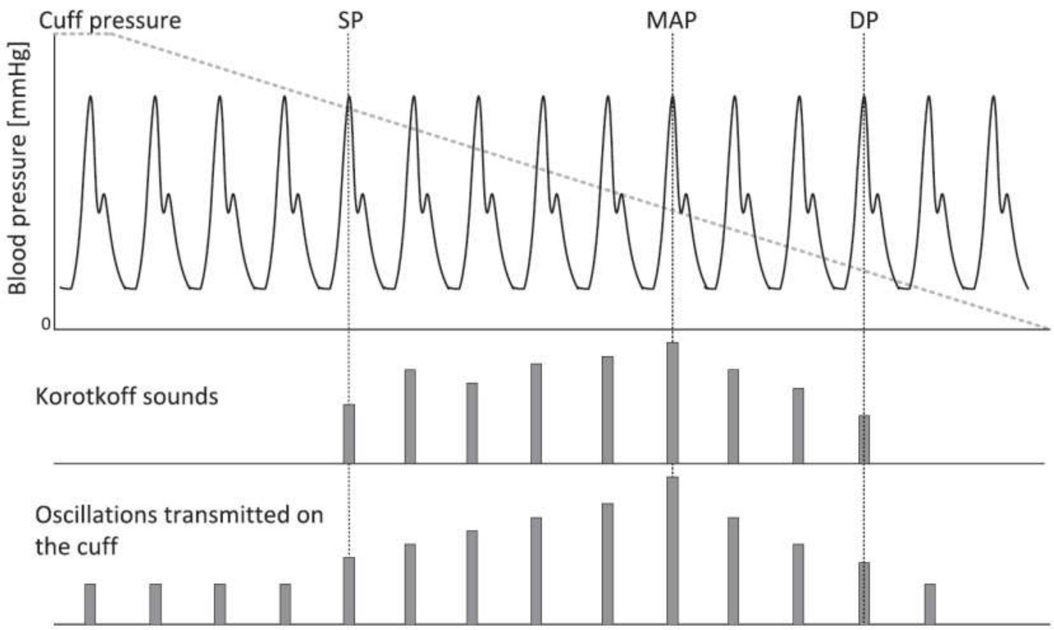
Fuzco - Optical Blood Pressure Estimate from Photoplethysmography via Machine Learning

Donnerstag, 11. März 2021 13:29

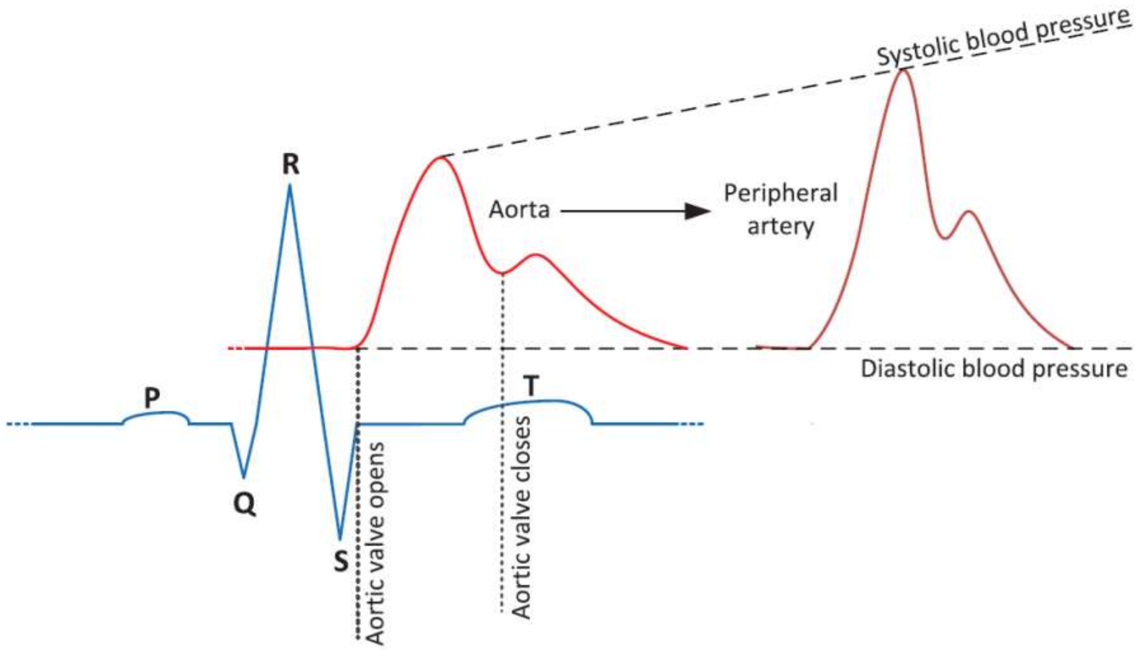
Summary : BP model in order to measure more easily BP and prevent the number one risk of death.

- Subjects of hypertension have to follow continuously their BP to avoid health issues/incidents
- BP measuring : auscultory or oscillometry method or tonometry
- Oscillometry: the difference between SBP and DBP must not exceed 5 and 8 mmHg, respectively, compared to the measurement taken using auscultatory method



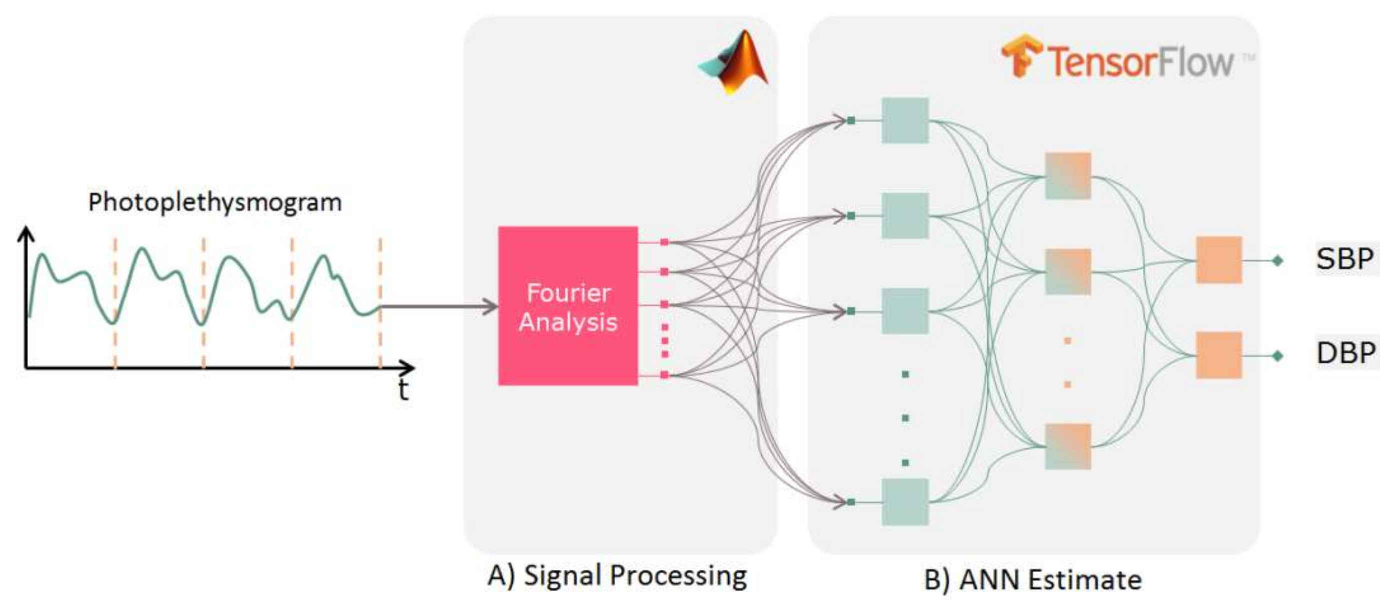
- Oscillometric method: A pressure sensor is attached to the pressure cuff to measure the oscillation of the blow flow through the artery. Thus, the method is based on the measurement of pressure oscillations appearing when the pressure in the cuff equals to the SP; are maximum at the mean pressure, and disappear at the DP. Such a measure is not ideal, since it is uncomfortable, noisy and painful
- Tonometry method : based on applying a controlled force orthogonally to the wall of a superficial artery against a bone. Additionally, tonometry is **extremely sensitive to motion artefacts**, hence it needs an accurate positioning of the sensor. The ideal measurement setting would be in the **resting position**.

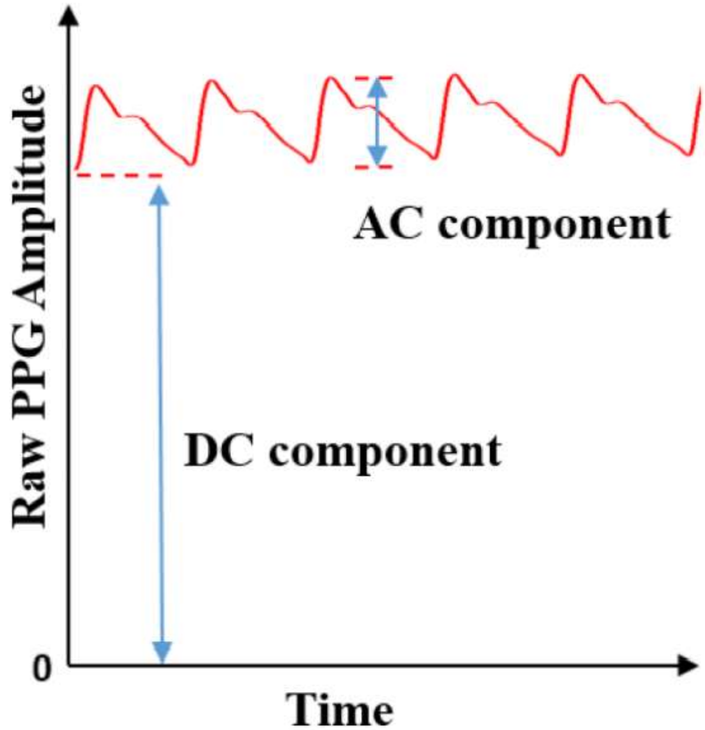
- PPG does not access directly to BP values but can measure blood volume changes in artery. Unfortunately, these volume changes cannot be transformed into pressure values because of the non-linearity of the elastic components of the arterial wall



- The relationship between PTT and BP can be analysed by using linear and non-linear regression.
- **Negative correlation PTT and blood pressure**, that is, when BP increases, arterial compliance decreases which reduce the pulse wave velocity and it causes PTT decreases
- a hybrid method, that used both PPG intensity information and PTT to derive BP

Signal processing





PPG signal decomposition

- the AC component shows blood volume variation occurring between the systolic and diastolic phases of the cardiac cycle; the fundamental frequency of the AC component depends on the heart rate and is superimposed onto the DC component

-

Interaction light- tissue

- The interaction of the light with biological tissue is a complex issue since includes the optical phenomena of (multiple) scattering, absorption, reflection, transmission and fluorescence.
- In particular, the absorption of the light (absorbance) is proportional to the material characteristics such as molar absorptivity, molar concentration and path length.
- The light absorbance can be modelled with Beer– Lambert law. The equation describes the attenuation of light travelling through a uniform medium containing an absorbing substance

$$I = I_0 exp(-h(\lambda)CL)$$

- h(λ) is the extinction coefficient of the absorbing substance
- C is the substance concentration
- L the optical path length through the medium

- Since the **blood has a higher absorption coefficient than the adjacent tissues**, changes in the blood content can easily be followed by the photoplethysmography
- In certain wavelength ranges – referred as skin optical window – the epidermis has a low absorption power. Thus, a **high penetration depth is guaranteed and the electromagnetic radiation can simply reach the red blood cells**.

Arterial Wall Mechanism

$$E = E_0 e^{\gamma P}$$

- E0 and γ depend on the site of measurement and upon the particular animal

$$E = (1-\sigma^2)\frac{r^2}{h}\frac{dP}{dr}$$

- σ is Poisson’s ratio = constant -> σ was assumed to be 0.5, which treated E as **incremental modulus**.
- we only care about the **circumferential stress** => E was chosen to represent the “tension-strain modulus” and σ was set to 0. Note that the choice of σ doesn’t affect the general conclusion drawn in the next section. h represents the thickness of the blood vessel wall, and r represents the mean radius of the blood vessel.

Interpretation of the PPG signal

$$V = C\pi r^2 + V_0$$

- C is a constant related to arterial blood vessel density
- V0 is related to microvascular and venous blood volume.
- finger vascular bed have a uniform radius r
- V in the measured area

= >

$$dV = \frac{2d\pi r^3}{E_0 h e^{\gamma P}} dP = \frac{2V^{3/2}}{E_0 h\sqrt{C\pi} e^{\gamma P}} dP$$

First order approximation of V

★ $$V = \frac{C(E_0\gamma h)^2\pi}{b}(1-\frac{2}{b}e^{-\sigma P})^2$$

★ $$PPG_{norm} = \frac{V - V_{min}}{V_{min}} = \frac{2(e^{\gamma P_{min}} - e^{\gamma P})}{b - 2e^{-\gamma P_{min}}}$$

- a linear scaling function is typically used to amplify and shift the normalized PPG signal.
- Thus the BP fitting error will be relatively large if only amplitude information is used. That’s why we also have to combine with shape information of the waveforms, which is indirectly influenced by the BP level [15],[19], to improve BP fitting accuracy

Data collection

- 50 patients with BP and PPG, sampling rate of 125Hz

•

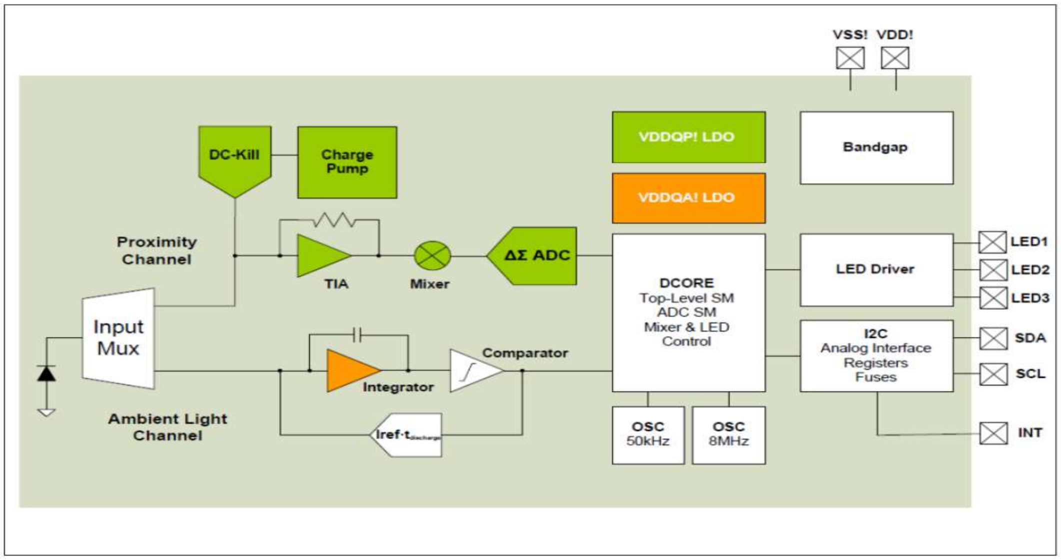


FIGURE 3.3: IFX PALS-2 Block Diagram

Infineon PALS-2 ASIC

- Proximity and ambiant light sensor (PROX // ALS)
- Integrated photodiode and multiple LED drivers output
- Independantly driving three LEDs throught a multiplexer
- Controlled by a I²C interface
- Two separate signals path for ambiant and prox
- Amb : filtering to reduce the influence of ambiant light
- GUI existing to visualize :
  - Raw data
  - Low pass filter
  - Heartbeat / beats per minute
- AC/DC ratio doesnt depend on current intensity => lower intensity allows for longer battery life
- Chosen driving current : 10mA

Main features of the ASIC:

- Integrated photodiodes for minimum package footprint and lowest noise;
- Programmable interrupt levels for both ASL and PROX functions;
- 300nA power-down current;
- 1.8V to 2.7V supply;
- I²C interface, 1.7V to 3.6V bus level.

Functionnality of Heart Rate Monitoring (HRM)

- Three integrated LED drivers outputs with 200mA driving capability;
- Up to 250P ROXreadouts/second, ambient light suppression in PROX- /HRM mode up to 100klux;
- 16 bit resolution digital output;
- HRM functionality with dark skin types;
- Pulse Oximetry function supported.

Physical needs :

- Sensor used in direct skin contact
- Air needed between the top sensor and the transparent cover
- White package plays a role in the light flux
- The photodiode suppresses Infrared (IR) light to reduce IR interference from external light sources,

e.g. sunlight.

BP Acquisition

- manual aneroid sphygmomanometer produced by Erka, Germany
- Manual bc the eletric one is subject to calibration drift over time

Process

- Phase 1: PPG and BP as comparative
- Phase 2: PPG alone

Asess the quality of good data :

- a Signal Abnormality Index (SAI) to assess BP quality
- . A linear Savitzky-Golay smoothing filter was firstly applied to SBP and DBP signal, and any data two standard deviation away from smoothed value were considered too noisy and discarded
-

Feature	Abnormality Criteria
SBP	$> 180mmHg$ or $< 80mmHg$
DBP	$< 20mmHg$
ΔSBP	$> 2 * SD_{sbp}$
ΔDBP	$> 2 * SD_{dbp}$
SBP-DBP	$< 20mmHg$
T	$< 0.3s$ or $> 3s$

- Multi-Channel Adaptive Filter (MCAF) method to give a Signal Quality Index (SQI) for PPG signal

Results

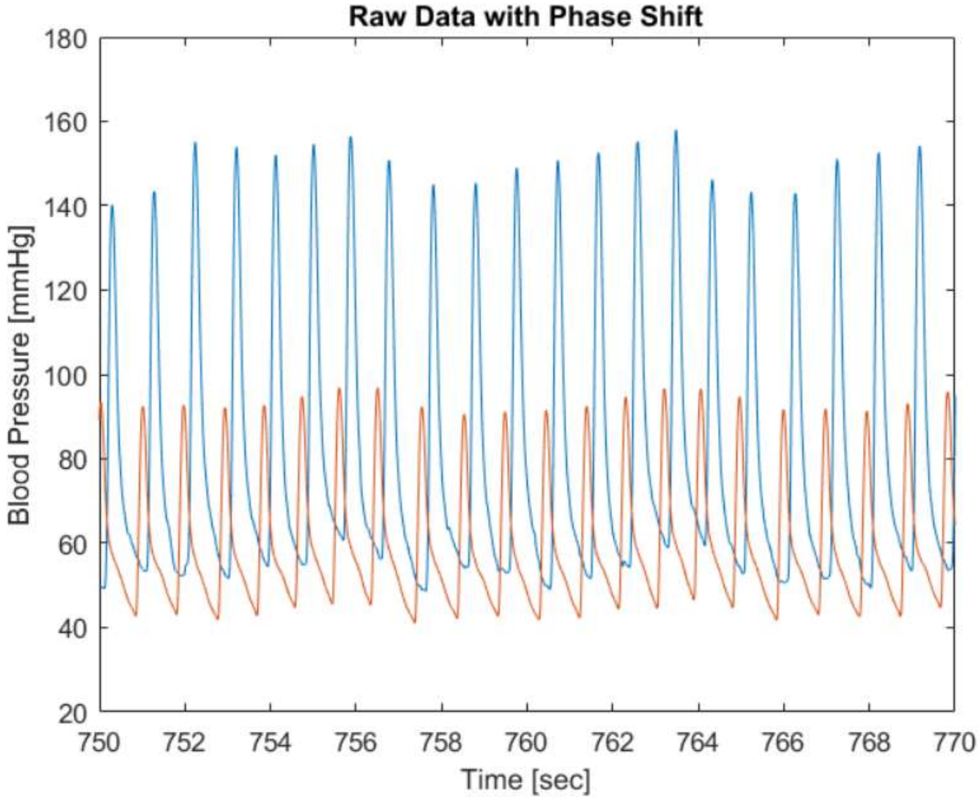
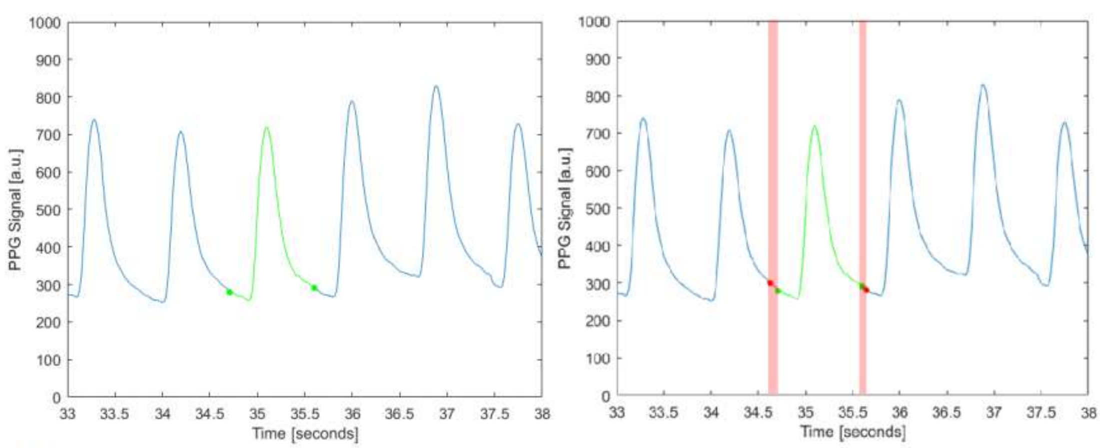


FIGURE 4.4: Graph showing PPG and BP signals from MIMIC II.

Why phase shift ? The reason is that the two signals are registered with two different sensors, in different body locations and the transmission speed of the signal is different. = > a cross correlation function g(Δt)

- Locate **cardiac cycl**e : s Finite Impulse Response (FIR) filter is applied.
- The following **rule has been defined:** we consider one window as the interval containing a complete cardiac cycle with additional 10% of the previous cycle and 5% of the following cycle.
- 

(A) PPG windowing considering minima only. (B) PPG window overlapping.

- The cardiac cycle dont have all the same length

Why data normalization?

- reduce the variance between different recordings, in order to assess both interand intra-patient variability;
- normalization speeds up convergence of the network

Data Acquisition

TABLE 4.1: Frequency bands in the photoplethysmographic signal.

Frequency	Range [Hz]	Description
Very low	0.001-0.03	Energy-saving mechanisms, increased readiness for circulatory demands, myogenic response to pressure changes and thermoregulation mechanisms.
Low	0.04-0.11	Reflect changes in sympathetic tone, usually with the most prominent peak at 0.1 Hz.
Intermediate	0.12-0.18	Reflect efferent vagal activity.
Respiratory	0.19-0.30	Respiratory-induced oscillations.
Cardiac	0.75-2.50	Arterial pulse-induced oscillations.

Neural Network ´-> to explore if time

Statistical Analysis

- Lilliefors test with the purpose of verifying whether data come from a normally distributed population.
- D = maxx|F(x) − G(x)|
  - F(x) is the empirical CDF (Cumulative Distribution Function) of the sample data
  - G(x) is the CDF of the hypothesized distribution with estimated parameters equal to the sample parameters

Comments of the results

- From a clinical point of view, the most important features are accuracy and precision of non-invasive BP measurement methods. Guidelines were created by the British Hypertension Society (BHS) and by Advancing Safety In Medical Technology (AAMI) to compare any method to the reference intra artery pressure(IAP)
- difference in error between systolic and diastolic values, the explanation has to be searched in the mechanical nature of the arterial wall mechanism.n elastic phenomenon is observed and the minimum is selected as one of the local minima in the fluctuation interval
- A full understanding of its morphology and underlying physiology is still lacking. We have investigated the intrinsic connection between BP and PPG, and derived a simple mathematical formula to describe their relationship, which is straight forward and based on fewer assumptions than methods using PTT