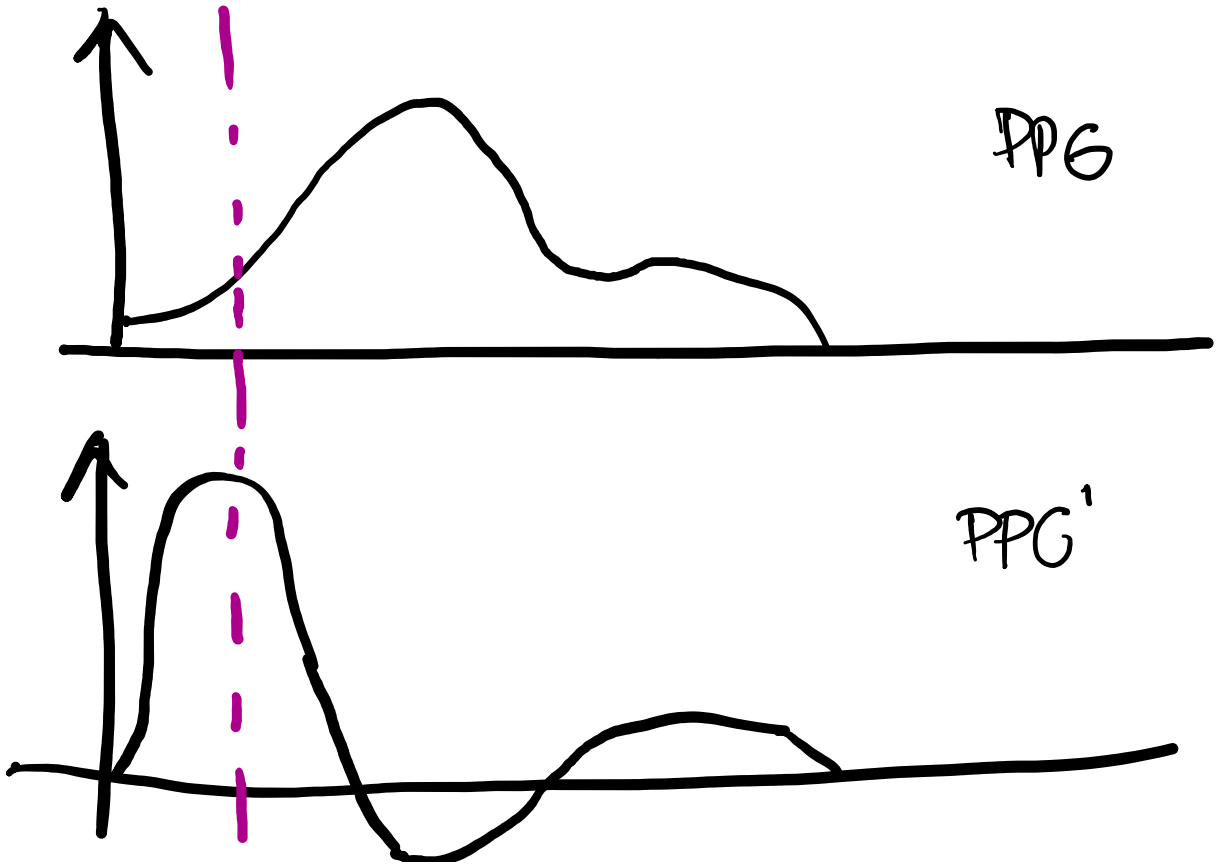
First and Second Derivative of PPG



Calculation of Pulse Onset

- On the PPG wave
  - Find the point corresponding to the max of the first derivative.
  - Draw tangent
  - Draw tangent on min point
  - Point 5 is the pulse onset

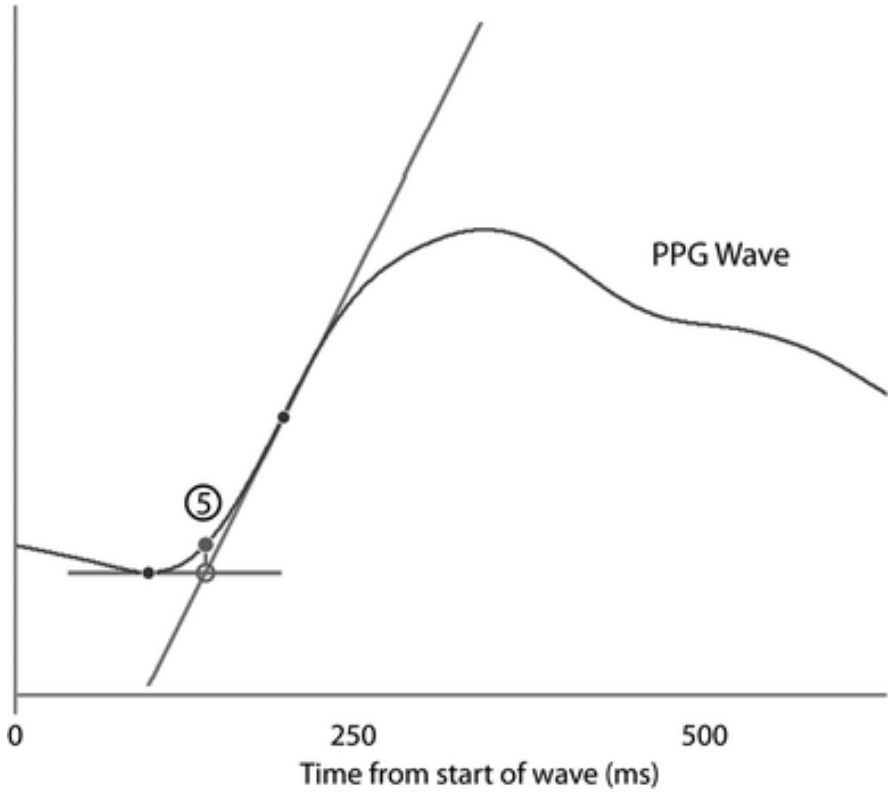


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Figure from Hemon MC, Phillips JP. Comparison of foot finding methods for deriving instantaneous pulse rates from photoplethysmographic signals. J Clin Monit Comput. 2016 Apr;30(2):157-68.

Arterial Fibrillation (AF) Detection

- Common from of arrythmia causing high risk of stroke.
- Features such as IBIs and pulse amplitude are used to classify samples AF or non-AF (time series of features).
- Calculate summary of statistics of these time series of features (mean, SD, entropy).
- Classification can be applied

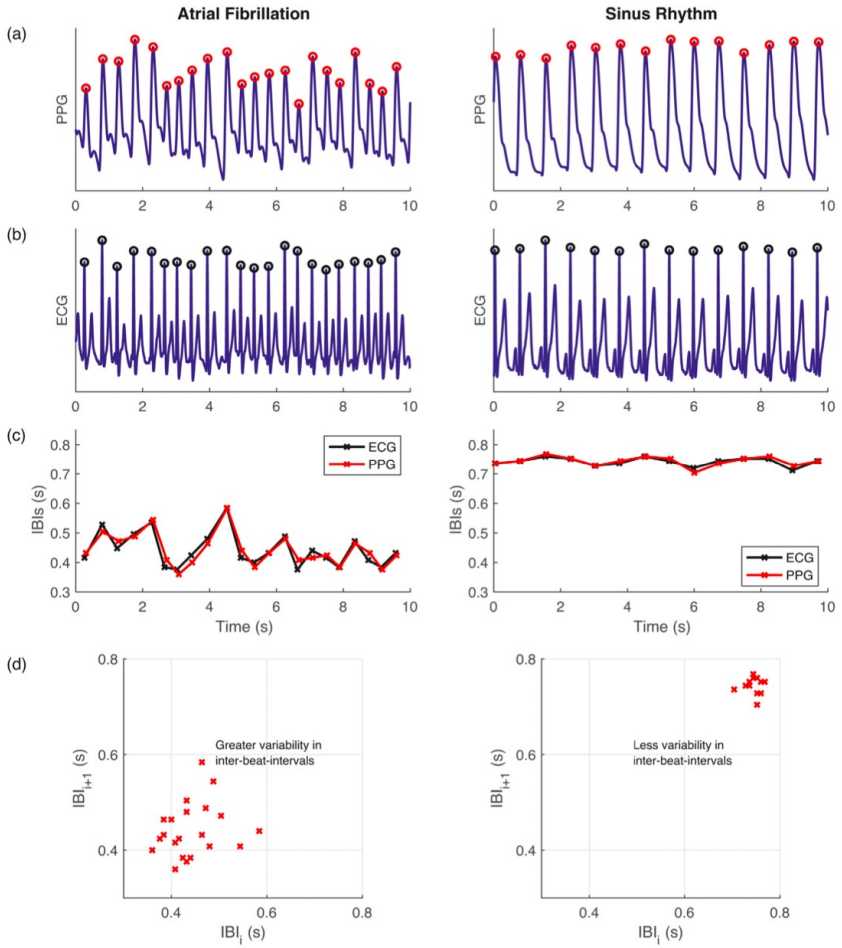

Image by P Charlton: Capitalising on Smart Wearables to Improve Health Monitoring. Presentation 2018

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Smartwatch PPG for AF

- PPG used over 1 minute, which were classified as regular or irregular on the basis of the variation in the pulse interval **while at rest**.
- the inter-peak intervals are plotted on a Poincare plot and degree of dispersion is used to determine irregularity.
- If 5/6 consecutive tachograms within a 48-hour period are classified as irregular, the user is notified of an irregular pulse.
- 419,297 participants
- The positive predictive value of an individual tachogram was 0.71 (wrt ECG)
- The positive predictive value of an irregular pulse notification was 0.84

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The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Large-Scale Assessment of a Smartwatch to Identify Atrial Fibrillation

Marco V. Perez, M.D., Kenneth W. Mahaffey, M.D., Haley Hedlin, Ph.D., John S. Rumsfeld, M.D., Ph.D., Ariadna Garcia, M.S., Todd Ferris, M.D., Vidhya Balasubramanian, M.S., Andrea M. Russo, M.D., Amol Rajmane, M.D., Lauren Cheung, M.D., Grace Hung, M.S., Justin Lee, M.P.H., Peter Kowey, M.D., Nisha Talati, M.B.A., Divya Nag, Santosh E. Gummidipundi, M.S., Alexis Beatty, M.D., M.A.S., Mellanie True Hills, B.S., Sumbul Desai, M.D., Christopher B. Granger, M.D., Manisha Desai, Ph.D., and Mintu P. Turakhia, M.D., M.A.S., for the Apple Heart Study Investigators*

Heart Rate Variability

- HRV has been used for diagnostic and monitoring purposes of several cardiovascular, autonomic, and mental diseases.

- HRV is measure as the time difference between adjacent peaks in a PPG signal. HRV is the beat-to-beat variation of the interbeat interval (IBI).

Article | Open Access | Published: 08 March 2022

Higher heart rate variability as a predictor of atrial fibrillation in patients with hypertension

San Ha Kim, Kyoung Ree Lim, Jeong-Hun Seo, Dong Ryeol Ryu, Bong-Ki Lee, Byung-Ryul Cho & Kwang Jin Chun

Scientific Reports **12**, Article number: 3702 (2022) | Cite this article

Abstract

The autonomic nervous system (ANS) plays an important role in the initiation and maintenance of atrial fibrillation (AF). However, the meaning of higher heart rate variability (HRV) in predicting AF remains unclear. Among 2100 patients in the Holter registry, a total of 782 hypertensive patients were included in this study. Baseline HRV was measured by time domain and frequency domain methods using 24-h Holter monitoring. The primary outcome was the development of AF. During an average follow-up of 1.1 years, 44 patients developed AF. Higher HRV parameters including high-frequency ($P < 0.001$), the square root of the mean squared differences of successive NN intervals ($P < 0.001$), and the percentage of NN intervals that are more than 50 ms different from the previous interval ($P < 0.001$) were associated with the occurrence of AF in univariate analysis. Premature atrial contractions burden, lower baseline heart rate, age, hemodialysis, coronary artery disease, and chronic heart failure were also associated with AF. In Cox regression analysis, higher HRV (representing excessive autonomic fluctuation) was an independent risk factor for AF. Excessive autonomic fluctuation represented by higher HRV in patients with hypertension was associated with an increased risk of AF.

Respiration Rate

- Respiratory rate (RR), the number of breaths taken in a minute, is used for diagnosis and prognosis in a range of clinical settings.

- Filter bands applied to keep frequencies at plausible Respiration Rate (RR).

- Time and Frequency domain features used in similar way as before:
  - Time domain: Identifying peaks in the signal (indicating breaths), and calculating RR from the number of peaks in a specified time.
  - Frequency-domain technique: calculating the frequency spectrum of the respiratory signal, and obtaining the RR as the frequency corresponding to the maximum power.

Blood Pressure

- Blood pressure (BP) is widely measured to assess cardiovascular health. Abnormal BP incites several diseases that can lead to complications for vital organs such as the heart and brain.

- PPG placed in two location and measuring the time it takes for the pulse wave to travel from one to the other.
- BP inversely proportional to pulse wave travel time.
- Peak time shift used to measure the travel time of the pulse wave.

Arterial Stiffness (AS)

- Arteries tend to stiffen as we age. Consequently, transmission of the pulse (and its return) tends to get faster.
- AS is measured similarly to BP by using pulse wave timing.

More details in Photoplethysmography. Technology, Signal Analysis and Applications. P. A Kyriacou and J. Allen. Elsevier, 2022.

Oxygen Saturation (SpO2)

- Oxygenated hemoglobin absorbs less red light emitted whereas deoxygenated hemoglobin absorbs less infrared light. Thus, the ratio between red and infrared light intensities measured by the PPG sensor can be used to estimate peripheral oxygen saturation (SpO2).

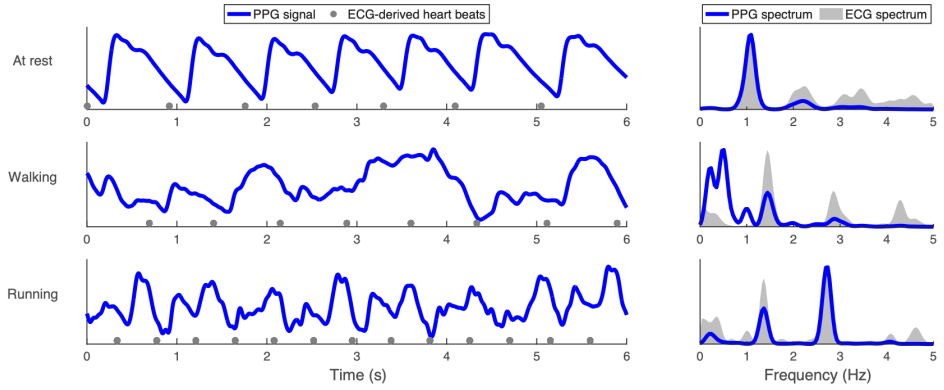
$$R = \frac{R_{red}}{R_{infrared}} = \frac{AC_{red}/DC_{red}}{AC_{infarared}/DC_{infrared}}$$

Control for …

- MOTION
- Demographics (age/height/weight)
- Location of sensing

Motion

- Avoid to sample when accelerometer detects activity.
- Correlate accelerometer data to filter out motion artifacts.
- Use estimates over time.
- Performance of wrist-worn devices for HR monitoring found summary mean absolute errors of 2.15 (95% confidence interval 1.84–2.46) bpm during rest, compared to 7.70 (6.32–9.07) during treadmill activities



Charlton, P.H., 2021. Realising the potential of wearables. IPEM Scope 31 (1), 50–53.

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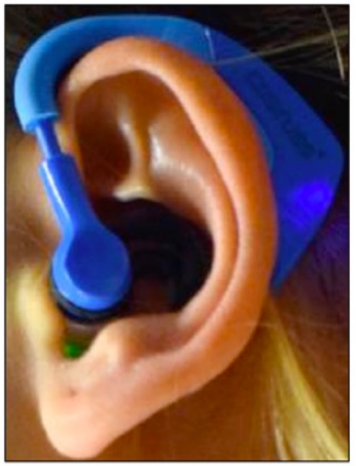
Wearable Devices: PPG

- Sampling:
  - Wearable devices typically sample the PPG at between 50 and 100 Hz
  - Studies have shown that HR can be estimated from PPG signals sampled at 9 Hz, pulse rate variability(PRV, equivalent to HRV) at 25 Hz, respiratory rate at 16–18 Hz. Generally PPG features can be accurately measured at sampling frequencies of at least 60 Hz.
- Battery: only sample when low activity detected.

More details in Chapter 12, Photoplethysmography Technology, Signal Analysis and Applications. 2021

The new frontier…







Questions