uOttawa

L'Université canadienne
Canada's university

Emerging Methods for Blood Pressure Measurement

Dr. Voicu Groza
School of Electrical Engineering and Computer Science

Université d'Ottawa | University of Ottawa

June 28, 2018

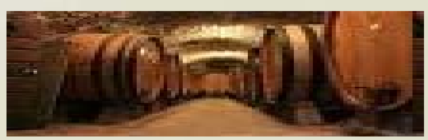
INTELLI 2018

www.uOttawa.ca

Outline

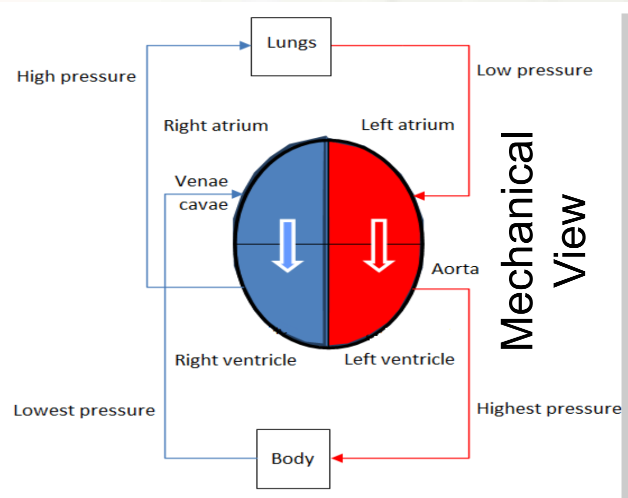
- Challenges and motivation
  - Problem (What?)
  - Motivation (Why?)
  - Methods (How?)
- Elements of the system
- Pulse processing
- Improving accuracy
- Connectivity and Telehealth
- Overall integration
- Conclusion

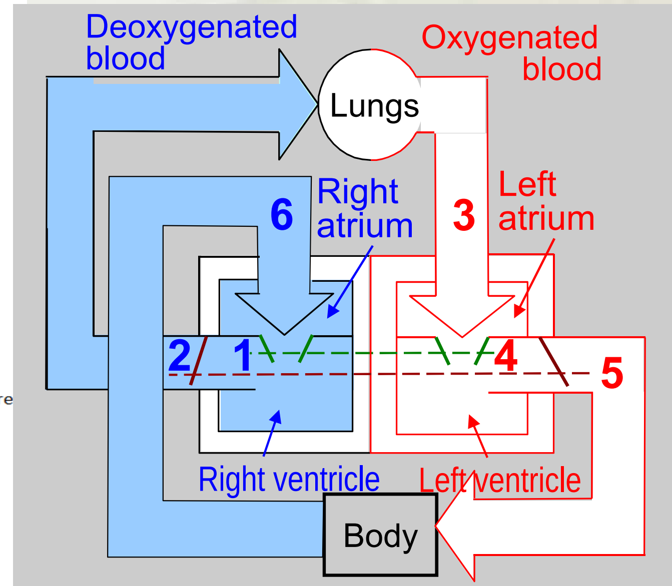
Cardiac Output

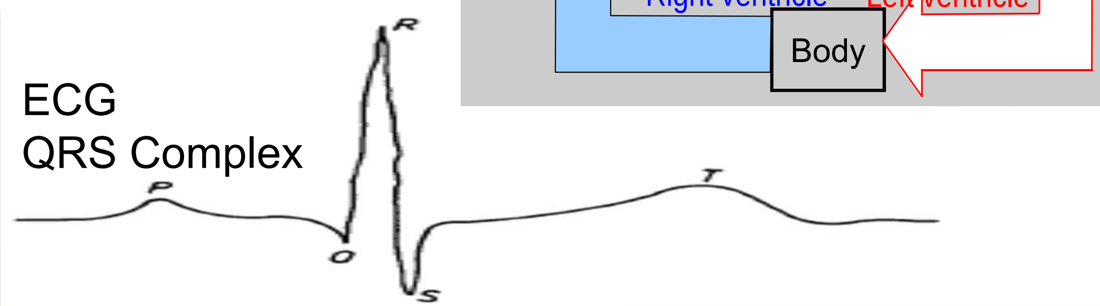


70	beats/minute
70	ml/stroke
5	l/min
300	l/hour
3	barrels / hour
70	barrels/day
25,000	barrels/year
2,500,000	barrels/100 years

Simplified Circulatory System - **Cardiac cycle**







	while
1. The right atrium pushes deoxygenated blood to the right ventricle.	4. The left atrium pushes the oxygenated blood to the left ventricle
2. The right ventricle ejects blood into the pulmonary circulatory system.	5. The left ventricle ejects blood into the arteries of the systemic circulatory system.
3. The oxygenated blood returns from the lung to the left atrium	6. Deoxygenated blood from the body flows back to the right atrium and the cycle repeats.

	0–0.1	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8 sec
Atria	Syst. 1,4	Diastole							Systole 1,4
Ventricles	Diastole	Syst. 2,5			Diastole				
Atrioventr. AV Valves	Open	Closed			Open				
Semilunar SL Valves	Closed	Open			Closed				
Heart Sounds	S4 S1			S2	S3				

1 Atrium + 1 Ventricle = 1 pump
Heart = 2 synchronous pumps
= Left pump + Right pump

The Measurand = Pulse pressure in arteries

Mean Arterial Pressure (*MAP*):
The average value of the pressure over time

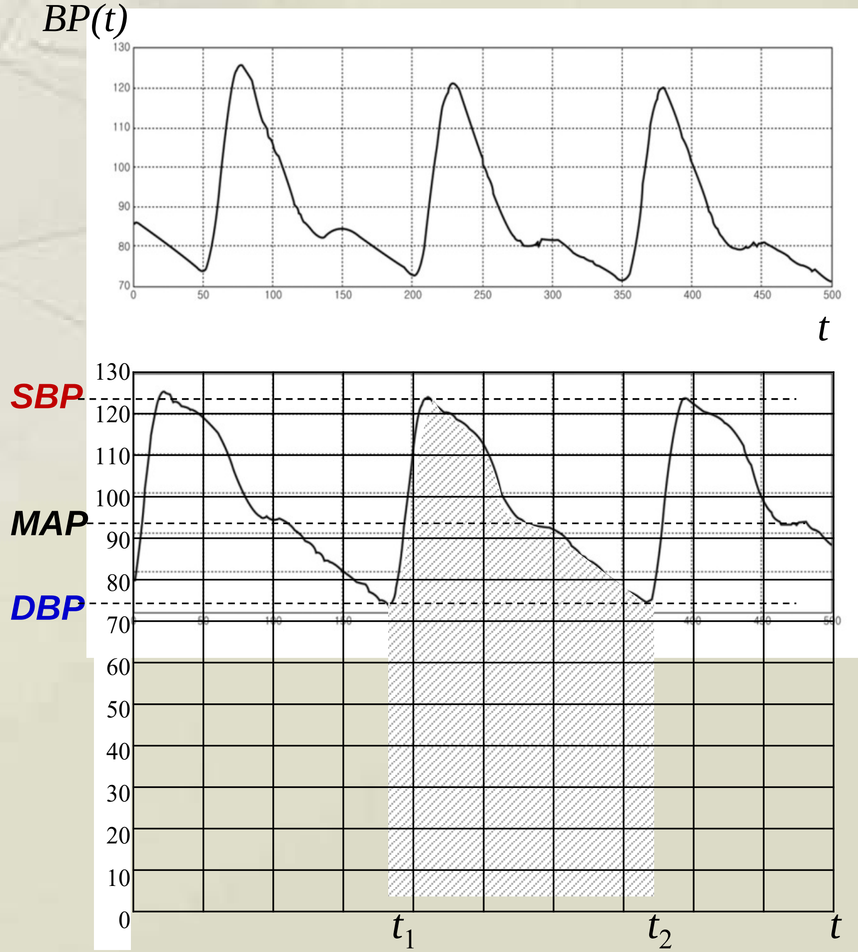
$$MAP = p_{mean} = \frac{1}{t_2 - t_1}\int_{t}^{t_2} p(t)dt$$

The DC Component of the Fourier transform of the pressure waveform

- **Systolic Blood Pressure:** Pressure in the artery as heart contracts (maximum)
- **Diastolic Blood Pressure:** Pressure in the artery as heart relaxes (minimum)

SBP*, *DBP*, and *MAP

- Cannot fully describe the blood pressure waveform (discard information)
- Provide a simple, easy to read glimpse into a patient's condition, while still having some diagnostic value
- More readily obtainable (non-invasively)



Two pressure waveforms recorded from the same patient at different times. SBP and DBP are the same, while MAP and overall shape are not.

BP = COMPLEX SIGNAL

- The current view on blood pressure is a simplistic one!
- As engineers, we perceive the blood pressure as a complex signal
- Physicians need to know the hemodynamic characteristics of their patients
- They don't trust automatic blood pressure monitors (most of the time for good reasons),
- Employing a sampling frequency based on doctors' schedule doesn't make any scientific sense.
- SBP/DBP taken every now and then is insufficient to characterize BP and the evolution of a patient
- BP should be measured with an **adaptive sampling frequency** that follows the patient's state
- Vast majority of patients have chronic diseases and need home monitoring

Designing IT for Health Care from First Requirements (Hippocrates)

- Do no harm
  - Device quality
  - Data integrity; in context
- Do some good
  - As intended – detect abnormal BP
    - Normative operation; actually nobody needs METERS
- Be friendly
  - Easy to use (autonomous operation)
    - Self-corrective operation; error handling/awareness

Blood Pressure (BP) Measurement Techniques

Invasive measurement:

Continuous monitoring of BP. Most accurate. Inconvenient. Risky.

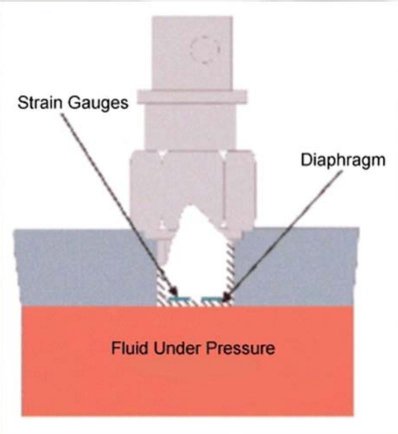
Noninvasive measurement:

- Sphygmomanometry (with cuff)
  - Manual
    - Palpation
    - **Auscultation - Korotkov: Most common manual technique**
  - Automated
    - Continuous techniques
      - Vascular unloading technique: FINAPRES
    - Sampling techniques
      - Automated Auscultation
      - Doppler ultrasound Sphygmometry
      - **Oscillometry**: **Most popular automated technique as it can be relatively easily implemented in automated BP measurement devices**
      - Pulse transit time analysis
- Cuffless – Continuous techniques
    - Pulse sensing techniques:
      - Photoplethysmography,
      - Tonometry

Heisenberg Uncertainty Principle in Blood Pressure Measurement

Stavros Tavoularis, Measurement in Fluid Mechanics,

New York : Cambridge University Press, 2005



"How To Measure Pressure with Pressure Sensors," National Instruments

- One can measure pressure of a fluid inside of a pipe only if a sensor is inserted in it!
- BP cannot be **measured** non-invasively but only **estimated** from indirect measurements (Korotkov sounds, cuff pressure oscillations, tonometry, etc)
- It is the result of internal REGULATION
  - It is an internally measured property
  - Actually **you measure the measure in which the regulator responds to measurement!!!**
  - If taken several times, BP will "regress to the mean"
- Direct measurement of blood pressure is invasive, and, as such, it has a very limited clinical value.
- The SBP/DBP is estimated by using various "educated" guesses which don't work for all the cases…

One Hundred Years of **Noninvasive Blood Pressure Measurement**

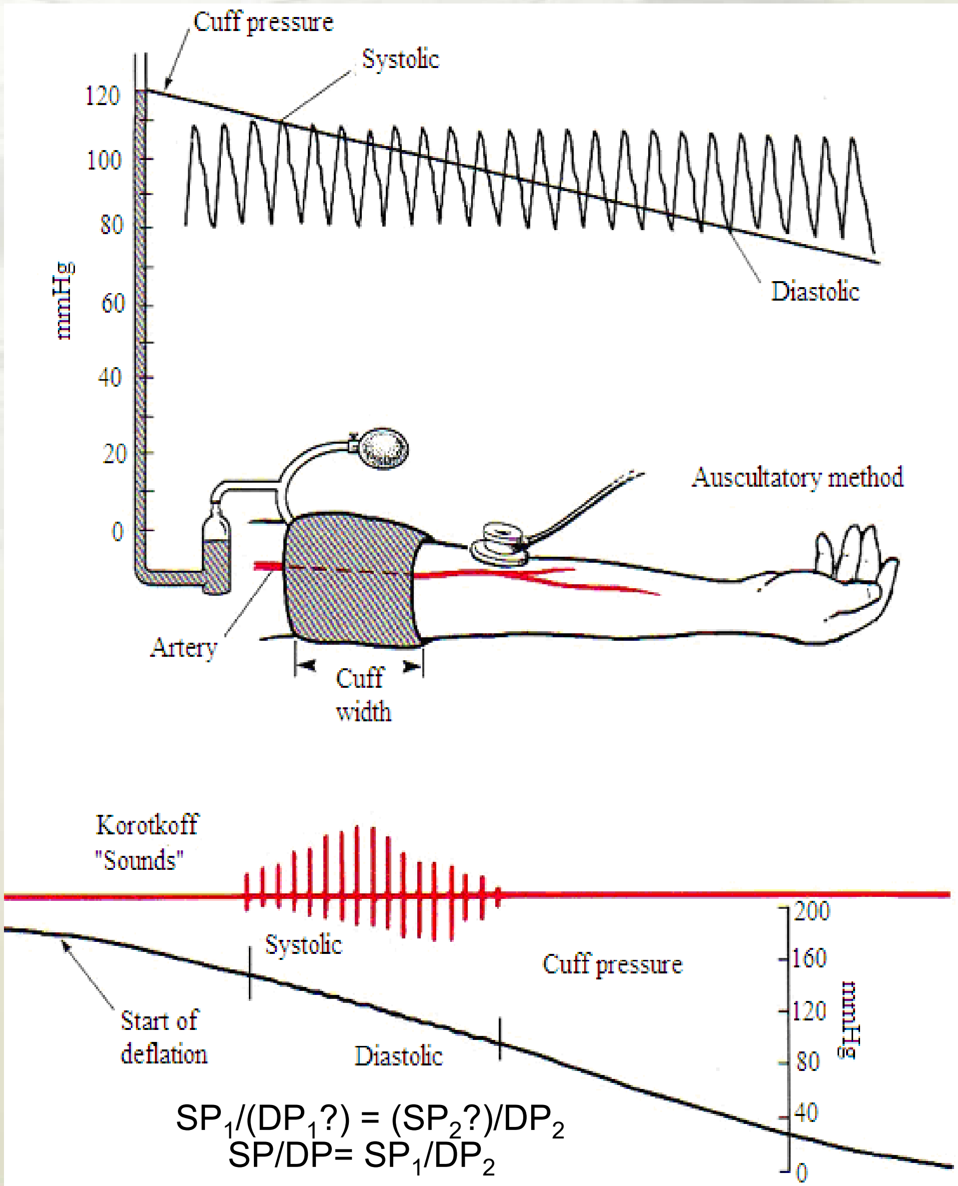
1905, Nov. 8, Nikolai Sergeevich **Korotkoff**,

"To the question of methods of determining the blood pressure,"

Reports of the Imperial Military Academy 11: 365-367.

“The **cuff of Riva-Rocci** is placed on the middle third of the upper arm; the pressure within the cuff is quickly raised up to complete cessation of circulation below the cuff. Then, letting the mercury of the manometer fall one listens to the artery just below the cuff with a children's **stethoscope**. At first no sounds are heard. With the falling of the mercury in the manometer down to a certain height, the first short tones appear; their appearance indicates the passage of part of the pulse wave under the cuff. It follows that the manometric figure at which the first tone appears corresponds to the **maximal** pressure. With the further fall of the mercury in the manometer one hears the systolic compression murmurs, which pass again into tones (second). Finally, all sounds disappear. The time of the cessation of sounds indicates the free passage of the pulse wave; in other words at the moment of the disappearance of the sounds the minimal blood pressure within the artery predominates over the pressure in the cuff. It follows that the manometric figures at this time correspond to the **minimal** blood pressure.”

Auscultation



$SP_1/(DP_1?) = (SP_2?)/DP_2$
$SP/DP = SP_1/DP_2$

- Compression of the brachial artery using an elastic, inflatable cuff;
- Recording of blood pressure levels using a manometer and a stethoscope
- **Korotkov** sounds (generated by the turbulent flow of blood and the oscillations of the arterial wall) are heard during auscultation over the brachial artery distal to the cuff;
- When the first sound is heard, a reading is recorded and taken to be **systolic pressure (SBP)** and when the last sound is heard a reading is taken to be **diastolic pressure (DBP).**

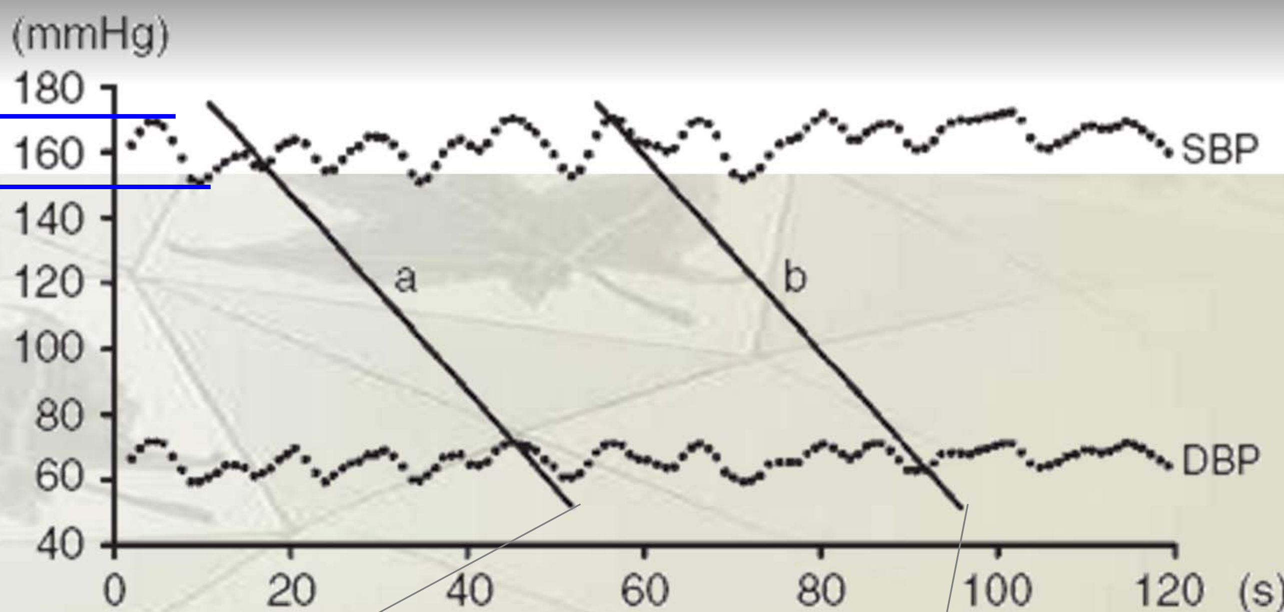
Wilmer W. Nichols, Michael F. O'Rourke: McDonald's Blood Flow in Arteries, 4th Edition – Fig. 6.10 (A), page 132

The Problem is …

- NOT calibration by ear:
  - ✓ SP10 requires verification against **either** auscultatory (Korotkoff) **or** direct intra-arterial,
    - ✓ but the two methods give different readings, with a difference higher than the acceptable error required by the standard SP10
  - ✓ Observer Factors for Inaccurate Korotkoff Measurement
    - ✓ auscultation requires clinical expertise;
    - ✓ detecting Korotkoff signs requires good auditory acuity;
    - ✓ distraction and noise from a busy clinic;
    - ✓ practitioners demonstrate digit preference to rounding measurements;
    - ✓ deflation faster than 2mmHg per heartbeat.
- BUT correct characterization of the BP signal
  - ✓ Medical significant acquisition rate
  - ✓ Confidence in
    - ✓ Characterization of the acquisition conditions
    - ✓ Measurement uncertainty

Variability of blood pressure

Up to 20 mmHg



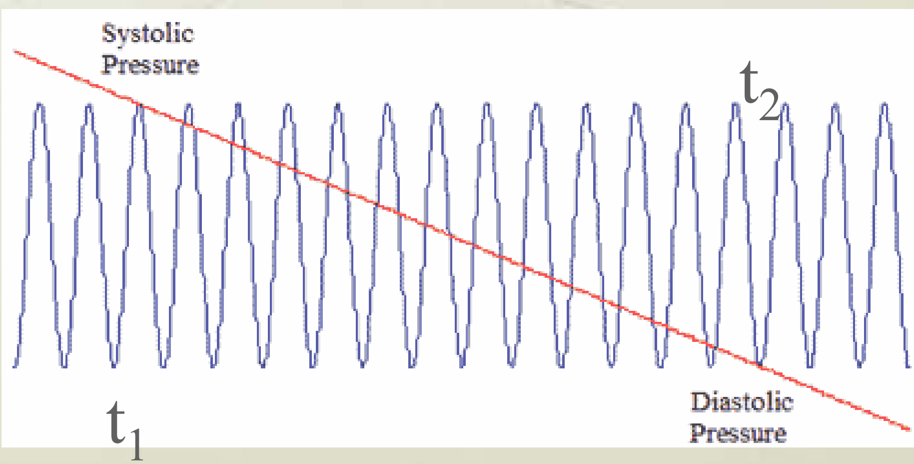
Cardiovascular

Mayer Waves

Respiration

157/71 SBP/DBP

169/63 = SBP/DBP

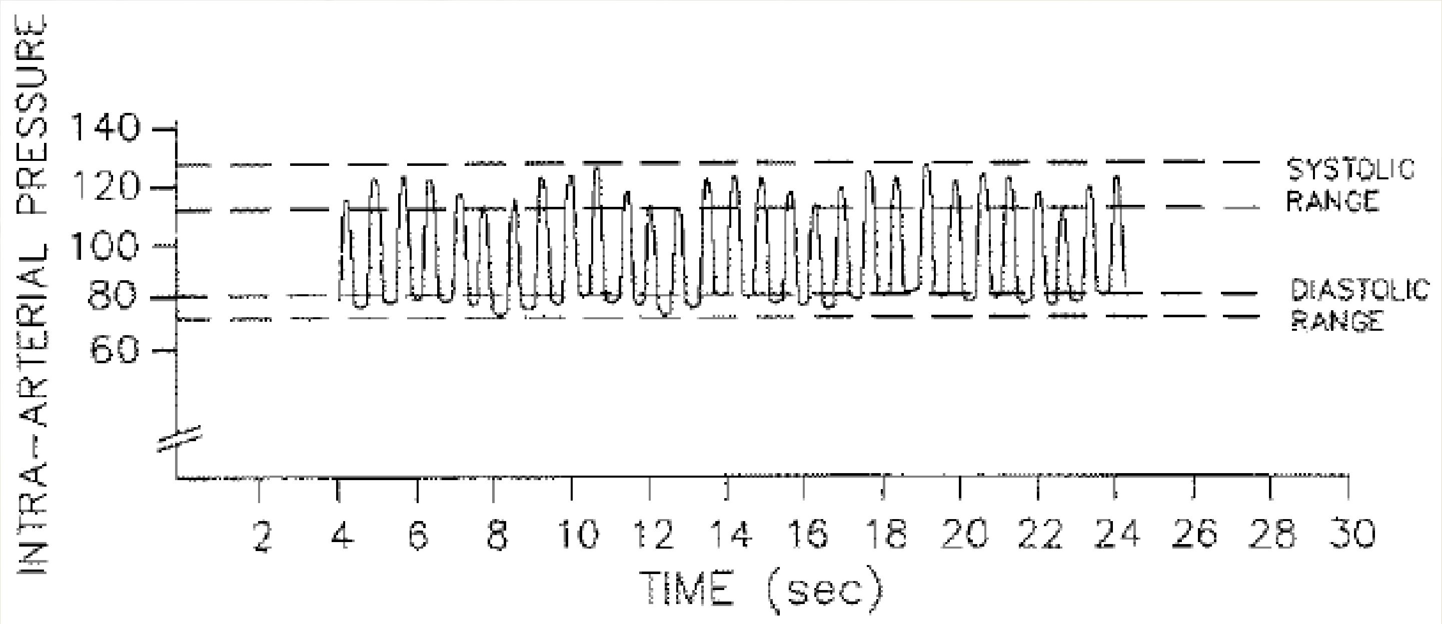


$SP_1/(DP_1?)= (SP_2?)/DP_2$

$SP/DP= SP_1/DP_2$

Breathing & Blood Pressure

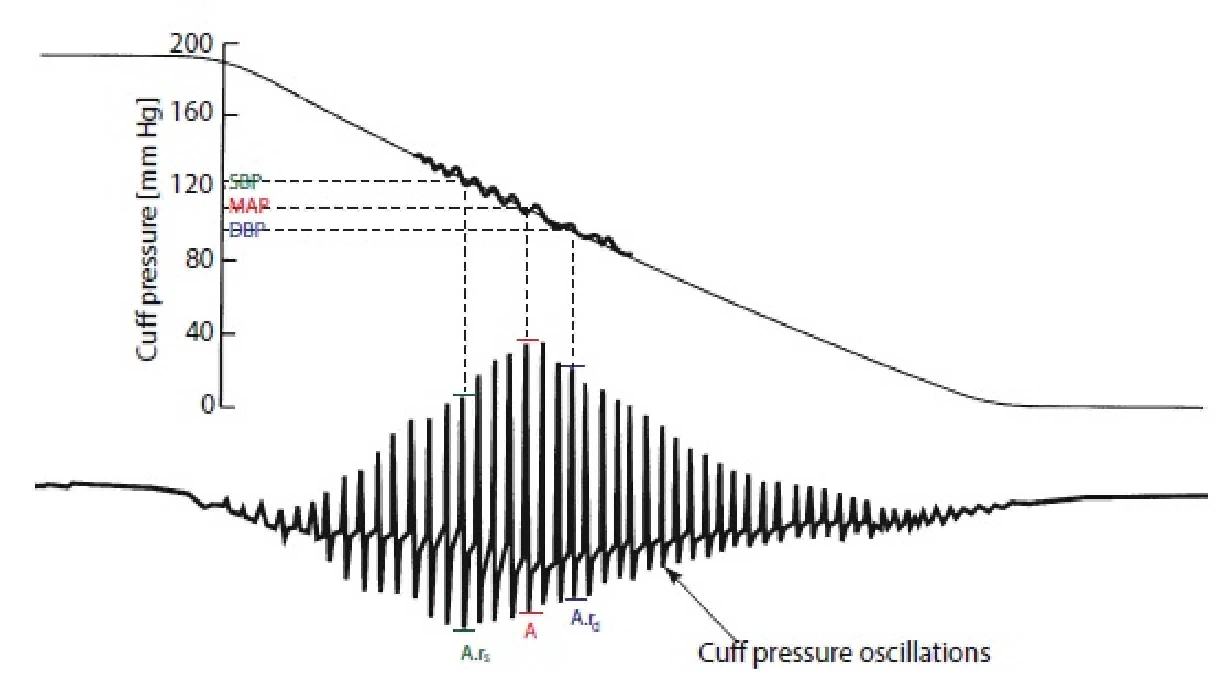
- SBP and DBP fluctuate with inspiration and expiration; one study finds that respiratory variation in SBP to be 15 mmHg due to pronounced breathing and 3-6 mmHg from normal breathing



- SBP and DBP varies over 24 hours

Oscillometric Algorithms:

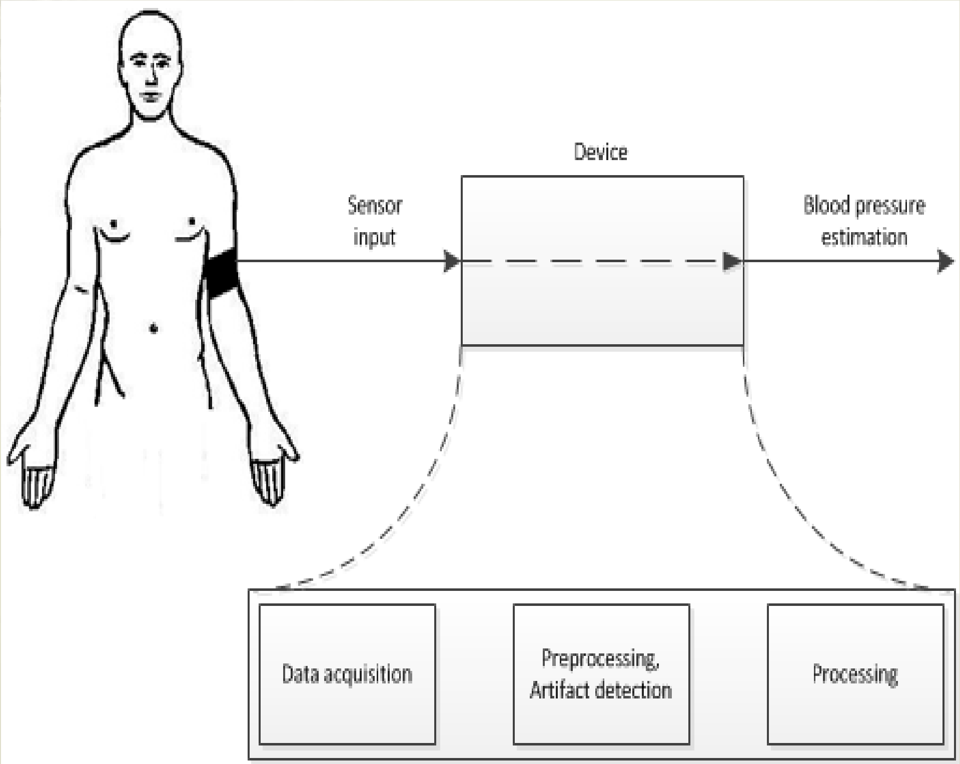
– Maximum amplitude algorithm (MAA)



– Linear Approximation Algorithm
– Derivative Oscillometry
– Neural network method
– Pulse morphology method

Main elements of the oscillometric device

- Data acquisition system
- Preprocessing block
  - Extract the oscillometric waveform
  - Clean the waveform
  - Define the feature that will be analyzed as a function of cuff pressure
  - Smooth the function
- Estimation algorithm
  - Estimating MAP, SYS and DIA blood pressure
  - Data fusion
- Overall control that includes pump, valve release, display, communication



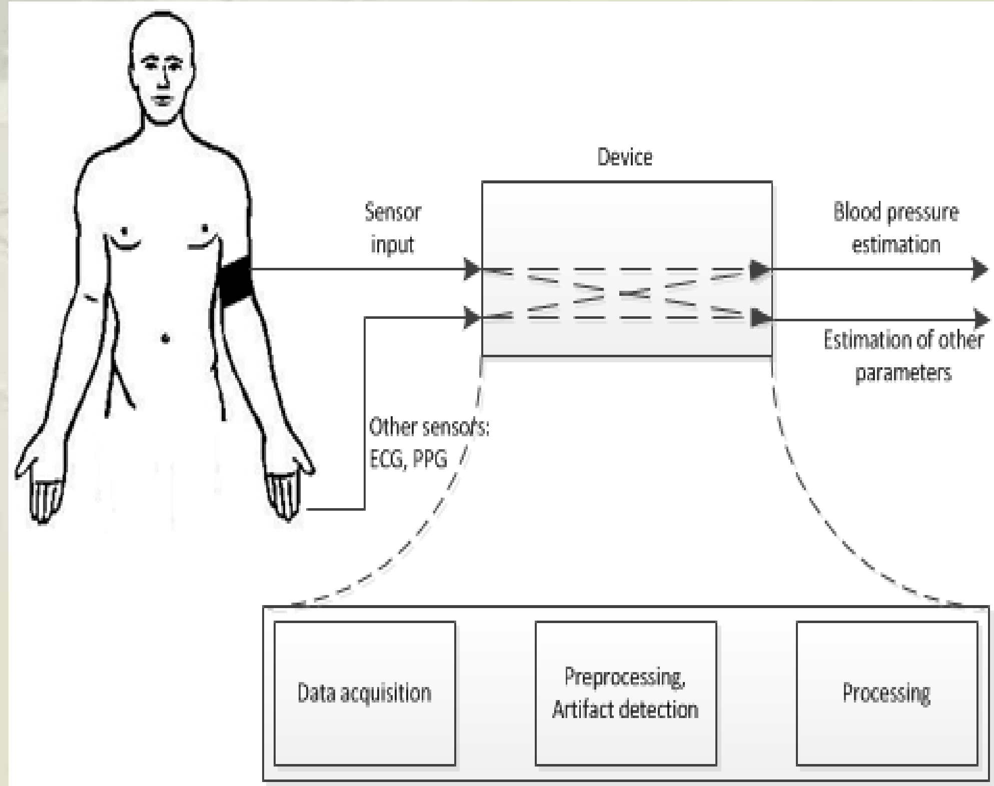
Oscillometric method: Types of measurement errors

- Incorrect cuff size
- Incorrect cuff application
- Arrhythmias
- Patient Factors
    - Rapid changes in pressure
    - Patient not on “idle”
    - Movement (twitching, shivering, etc.)
    - The white coat effect
- Cuff not at heart level
- Environments motions in case of an use in an ambulance
- Automated instruments require periodic testing and calibration

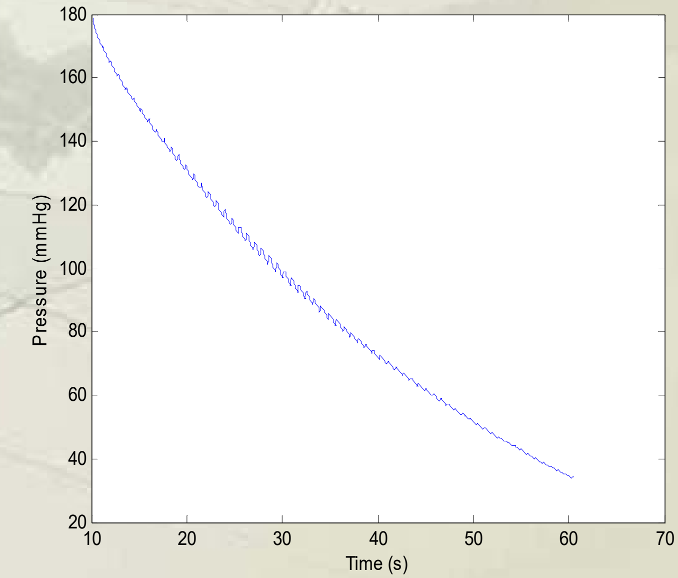
Philips Healthcare, About Non-Invasive Blood Pressure, Application Note, 2011.

Including Other Sensors

- Sensors
  - ECG
  - PPG
  - Accelerometer
  - …
- Goal
  - Estimating blood pressure
  - Estimation of other physiological parameters:
    - Heart rate
    - Arterial stiffness
    - Detection of arrhythmias



Innovations - When



When to start the measurement

Before the measurements

- Monitoring status of the patient

During the inflation

During the deflation

- Real-time artifact detection and removal
- Adherence to the measurement procedure
- Real-time control of deflation
- Processing

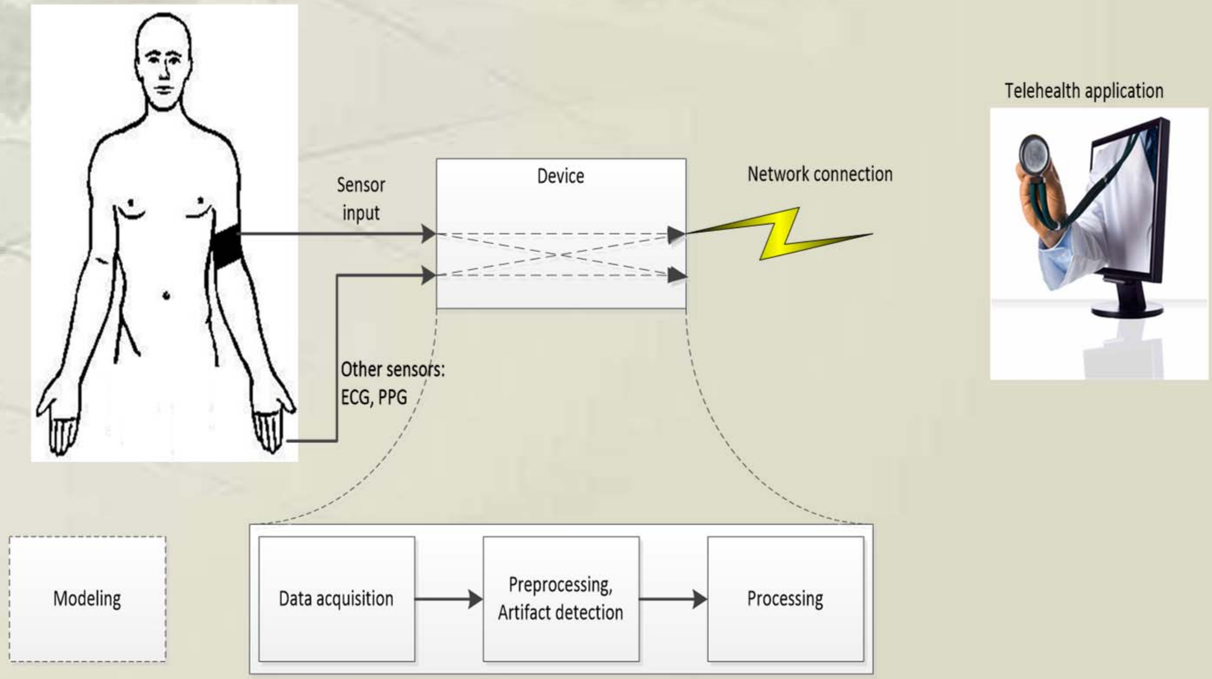
After measurement

- Data fusion
- Analysing quality of data
- Communication and feedback

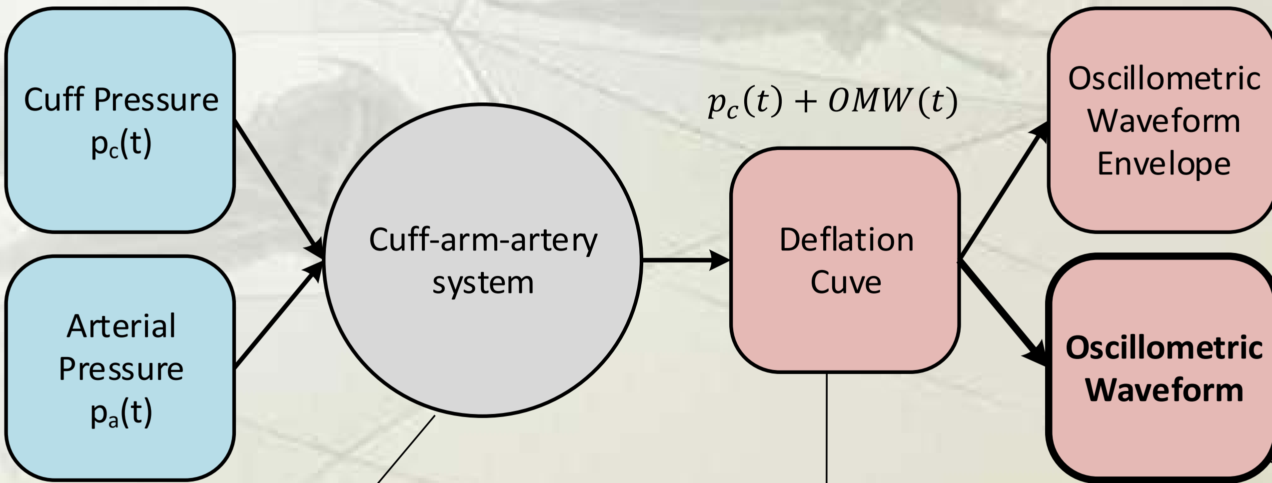
Time

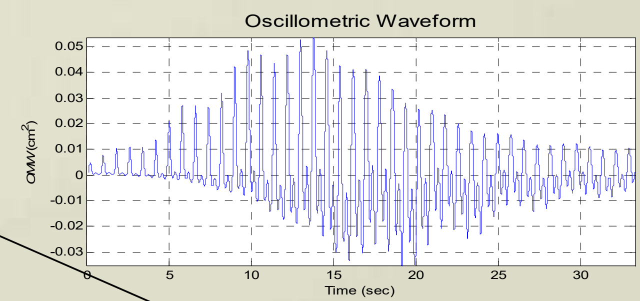
Innovation - modeling

- Accuracy needs to be improved
  - Rely on scientific approach - modeling
- Applications
  - Development of new algorithms
  - Understanding the mechanisms
  - Setting parameters of existing algorithms
- Types
  - Physiological models
  - Analytical models



Innovation - modeling





Sum of harmonically related sinusoids modulated by respiration

Oscillometric pulses are proportional to the oscillations of the arterial lumen area

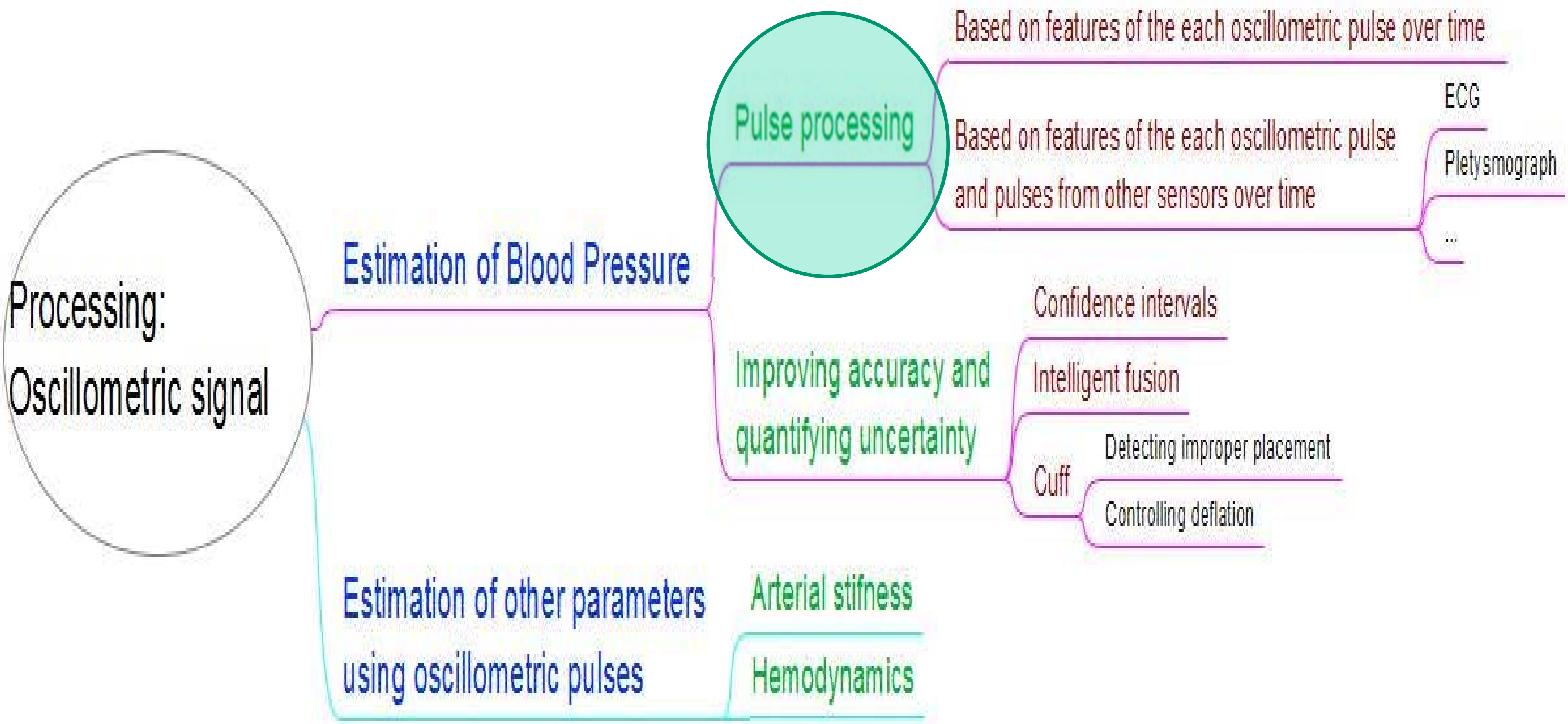
$$OMW(t) = \eta \times \big(A(p_a(t), p_c(t), constants) - A(MAP, p_c(t), constants)\big)$$

Arterial pressure - area relationship?

$$A(p_a(t), p_c(t), constants)$$

Two exponentials representing the arterial collapse and distension

Processing - Classification

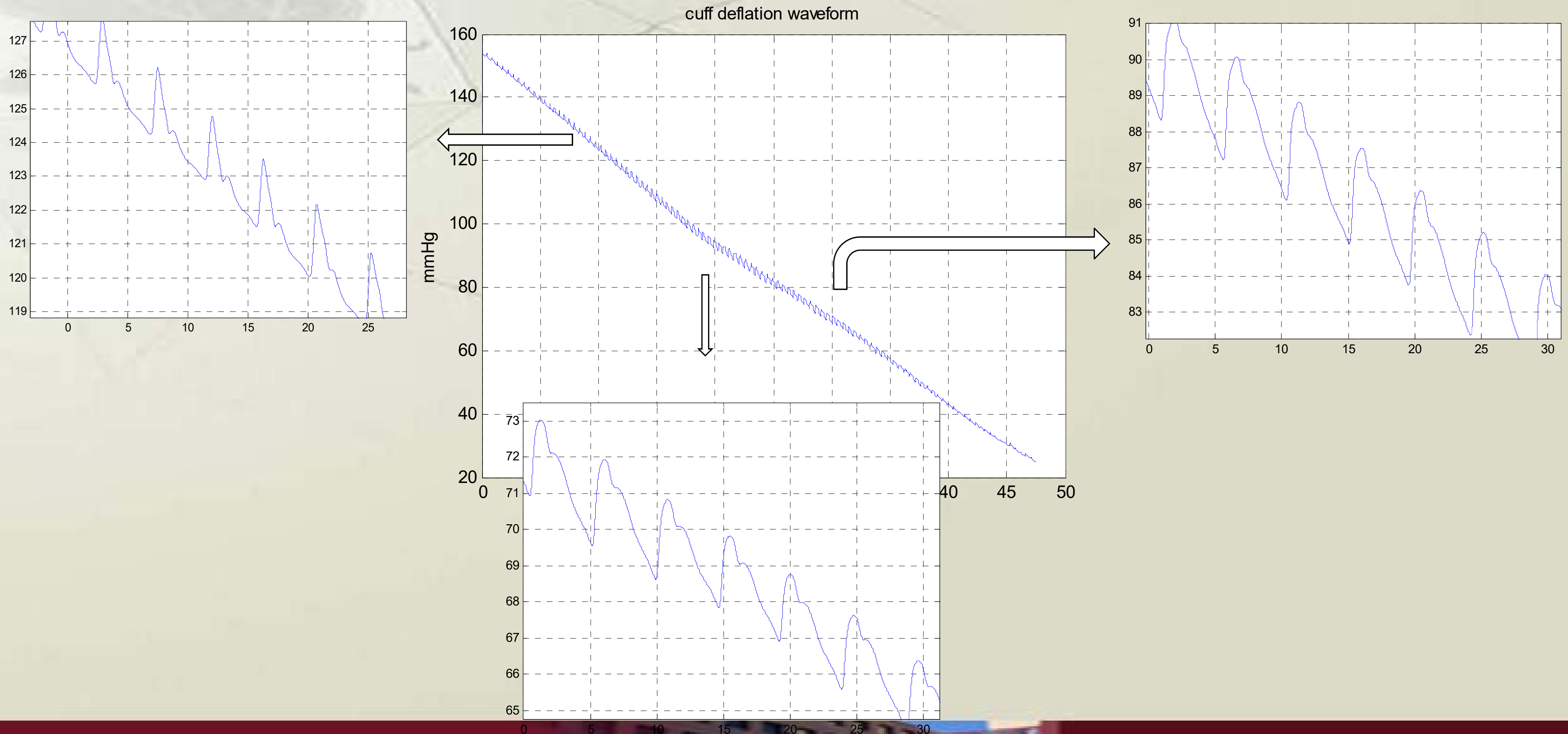


How one can process the pulse

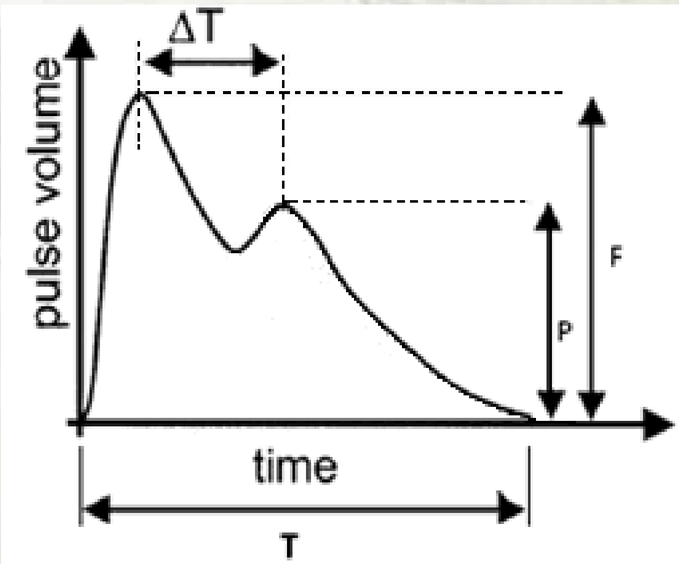
Features of the pulses	Procedure	Estimates and/or Results
Each oscillometric pulse separately	**Track features during deflation**	• **SYS, DIA, MAP**
Other sensors + oscillometric – Deriving common features for each pulse	Track features during deflation	• SYS, DIA, MAP
Features among neighbouring oscillometric and/or other pulses	Track features during deflation	• Breathing detection and removal • Artifact detection
Each oscillometric pulse separately	Several pulses at constant cuff pressure	• Augmentation index • Pulse wave velocity • Estimated of arterial BP
Changes in the pulses from the other sensors	During cuff deflation	• Automatically start of the next oscillometric measurement • Estimate SYS and DIA
Beat-to-beat monitoring using pulses from other sensors	Oscillometric method is used only for callibration	• Beat-to-beat pulse pressure

Pulse waveform at different pressure

- Pulse waveforms characteristics change at different pressure points in oscillometric cuff deflation pressure waveform

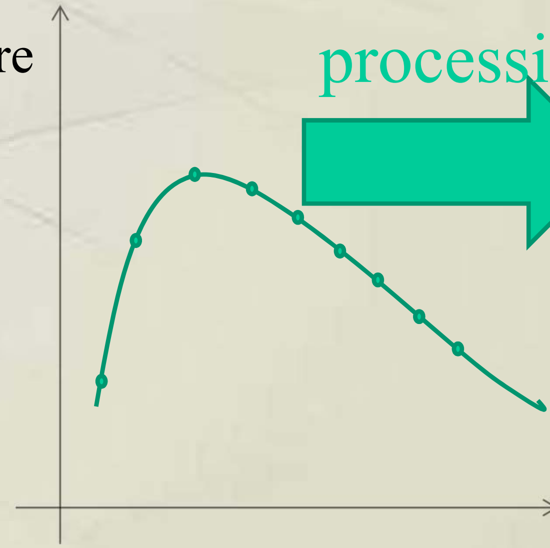


How can we process the pulse



Feature

Feature



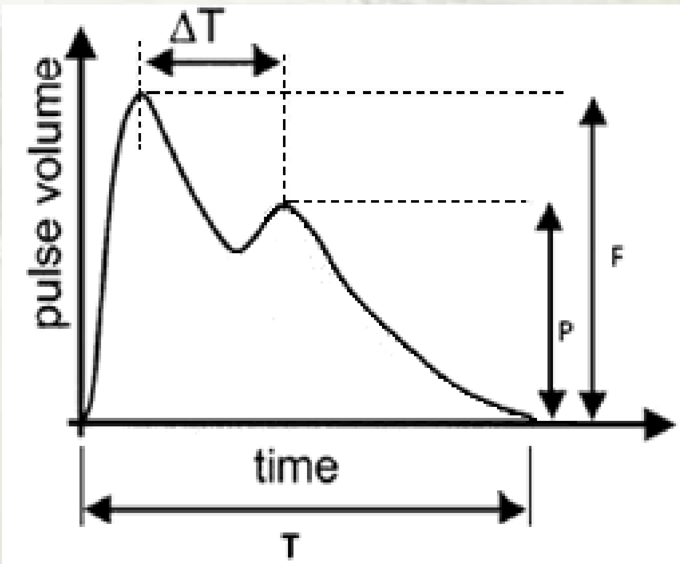
Preprocessing and processing

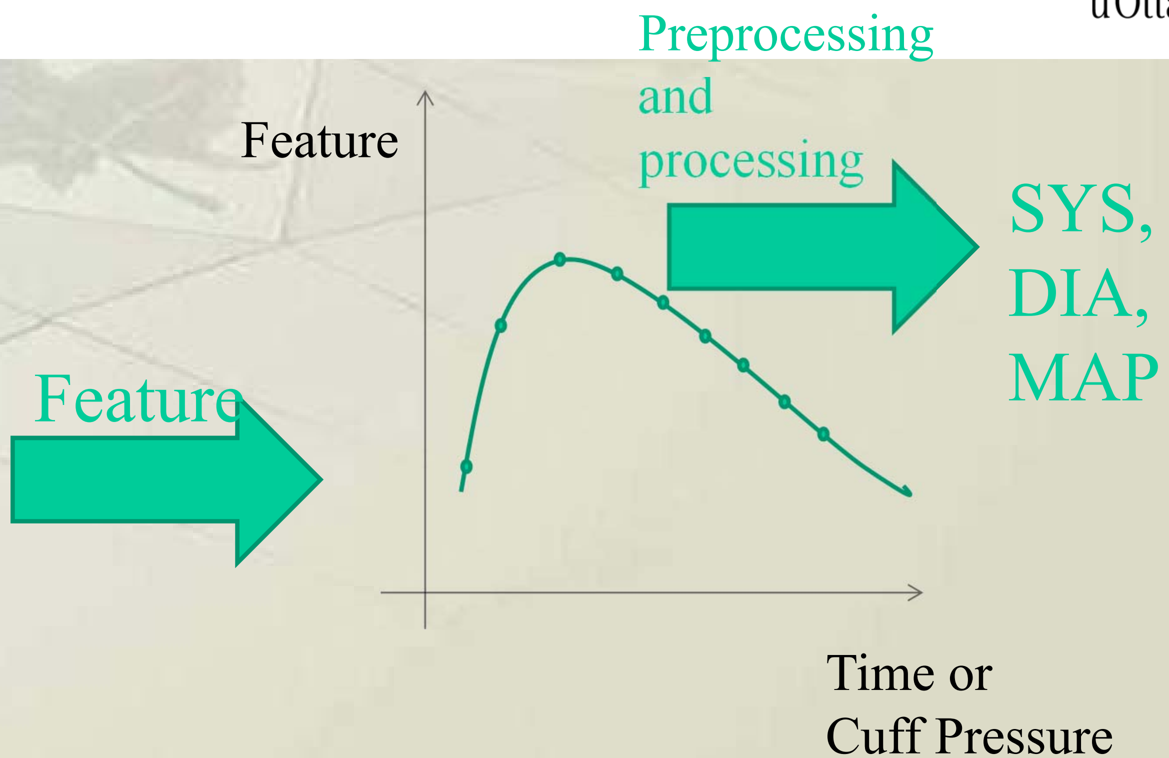
SYS, DIA, MAP

Time or Cuff Pressure

- Extracting features from a single pulse
- Looking at the function: the feature vs. time or vs. pressure
- Estimating the values of Systolic and Diastolic from the function.

How can we process the pulse – Innovation?





- What features to extract that would lead to determination of SYS, DIA and MAP
  - that have physiological sense?
  - that has high correlation with some other values?

Pulse processing – Amplitude based

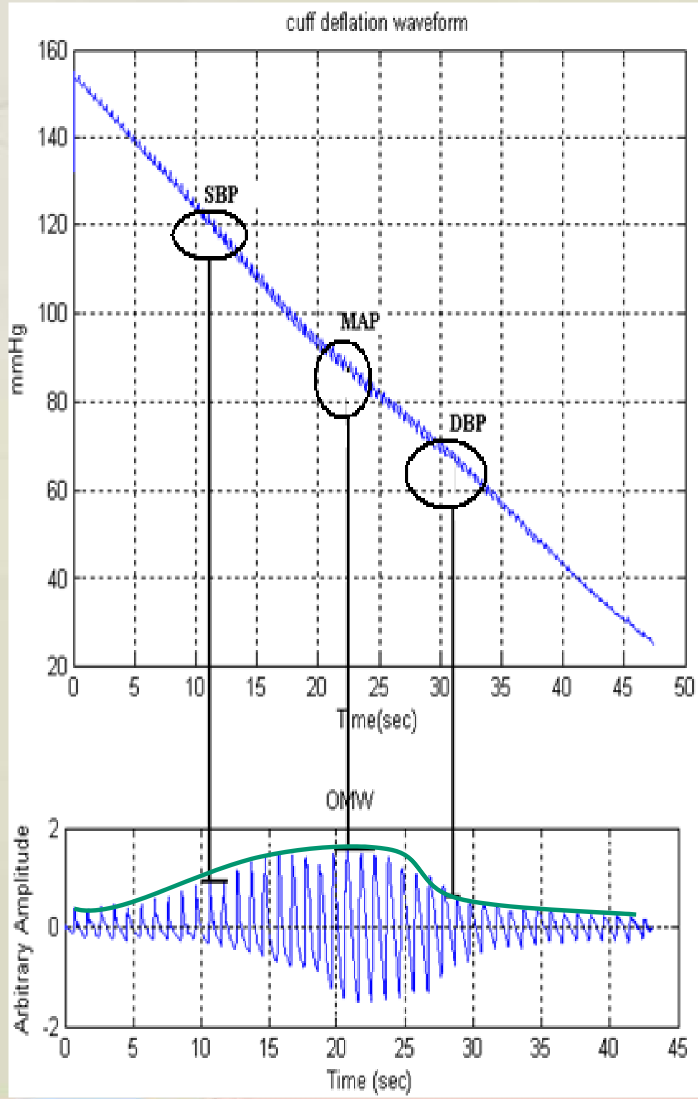
Feature of interest: Maximum of area or amplitude of pulses

Physiology: maximum of the function is found to correlate with MAP

- Preprocessing
  - Find maximum of pulses
  - Generate the function - envelope
  - Clean the envelope

- Processing
  - MAP - pressure that corresponds to the maximum
  - SYS = MAP * K_SBP
  - DIA = MAP * K_DBP

Maximum amplitude algorithm



Pulse processing - Amplitude Based

Disadvantages

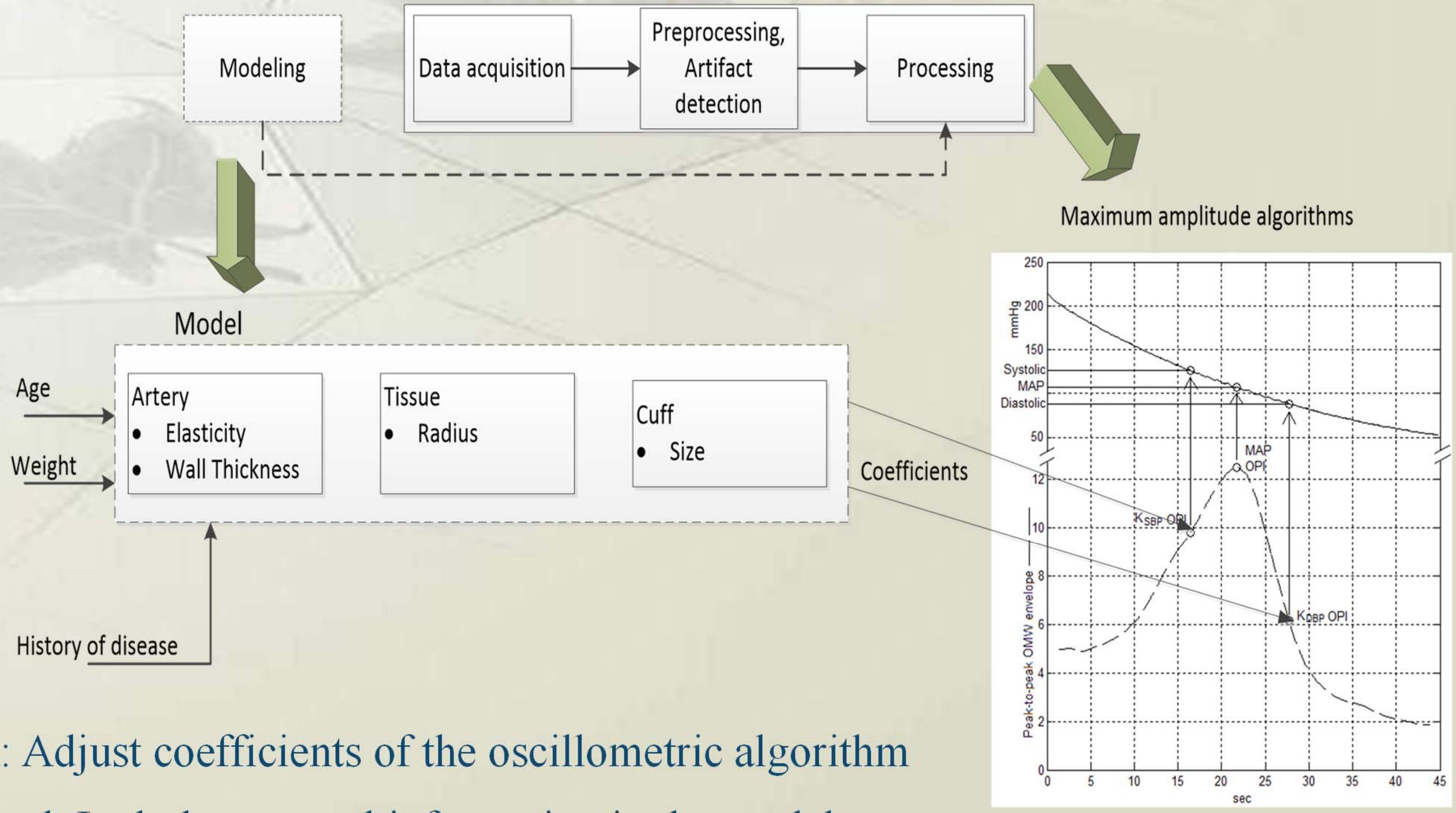
Disadvantages:

- Does not use the wealth of information from the pulse
- It is based on empirically derived coefficients for computing systolic and diastolic BP

Solution:

- Estimate coefficients
- Coefficient-free processing
    - Neural networks
    - Analysis of the pulse

Envelope processing – Amplitude based
Estimating coefficients



- Goal: Adjust coefficients of the oscillometric algorithm
- Method: Include personal information in the model

M. James, Simplified Model for the Design of an Oscillometric Blood Pressure Measuring System, PhD Thesis, University of Guelph, 2012.

Envelope processing – Amplitude based

Neural Networks

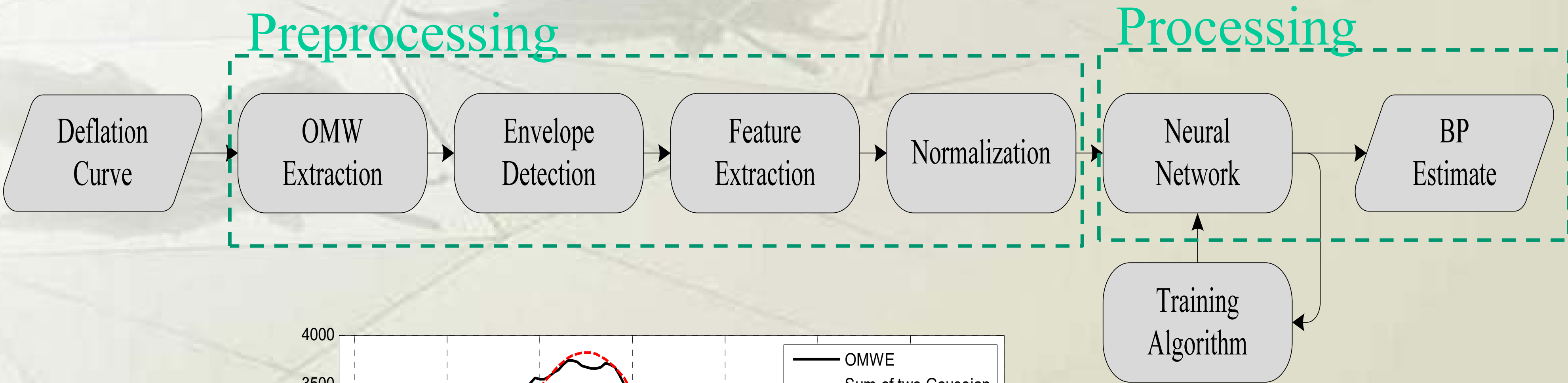
- Neural networks (NNs) can approximate almost any nonlinear relationship that exist between inputs and outputs

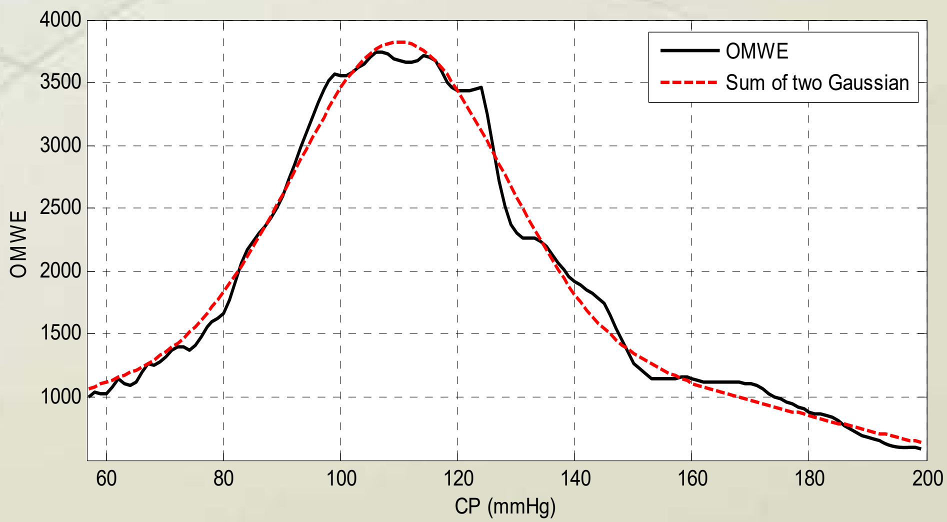
- Existing work:
  - The raw oscillometric waveform envelope (OMWE) is evenly sampled at specific increments of CP
  - The resultant samples are fed to the NN as input.

- Our approach:
  1. Modeling of the oscillometric waveform envelope as sum of two Gaussian functions as suggested in the literature
  2. Parameters from Gaussian functions are extracted
  3. These parameters are input to the network

Envelope processing

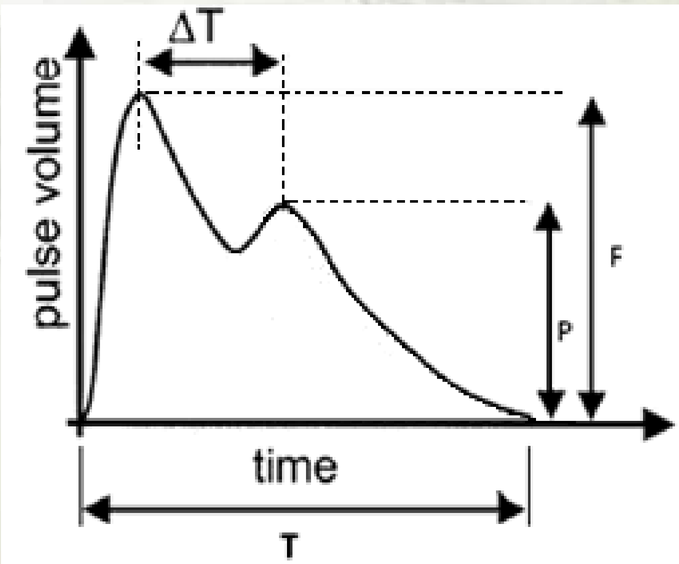
Neural Networks





$$OMWE(t) = A_1 \cdot \exp\left\{\frac{-(x-\mu)^2}{2{\sigma_1}^2}\right\} + A_2 \cdot \exp\left\{\frac{-(x-\mu)^2}{2{\sigma_2}^2}\right\}$$

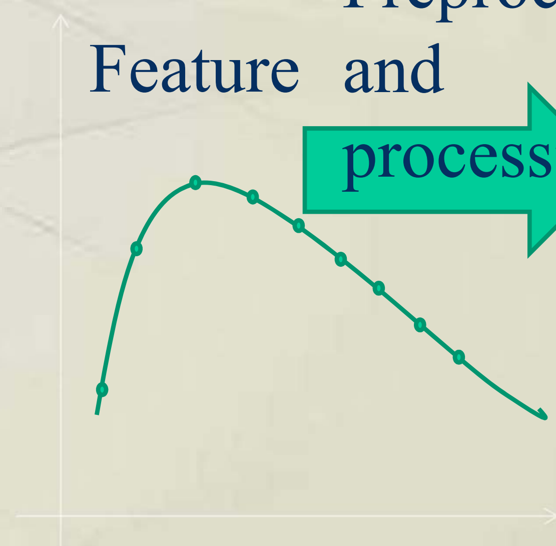
Features that can be extracted from a single pulse and tracked in time



Feature

Feature

Preprocessing and processing



SYS, DIA, MAP

Time or Cuff Pressure

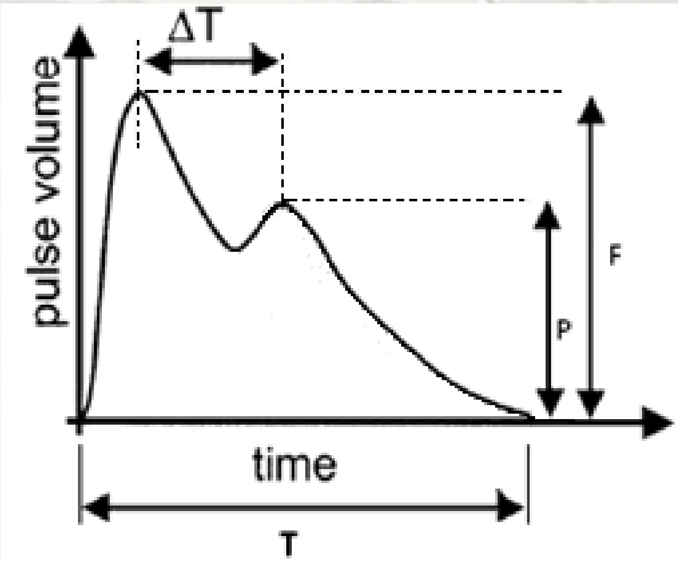
- Systolic & diastolic amplitude
- Systolic, diastolic slope
- ΔT/T ratio
- Area under systolic curve

- Pulse duration
- Existence of dicrotic notch
- Stiffness Index (SI)
- Reflection Index (RI)

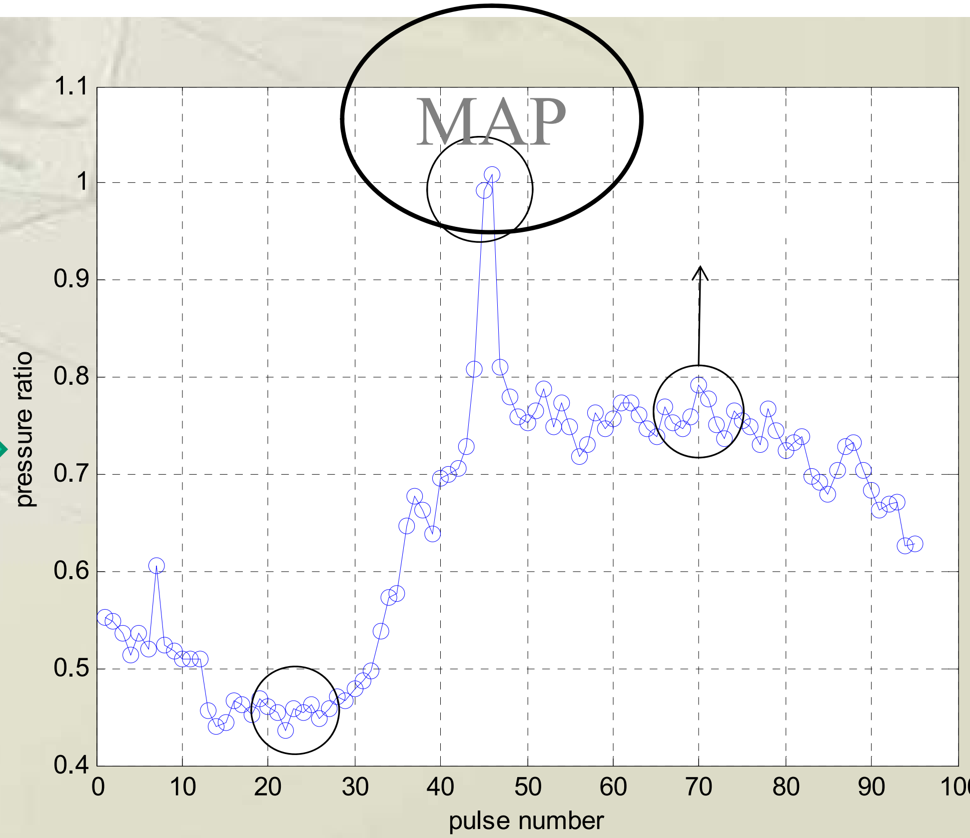
uOttawa

Analysis of the pulse

Other features



Feature



Reflection Index

$$(RI = \left[\frac{P}{F}\right] \times 100\%)$$

Processing:

- MAP – maximum of the function

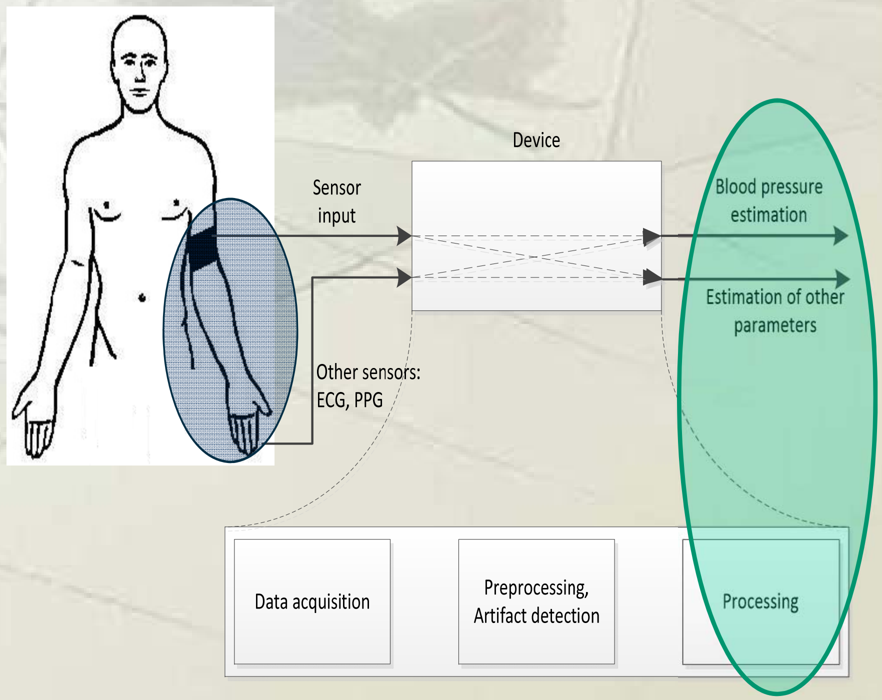
uOttawa

How can we process the pulse

Features of the pulses	**Procedure**	**Estimates and/or Results**
Each oscillometric pulse separately	Track features during deflation	• SYS, DIA, MAP
Other sensors + oscillometric – Deriving common features for each pulse	**Track features during deflation**	• **SYS, DIA, MAP**
Features among neighbouring oscillometric and/or other pulses	Track features during deflation	• Breathing detection and removal • Artifact detection
Each oscillometric pulse separately	Several pulses at constant cuff pressure	• Augmentation index • Pulse wave velocity • Estimated of arterial BP

Additional sensors besides a single cuff

uOttawa

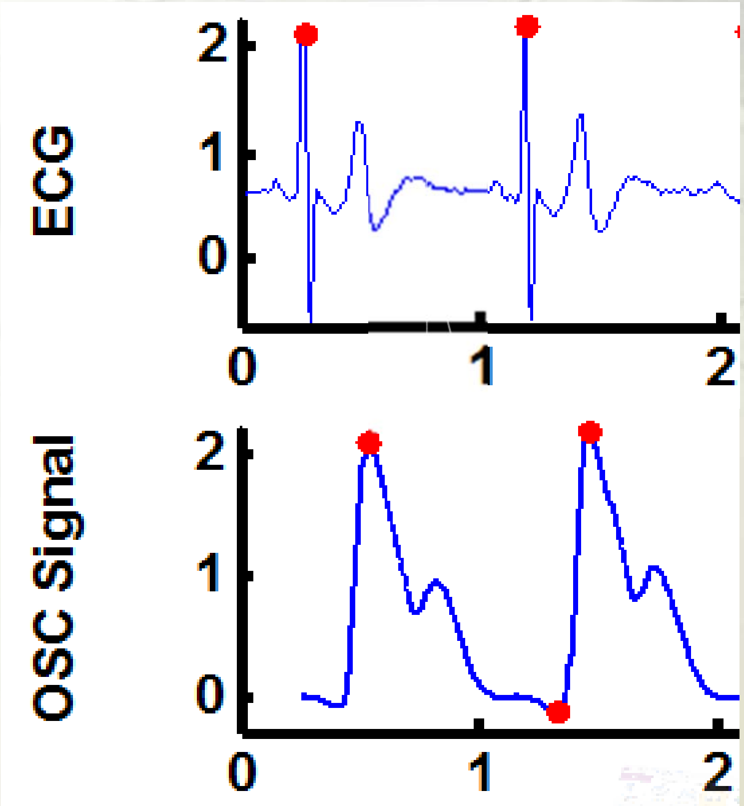


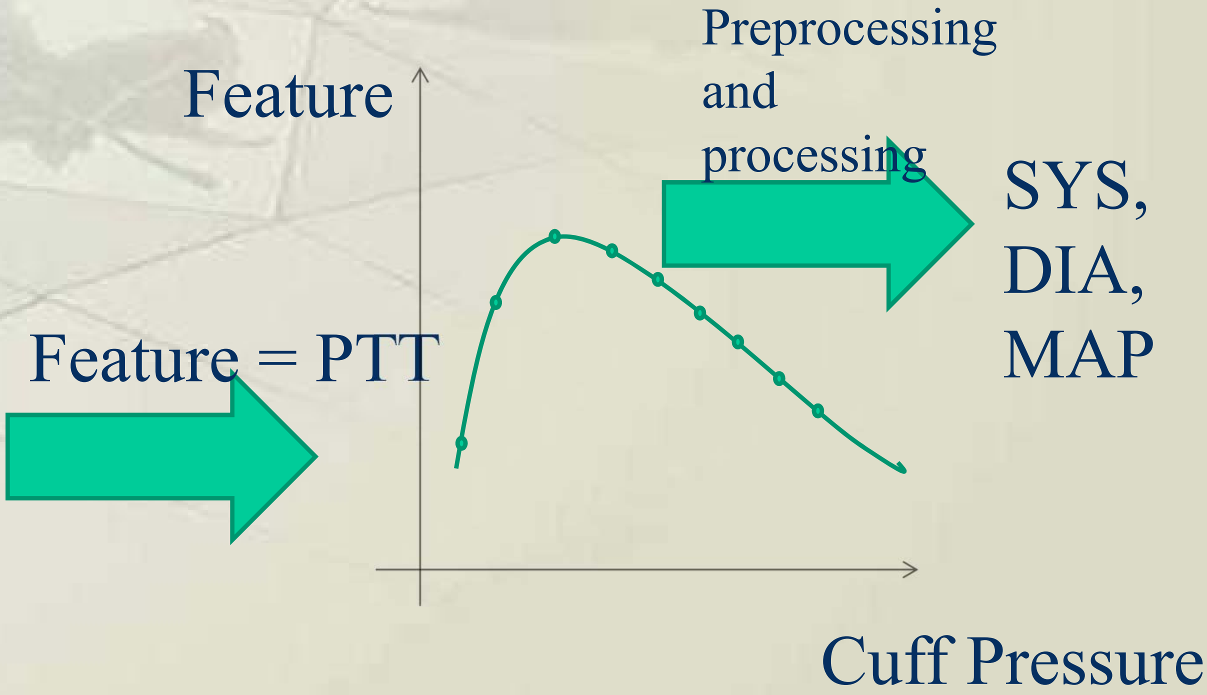
- Continuous (beat-to-beat) techniques
  - Pulse sensing techniques: Photoplethysmography, Tonometry
- Sampling techniques
  - Automated Auscultation
  - Doppler ultrasound Sphygmo-manometry
  - Oscillometry
  - Pulse transit time analysis

Pulse transit time

- Pulse transit time (PTT) is the time between two pulse waves propagating on the same cardiac cycle from two separate arterial sites.
  - has a correlation with systolic blood pressure
  - suitable for indirect BP measurements
- Blood pressure ↑
  The arterial compliance ↓
  Pulse wave velocity ↑
  PTT ↓
- Types of analysis
  - PTT-BP Correlation Analysis
  - PTT-Cuff Pressure Dependence Analysis

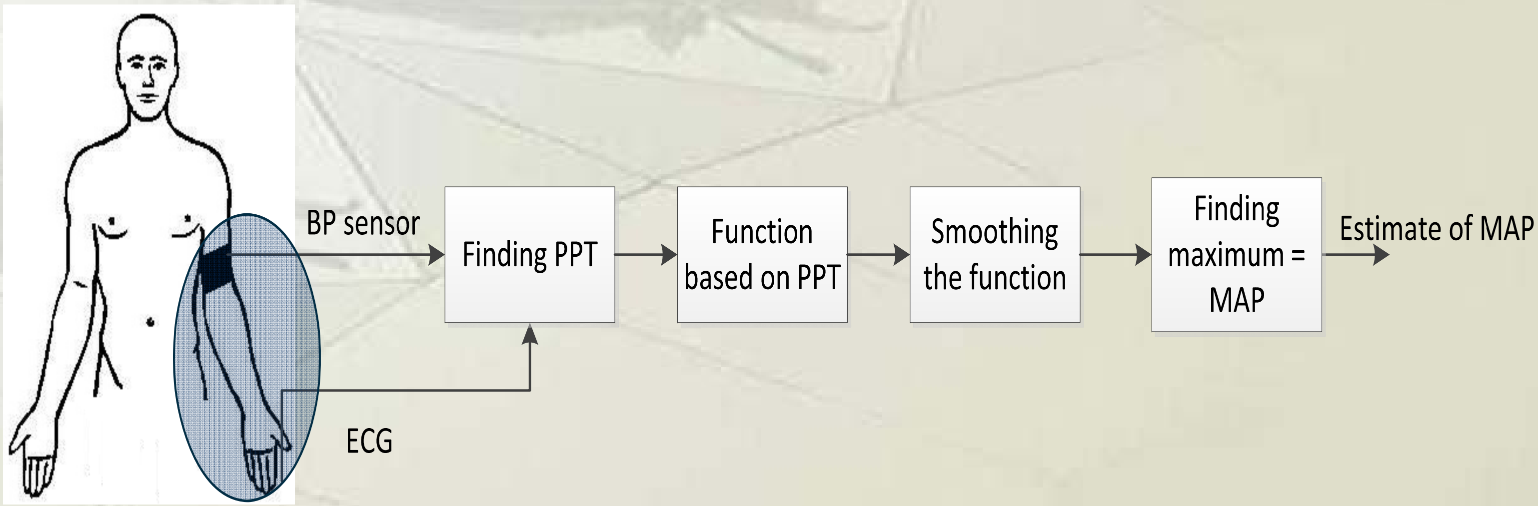
How can we process the pulse - PTT





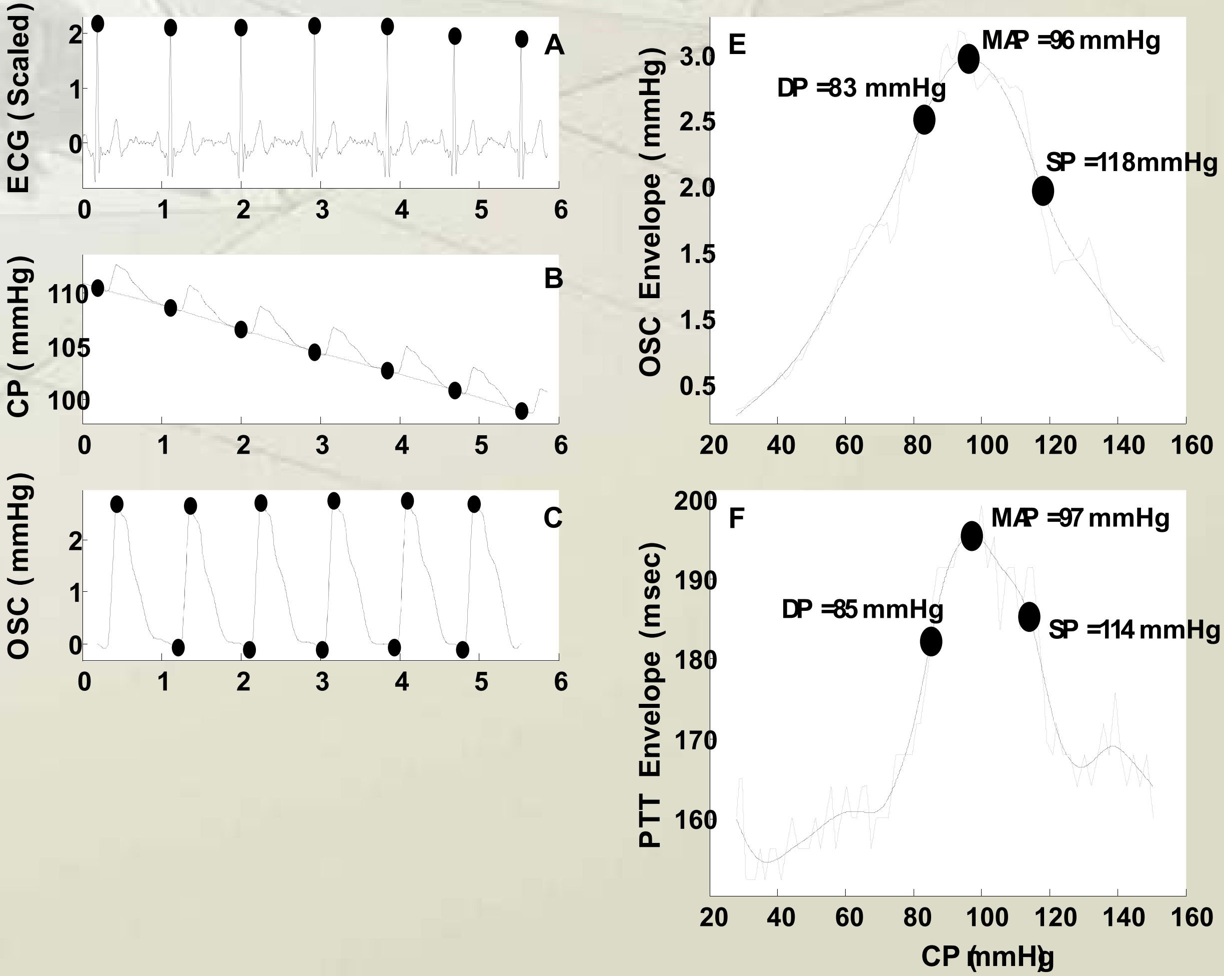
- Extracting PTT from a single ECG and oscillometric pulse
- Deriving a function PTT=f(cuff pressure)
- Maximum of the function corresponds to MAP

PTT-Cuff Pressure Dependence Analysis



- Require pressure/ECG sensors auxiliary to cuff
- Low diastolic accuracy

Pulse transit time



Pulse transit time - Results

Algorithm	Measure	Mean Absolute difference Between InBeam and Omron (mmHg)	
		≤ 5	≤ 10
Oscillometric Analysis	DP	84%	99%
	MAP	89%	100%
	SP	71%	97%
PTT-CP Analysis	DP	75%	97%
	MAP	89%	99%
	SP	61%	83%

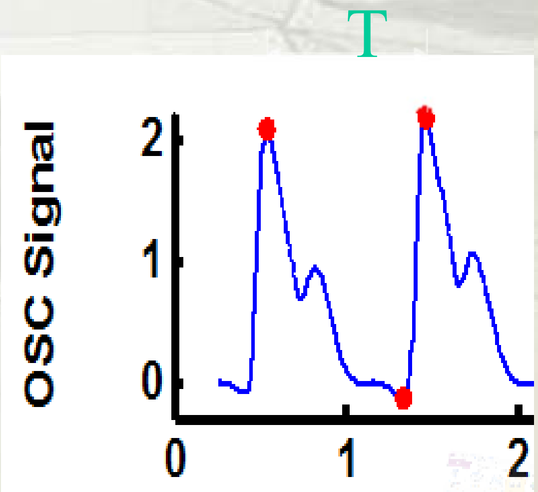
uOttawa

How can we process the pulse

Features of the pulses	Procedure	Estimates and/or Results
Each oscillometric pulse separately	Track features during deflation	• SYS, DIA, MAP
Other sensors+ oscillometric – Deriving common features for each pulse	Track features during deflation	• SYS, DIA, MAP
Features among neighbouring oscillometric and/or other pulses	**Track features during deflation**	• **Breathing detection and removal** • **Artifact detection**
Each oscillometric pulse separately	Several pulses at constant cuff pressure	• Augmentation index • Pulse wave velocity • Estimated of arterial BP

uOttawa

Extracting features from neighboring pulses



Features

- Detection and removal of respiratory component
- Arrhythmia detection

- Features of the oscillometric pulses
  - Time between oscillometric pulses
  - Difference in the amplitude

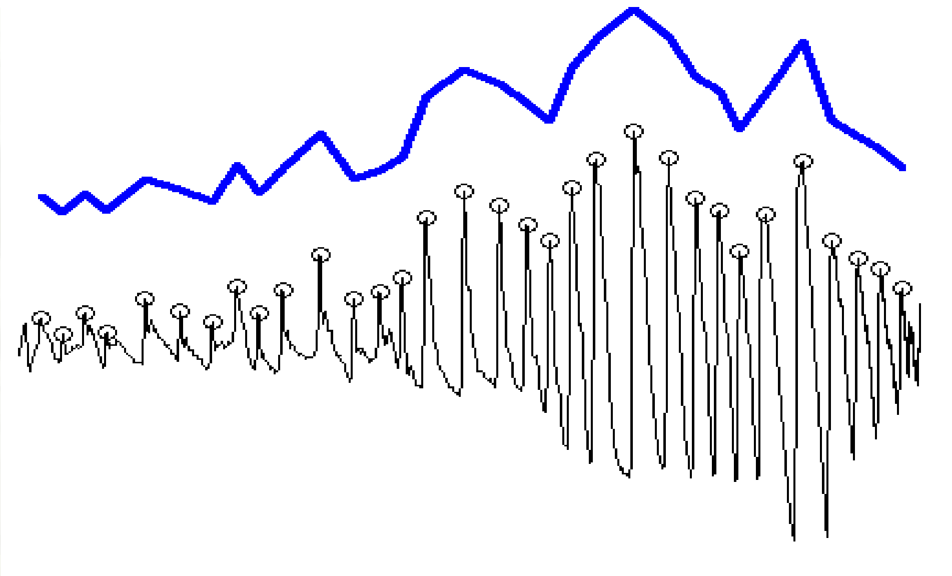
uOttawa

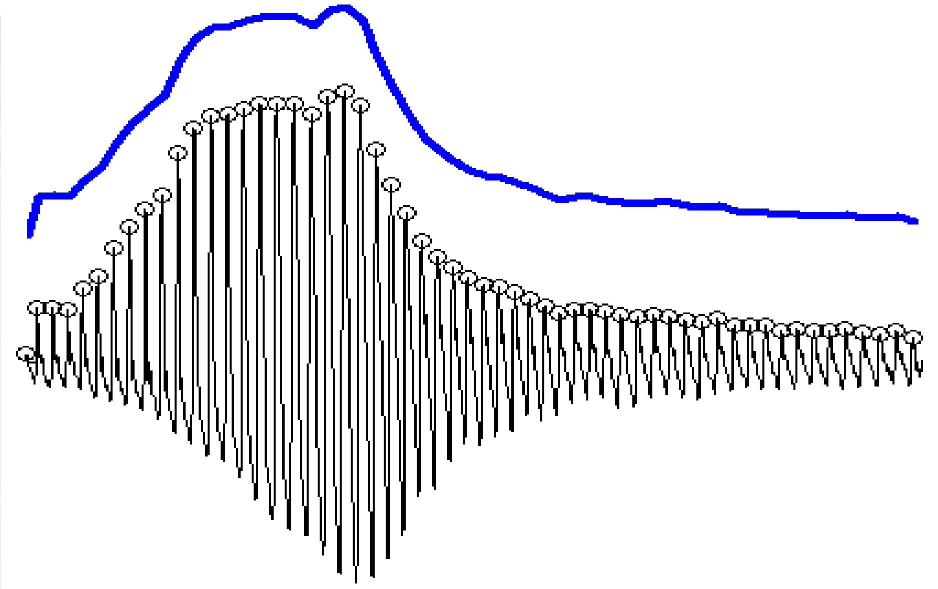
Detecting atrial fibrillation

- One of most common types of arrhythmia
- 0.5-1% of people with atrial fibrillation in developed countries
- Increases risk of stroke

- Oscillometric devices
  - e.g. (Microlife BPA100 Plus, Microlife, Heerbrugg, Switzerland)
  - Algorithm analyzes pulse rate irregularities
    - Irregularity Index=STD (of time intervals between successive heartbeats)/Mean > 0.06
- ECG assisted blood pressure device
  - Heart rate variability can be calculated the standard deviation of the RR intervals
  - Usually requires longer interval to collect data.

Breathing & Blood Pressure

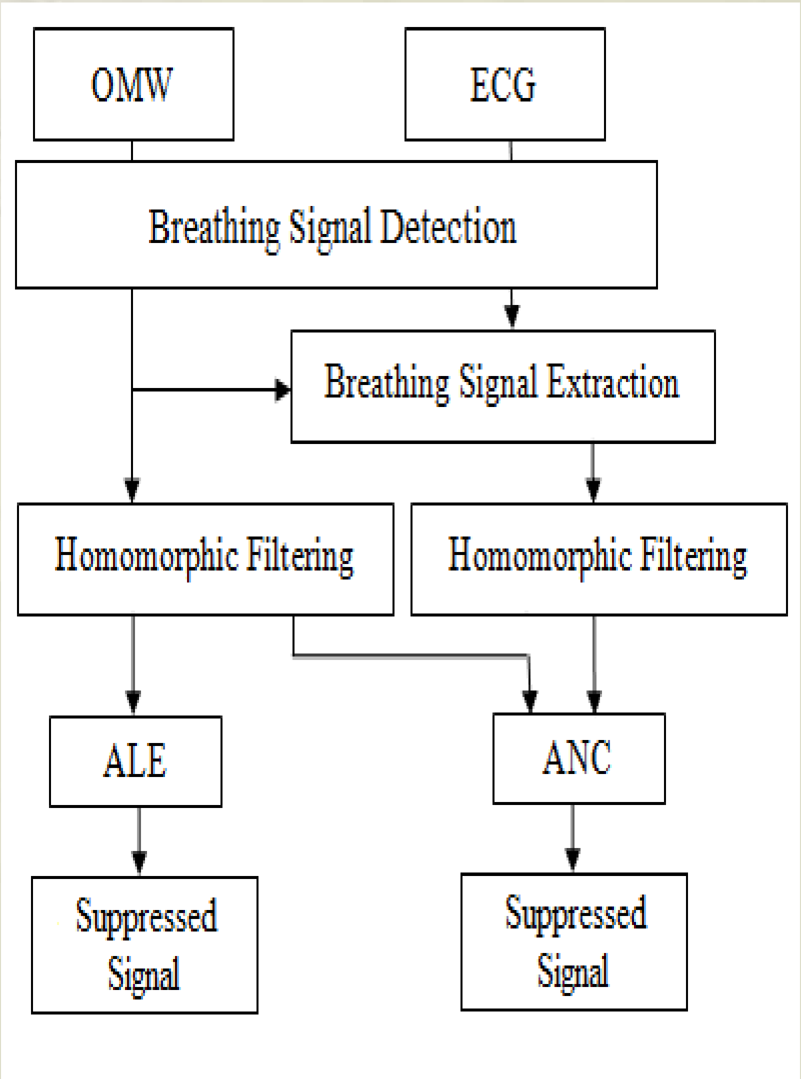




- SBP and DBP are known to fluctuate with inspiration and expiration;
  - respiratory variation in SBP can be 15 mmHg due to pronounced breathing
- Goal: Reduce effects of breathing on oscillometric BP signals
- Result: by reducing effects of breathing, the standard deviation of our estimates reduced.

Breathing & Oscillometric method

- Breathing effects manifest as AM, FM and additive effects in BP waveforms
- Existing techniques:
  - Adaptive filter with a proper reference signal
- In the case of oscillometric method:
  - Multiplicative noise must be dealt with
  - Possible situation to have no breathing waveform as reference



uOttawa

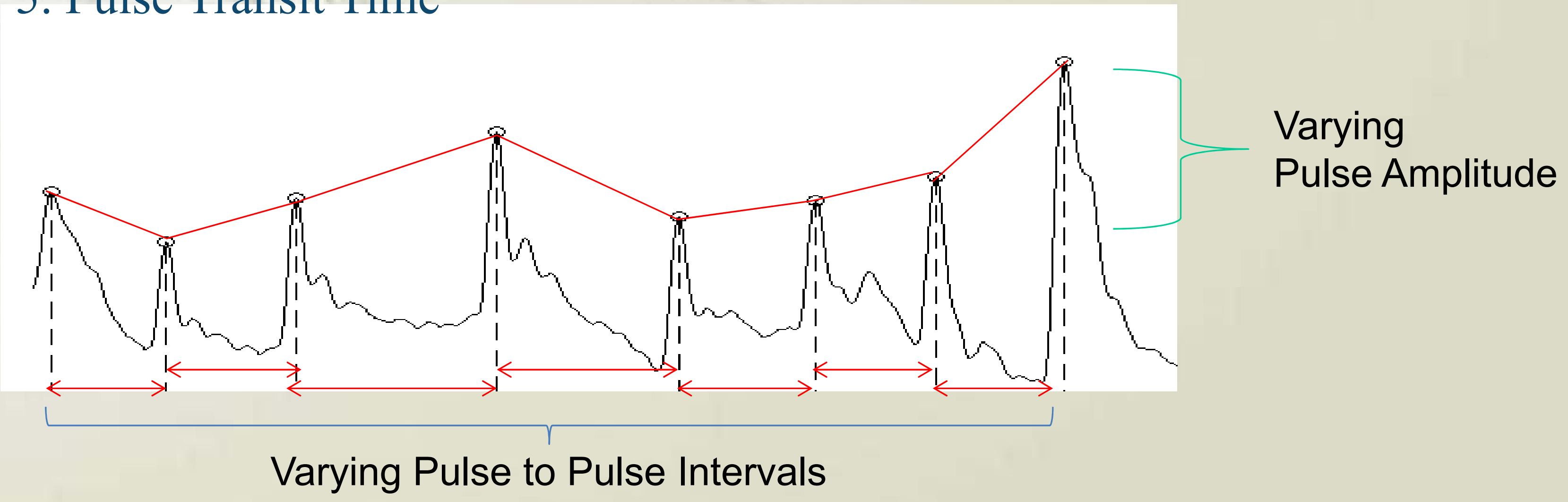
Breathing Detection

Breathing signal extracted from:

1. RR intervals of ECG 2. Amplitude of ECG

3. Pulse intervals of OMW 3. Amplitude of OMW

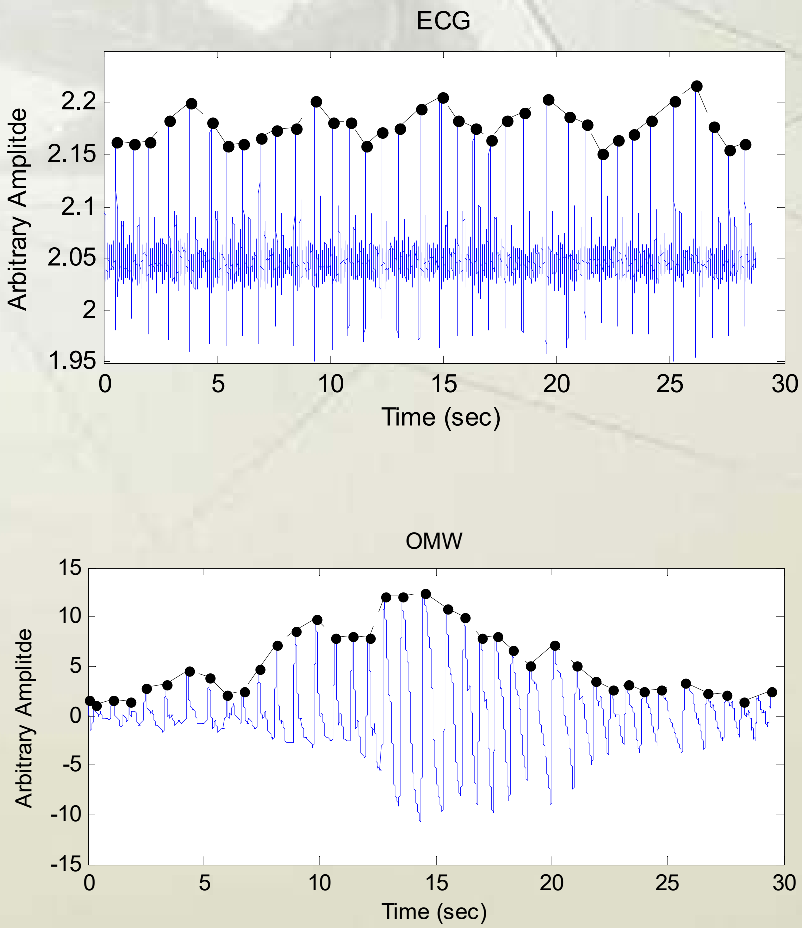
5. Pulse Transit Time

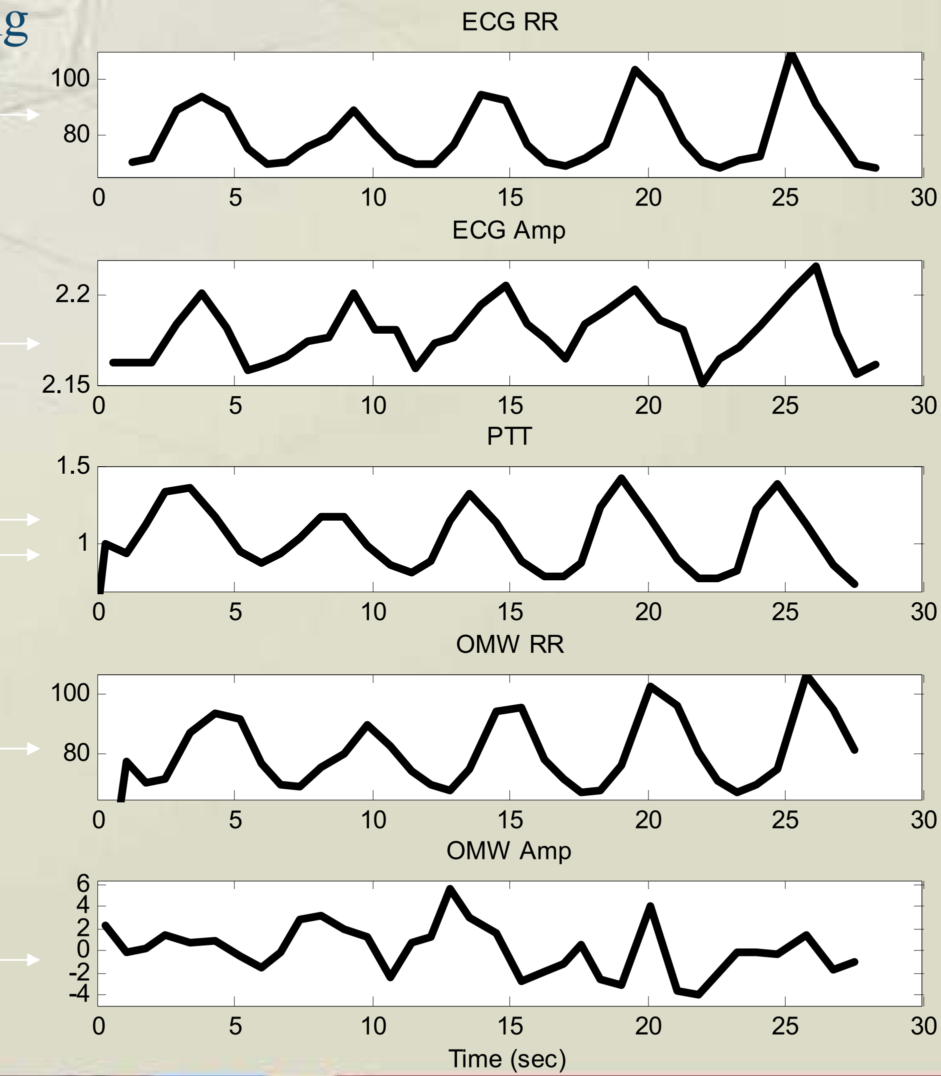


- Breathing interference detected by:
  - Frequency = 10 – 30 breaths per minute (12-20 is normal)
  - Amplitude = 20 – 50 ms RR interval

Breathing Detection

- ECG + OMW used to extract breathing



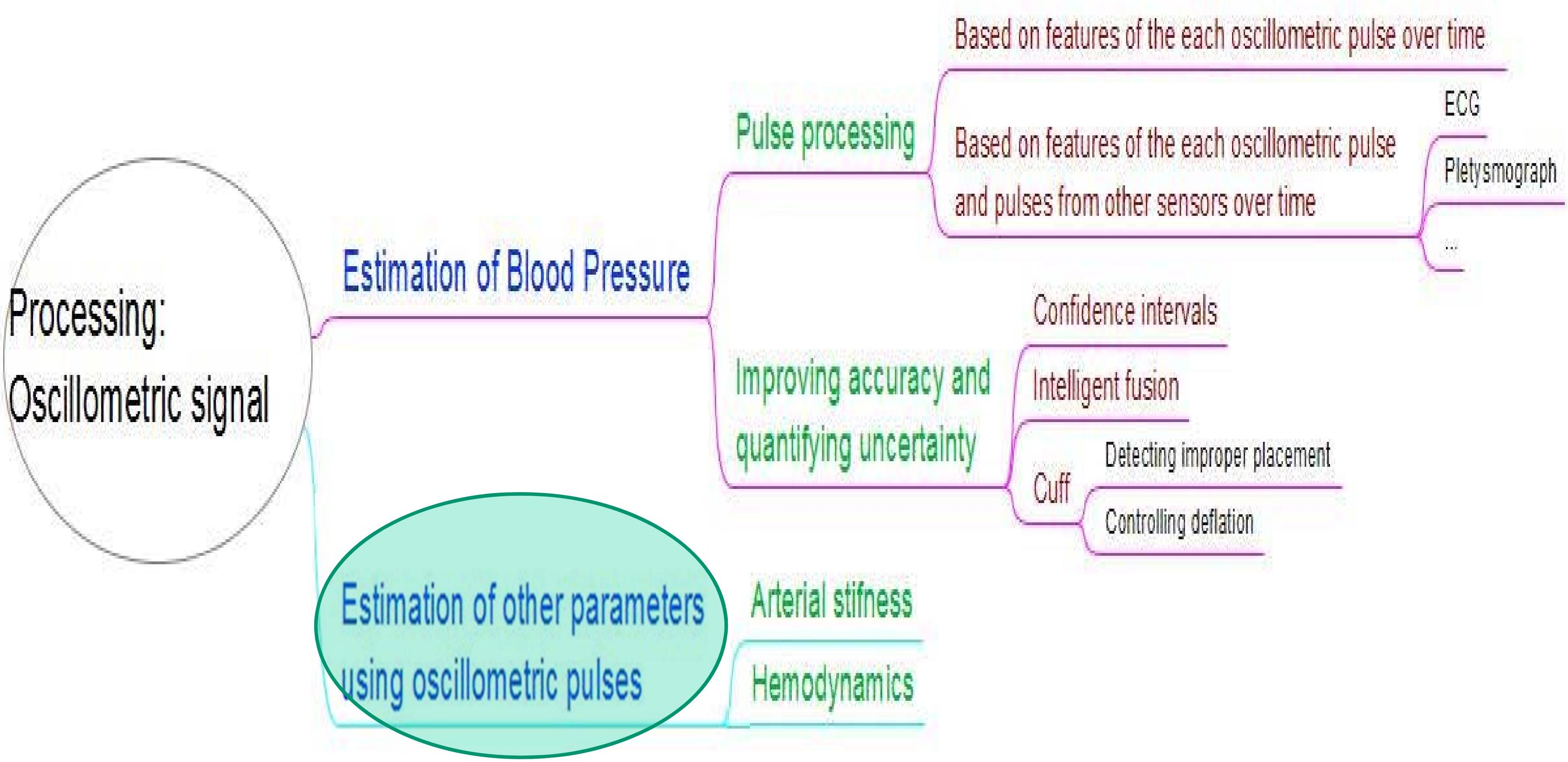


How can we process the pulse

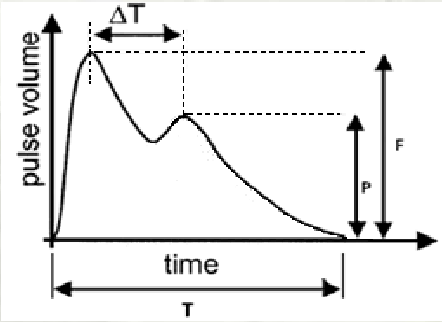
Features of the pulses	Procedure	Estimates and/or Results
Each oscillometric pulse separately	Track features during deflation	• SYS, DIA, MAP
Other sensors+ oscillometric – Deriving common features for each pulse	Track features during deflation	• SYS, DIA, MAP
Features among neighbouring oscillometric and/or other pulses	Track features during deflation	• Breathing detection and removal • Artifact detection
Each oscillometric pulse separately	**Several pulses at constant cuff pressure**	• **Augmentation index** • **Pulse wave velocity** • **Estimated of arterial BP**

uOttawa

Processing - Classification

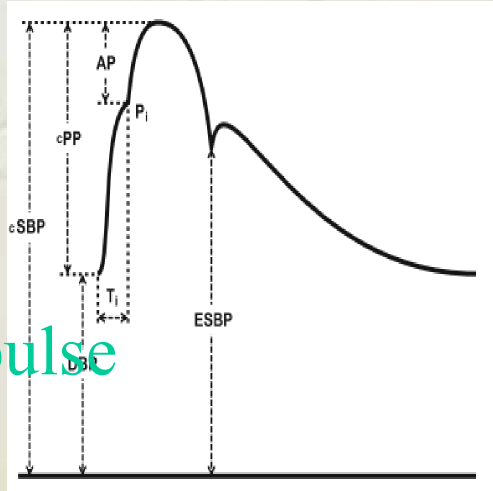


Processing the pulse



Features

Transfer function



Central pulse wave

Features

- Estimating
  - Central blood pressure
  - Arterial stiffness
  - Other parameters

uOttawa

Other application of oscillometry

- Estimating central blood pressure
  - Direct methods:
    - carotid tonometry
  - Indirect method: transfer function
    - Usually radial tonometry is performed, calibrated using oscillometric method and central blood pressure is calculated.
    - Based only on oscillometry

- Estimating arterial stiffness
  - Based on transfer function
  - Based on properties of the pulse

- Estimating hemodynamics [1] and other parameters
  - Heart rate variability
  - Left ventricular ejection time (LVET)
  - Cardiac output (CO)

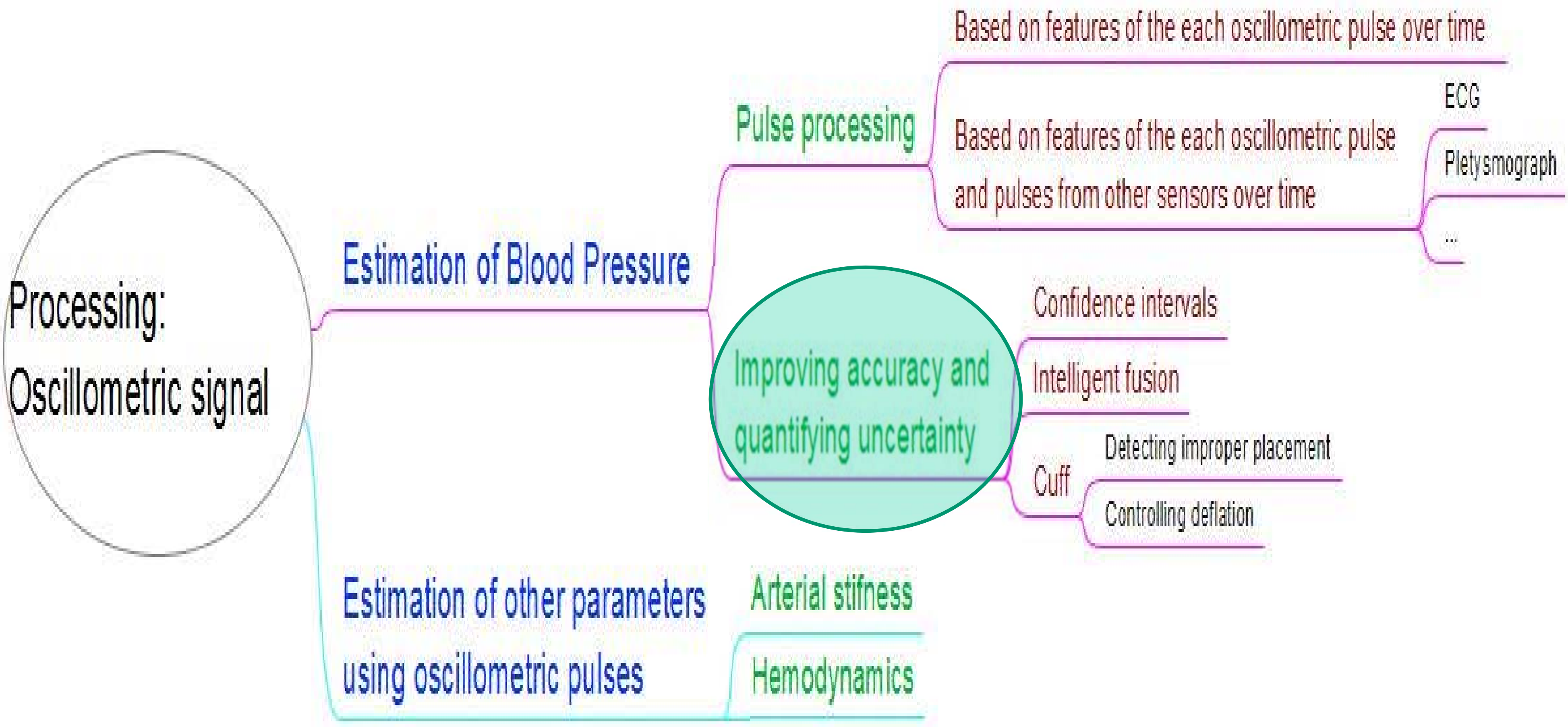
[1] J. Jilek, Oscillometric pressure pulse waveforms: their current and prospective applications in biomedical instrumentation, 13th WSEAS International Conference on SYSTEMS, 2009

Outline

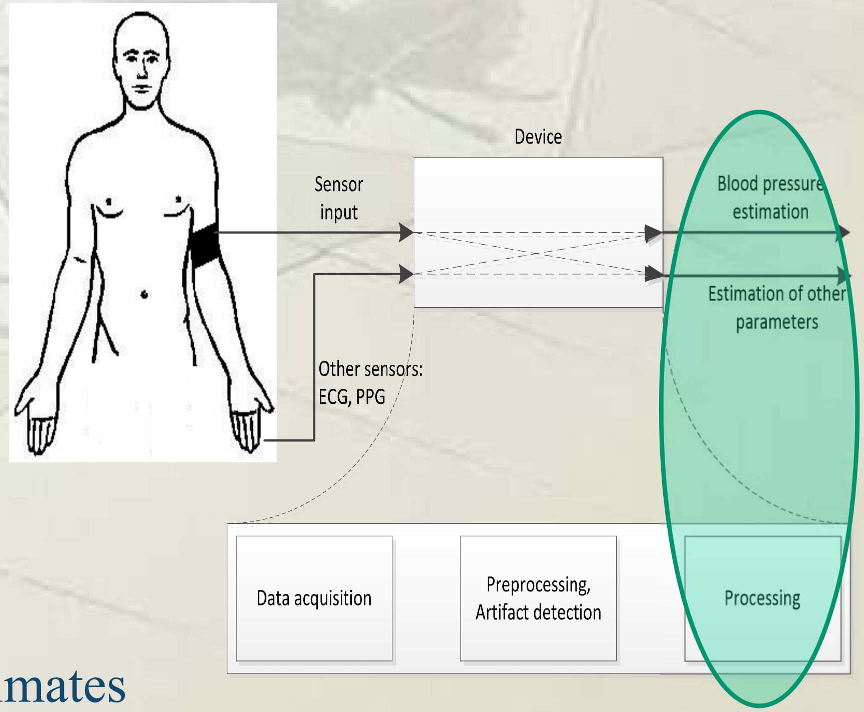
- Challenges and motivation
- Elements of the system
- **Pulse processing**
- Improving accuracy
- Subject and measurements
- Connectivity and Telehealth
- Overall integration
- Conclusion

uOttawa

Processing - Classification



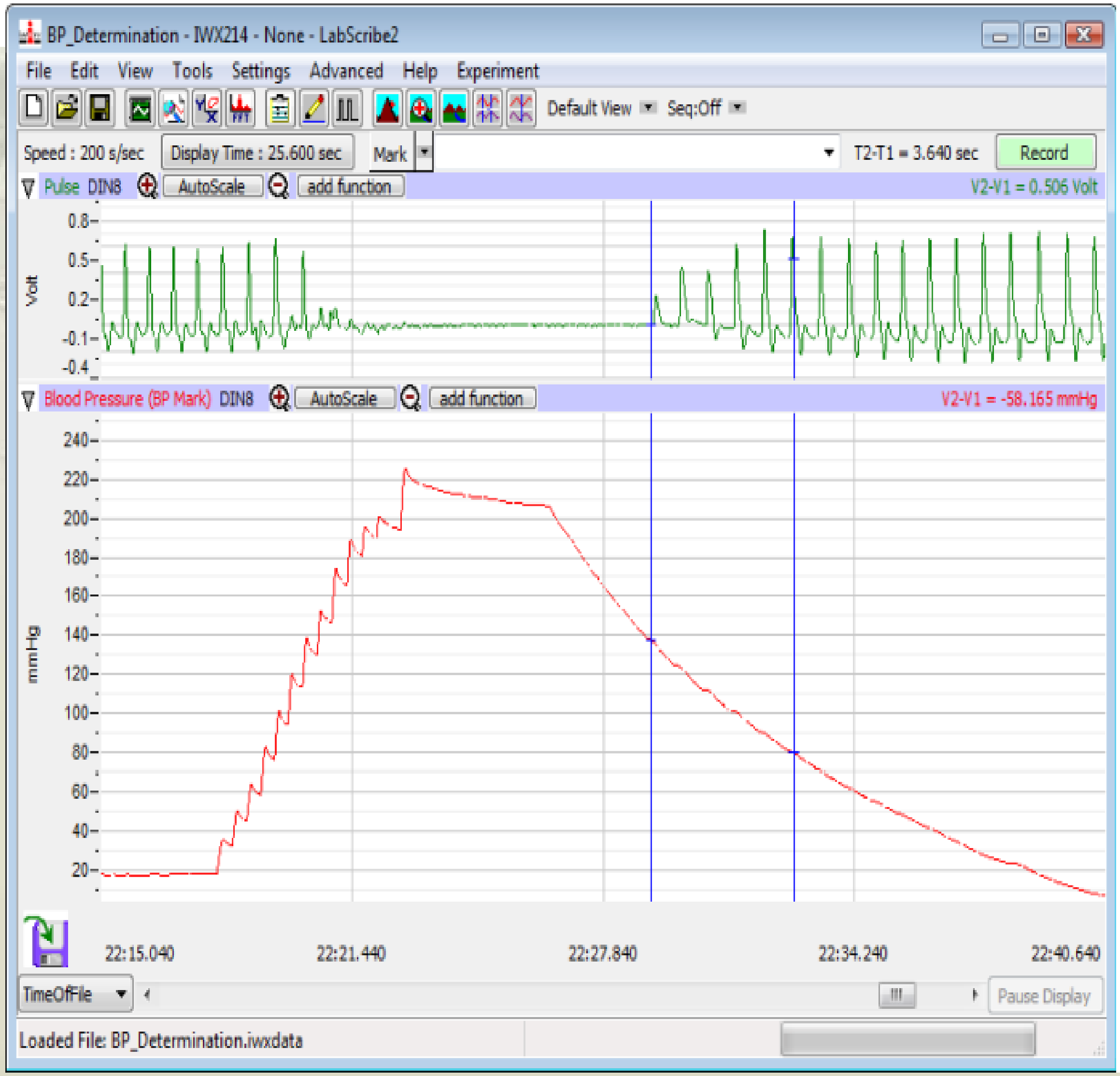
Processing – Fusion



- Combining estimates
  - hybrid estimate is able to overcome many problems affecting each individual algorithm
- How to combine
  - By selecting an appropriate algorithm
  - By weighing the estimates of different algorithms

Processing – Sensor fusion

- Fusing estimates from oscillometric and pulse plethysmograph
- Estimating BP from pulse plethysmograph
  - SYS: The pressure at which the plethysmograph pulse is first seen
  - DIA: The pressure at which the first maximum plethysmograph pulse wave is seen during the release of pressure



iWorx, BP-600 Noninvasive Blood Pressure Sensor

Processing – confidence intervals

- Resistant hypertension, is defined as > 140 mmHg
- Is the average pressure precise enough for classification or treatment effect, given the minute-to-minute variation of blood pressure?
- Confidence intervals: may provide cut-off points for classification as normal pressure, high normal pressure, or definite hypertension are to be excluded.

Processing – confidence intervals

Confidence intervals

- Computed for each measurement
- Computed based on the batch of measurements

Processing

- Preprocessing
  - Detecting the levels and type of the noise
- History
  - Take into account previous measurements
- Processing and fusion
  - Take information from several algorithms and compare them
  - Look at the individual pulses

Outline

- Challenges and motivation
- Elements of the system
- Processing techniques
- Preprocessing
- **Subject and measurements**
- Connectivity and Telehealth
- Overall integration
- Conclusion

uOttawa

Subject and Measurements

Adherence to measurement recommendations

- Recommendations
  - Patients must remain silent during measurements,
  - be seated correctly with back support and legs uncrossed,
  - must have rested at least 5 minutes prior to taking the measurement.
  - should reside in a quiet environment.

- Problem
  - current state-of-the art BP devices are not capable of sensing incorrect usage
  - Since only measurements follo wing the recommendations are considered reliable
  - data from the reported studies could be indeterminate

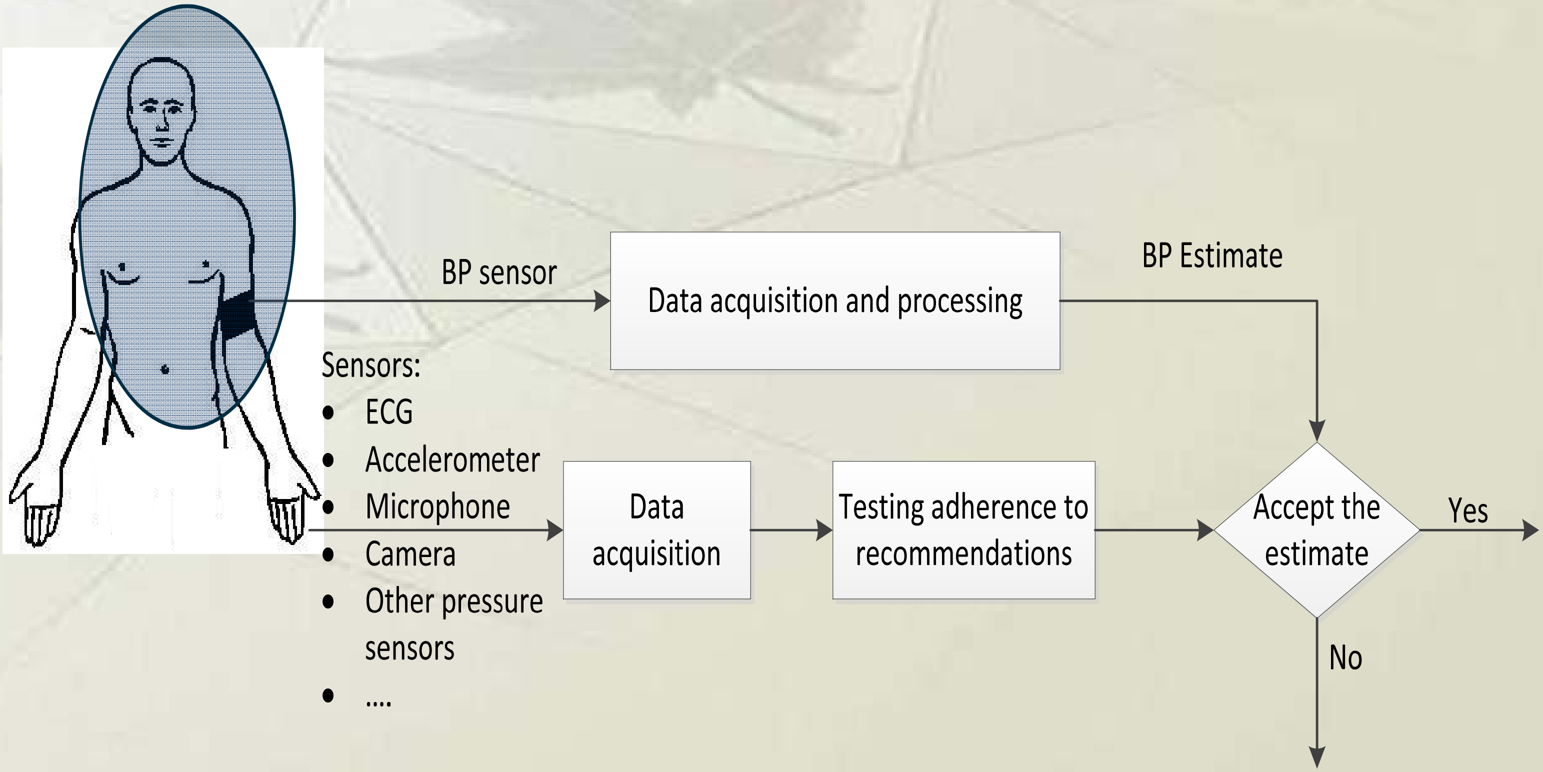
Factors that Can Elevate Blood Pressure Readings

Factors that Temporarily Increase Blood Pressure	Measurement Increase (mmHg)
Blood Pressure Cuff is too Small	Sys ▲ 10 to 40
Blood Pressure Cuff Used Over Clothing	Sys ▲ 10 to 50
Not Resting 3-5 Minutes	Sys ▲ 10 to 20
Arm/Back/Feet Unsupported	Sys ▲ 2 to 8 Dia ▲ 6
Emotional State	Sys ▲ 10 to 15 Dia ▲ 4 to 8
Talking	Sys ▲ 10 to 15
Smoking	Sys ▲ 5 to 10
Alcohol/Caffeine	Sys ▲ 5 to 10
Temperature	Sys ▲ up to 30 Dia ▲ up to 20
Full bladder	Sys ▲ 10 to 15

(Sys=Systolic; Dia=Diastolic)

Subject and Measurements

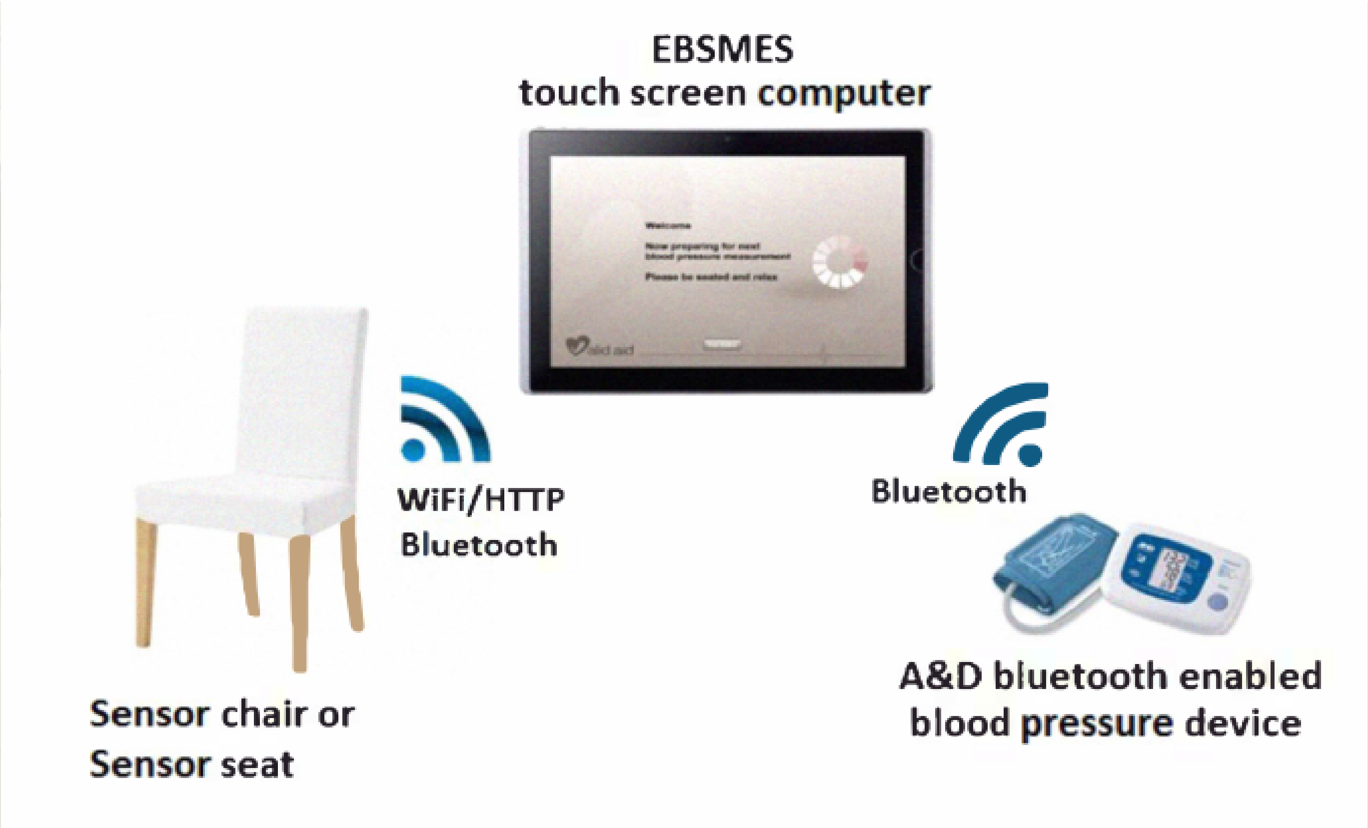
Adherence to measurement recommendations



- A number of sensors is used
- A number of research papers have appeared recently

uOttawa

Adherence to measurement recommendations



- The system monitors activity and posture
- The system records audio data and classifies as speech or silence.

uOttawa

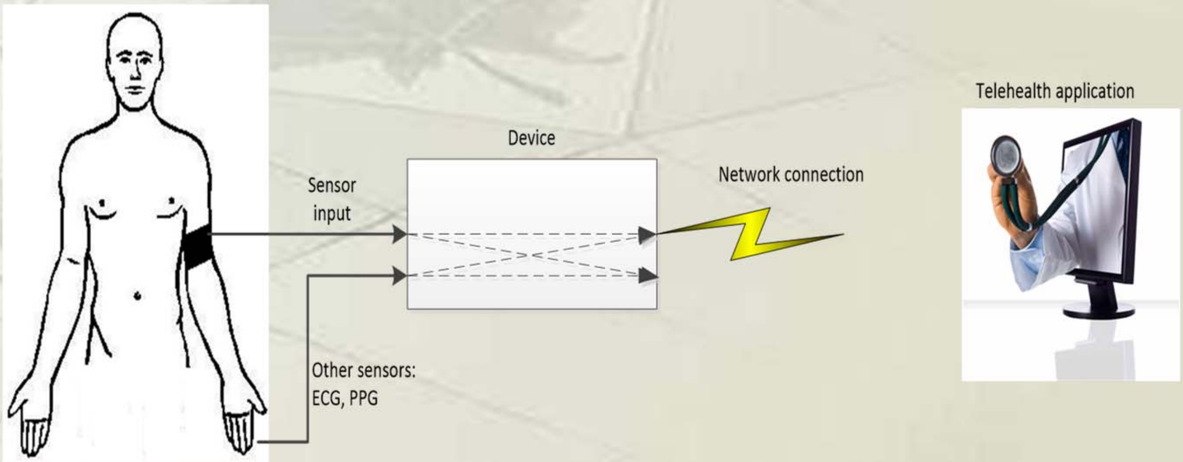
S. Wagner et. al. , Context Classification during Blood Pressure Self-Measurement using the Sensor Seat and the Audio Classification Device, PervasiveHealth Workshop, 2012.

Outline

- Challenges and motivation
- Elements of the system
- Processing techniques
- Preprocessing
- Subject and measurements
- **Connectivity and Telehealth**
- Overall integration
- Conclusion

uOttawa

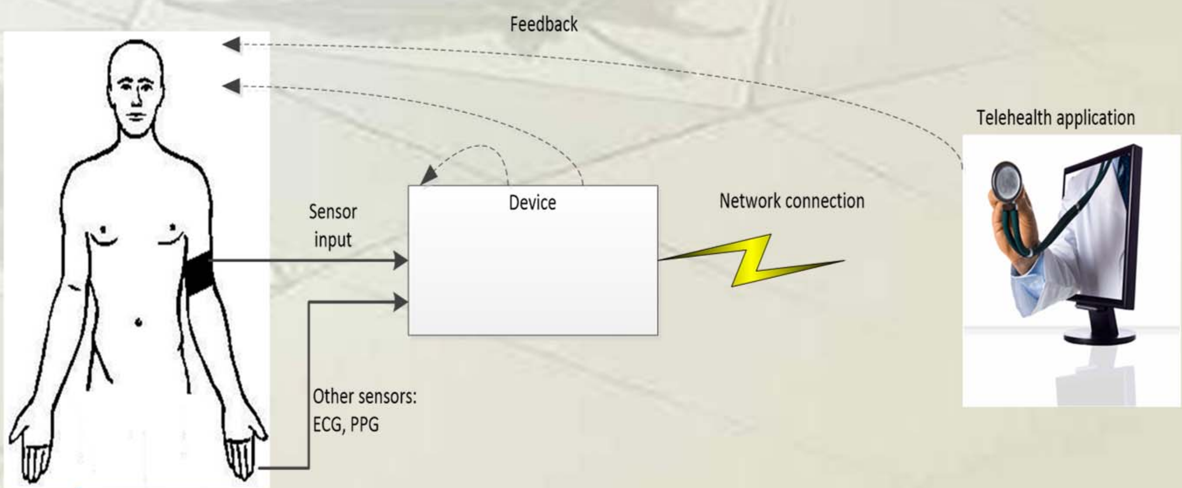
Connectivity



Purpose of connectivity:

- Algorithms run at the server
- Remote monitoring
  - Send vital information to a provider
- Telemonitoring
  - Real-time interaction between the patient and service provider
  - Store and forward – transmission of data for off-line processing

Providing feedback



Feedback

- Device
  - Correction of the algorithm after noise is detected.
- Device to the subject
  - Measurement recommendations are not followed and the subject is asked to repeat the measurement.
- Telehealth application to the subject

uOttawa

Outline

- Challenges and motivation
- Elements of the system
- Pulse processing
- Improving accuracy
- Subject and measurements
- Connectivity and Telehealth
- **Overall integration**
- Conclusion

uOttawa

Tons of Data

Health Level Seven (HL7)

Health Plans
- Plan coverage
- Negotiated provider rates

Secured

Health Professionals
- **Diagnosis**
- Health status
- **Medications**
- Physician notes per visit

Patient Record
- Personal history
- Tests, diagnostics
- Procedures
- Medications
- Insurance coverage

Patient
- **Family history**
- **Symptoms**
- **Diet journal**
- **Exercise notes**

Hospitals, clinics, labs
- Notes on procedures
- Signals (tests)
- Images

Research groups
- Government
- Academic institutions
- Industrial companies

Pharmacy
- **Prescriptions filled**
- Pharmacist reviews
- Coverage formulas

Anonymity

uOttawa

Data about Data

- Before considering the "information" contained in the table, one needs to see if there is enough information "about" that data:
  - Were BP and PR taken when the patient was "relaxed"?
  - Was the pulse regular? Otherwise both BP and PR are meaningless.
  - Was BG taken when the patient was "starving"?
  - Why once per day – that is, why this choice of sampling rate? Does "once per day" means "once, anytime during the day"?
  - Then, of course are the questions about the meters:
    - were they working as they should;
    - their precision and accuracy profile; and
    - did the patient used the same meter to take all those measurements?
- Since we have no data about the instrument use, no data on the patient condition at measurement time, etc., there is no point in even consider how informative such data set might be.

uOttawa

Data Acquisition

1. acquire the measured sample
2. verify the meter before each use
3. verify the patient “state” before each measurement
4. verify the results for “measurement error”
5. verify the results for “statistical significance”
6. verify the results for “clinical relevance”
7. If all checked, store the results in the record.
8. update the number of measurements required
9. update the sampling rate (when the next measurement should be taken)

uOttawa

Conclusions: Industry trends

- Specialization
  - Covering vertical markets that are not appropriately addressed
- Providing more information in a single device
  - Many devices do not provide only SYS and DIA blood pressure
- Personalization
  - Using information about the subject
- Miniaturization
  - Devices connected to the smartphone
- Automation
- Continuous, cuffless monitoring

Conclusions: Innovation

- Integration
  - Integrating many sensors
  - Integration with information systems
- Automation
  - Detecting a subject – detecting a signal, using NFC
  - Detecting patient medical condition (e.g. atrial fibrillation) and adjust the algorithm
  - Determining when to start the measurement
  - Checking adherence to measurement recommendations
  - Automated real-time control of the cuff
- Processing
  - Analysing quality of data acquired
  - Sensor and information fusion

uOttawa