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TU/e - Signal Processing Systems
*SEBAN (**S**mart **E**nergy **B**ody **A**rea Sensor **N**etworks for Pregnancy Monitoring)*

18th October 2011

Fetal monitoring on the move,
from a hospital to in-home setting

stw

TU/e Technische Universiteit **Eindhoven** University of Technology

Where innovation starts

Fetal monitoring

Overview

- Fetal monitoring introduction
- Physiology and abdominal signals
- The new approach
  - Top level power optimization
  - System level power optimization
  - Front end power optimization
  - Algorithmic optimizations
- Conclusion

Fetal monitoring

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Fetal monitoring

Problem

Two major problems in obstetrics:

Premature birth and ***asphyxia***

Premature birth

- > 10.000 cases in NL each year
- major cause of neonatal mortality
- <u>direct</u> health care costs ≤ 100k€

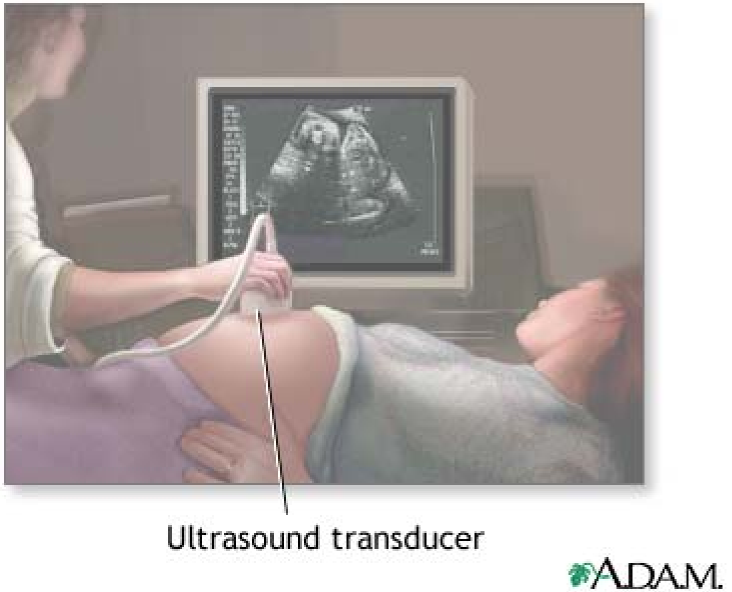
Perinatal asphyxia

- ca. 2000 cases in NL each year
- often needs life long special care
- follow up costs ≤ 900k€

Fetal monitoring

Clinical practice

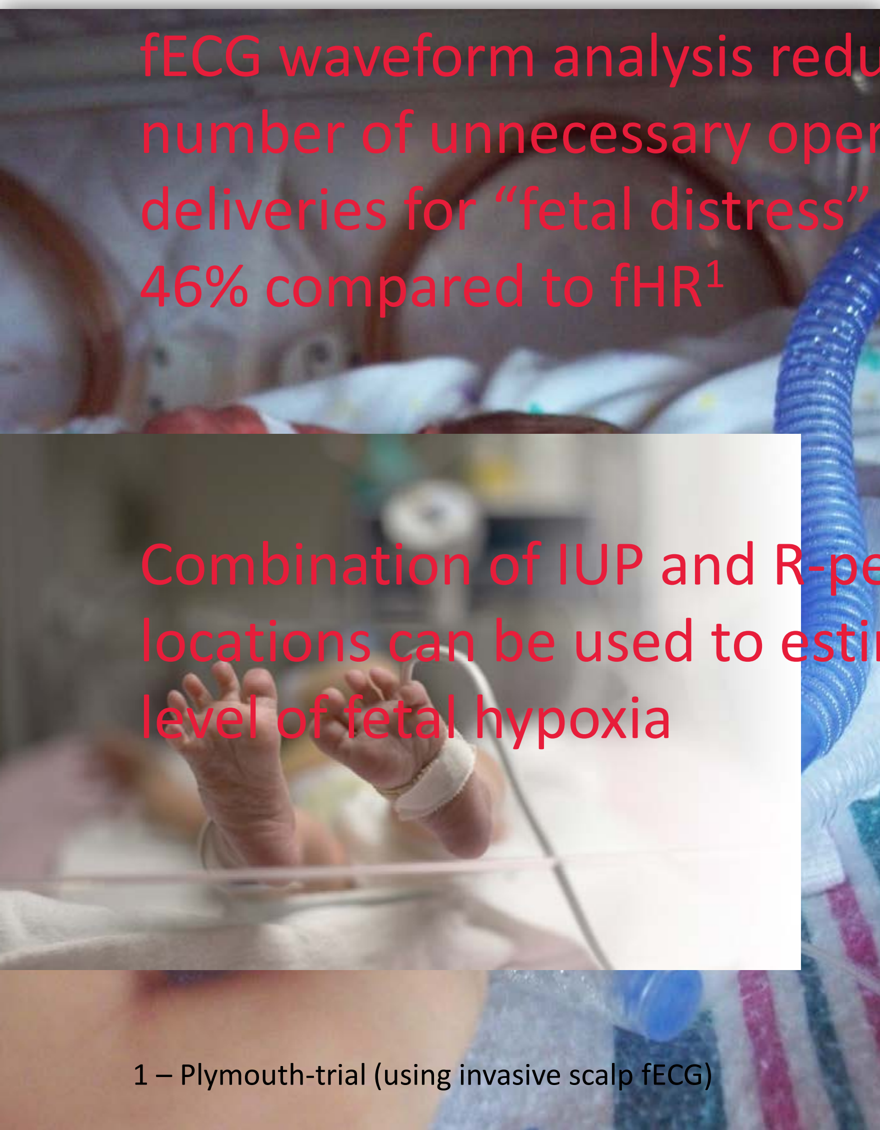
During pregnancy



- Intermittent measurements
- Fetal heart rate (no ECG)

Fetal monitoring

Clinical practice

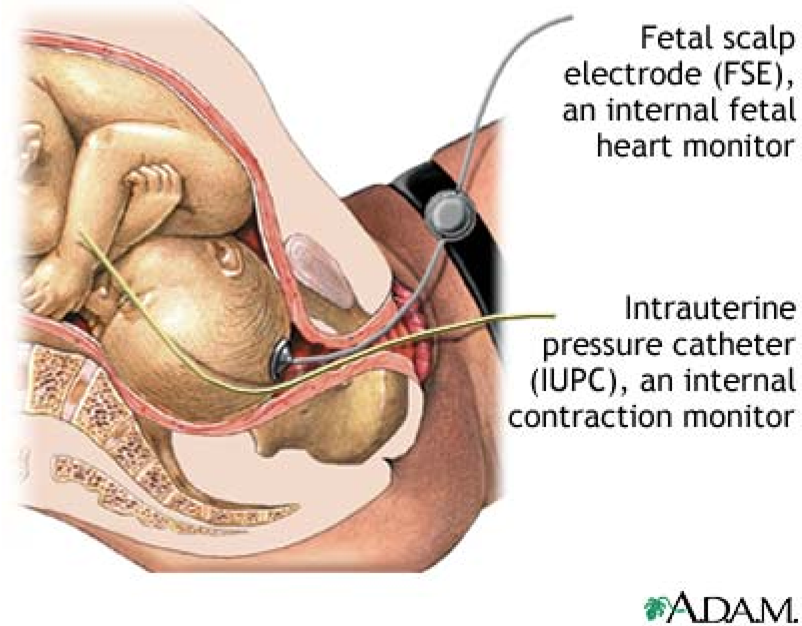


fECG waveform analysis reduces number of unnecessary operative deliveries for “fetal distress” by 46% compared to fHR[1]

Combination of IUP and R-peak locations can be used to estimate level of fetal hypoxia

1 – Plymouth-trial (using invasive scalp fECG)

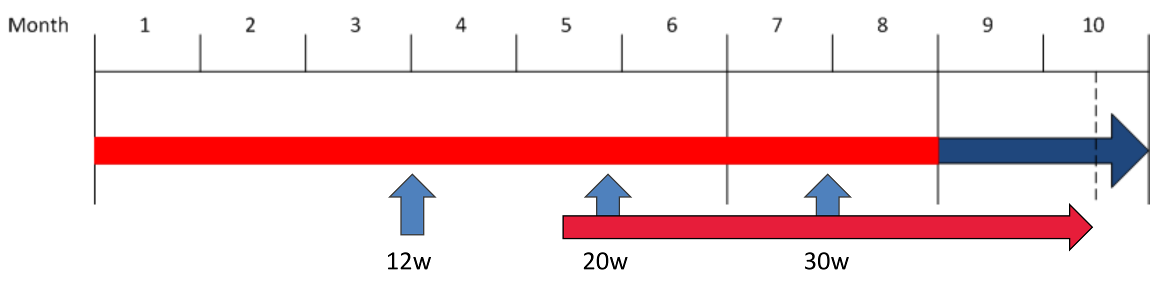
During delivery

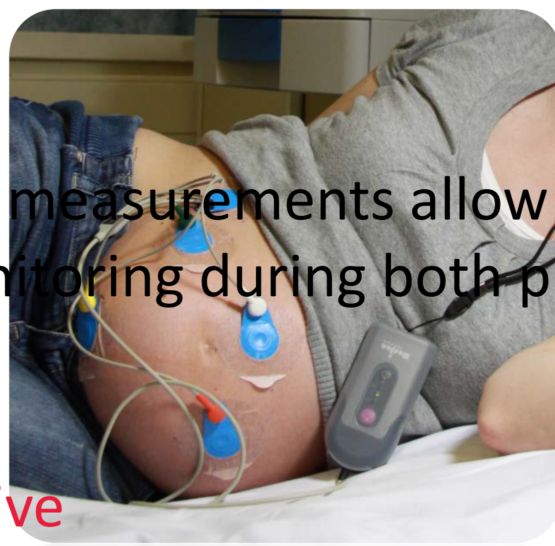


- Only during delivery
- Gives Fetal ECG (fECG)
- IUP using internal catheter

Fetal monitoring
Abdominal ECG/EHG

Goal: *Long term ambulatory monitoring*





Monica AN24 (Monica Healthcare)

Abdominal ECG measurements allow for ubiquitous ambulatory monitoring during both pregnancy and delivery

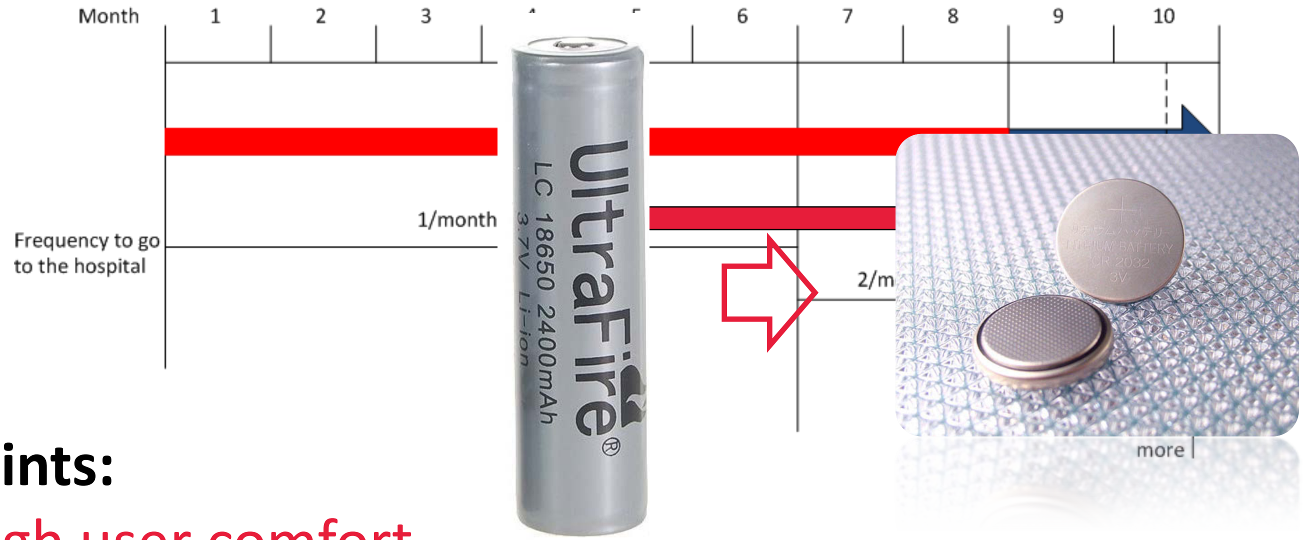
Advantages:

- Non-invasive
- Maternal and fetal ECG
- Estimation of uterine activity

Fetal monitoring

Abdominal ECG/EHG

***Goal:** Long term ambulatory monitoring*



Constraints:

- High user comfort
- Small form factor → Limited electrode distance
  → Limited battery size
- Limited battery lifetime
- Low signal to noise ratio (SNR)

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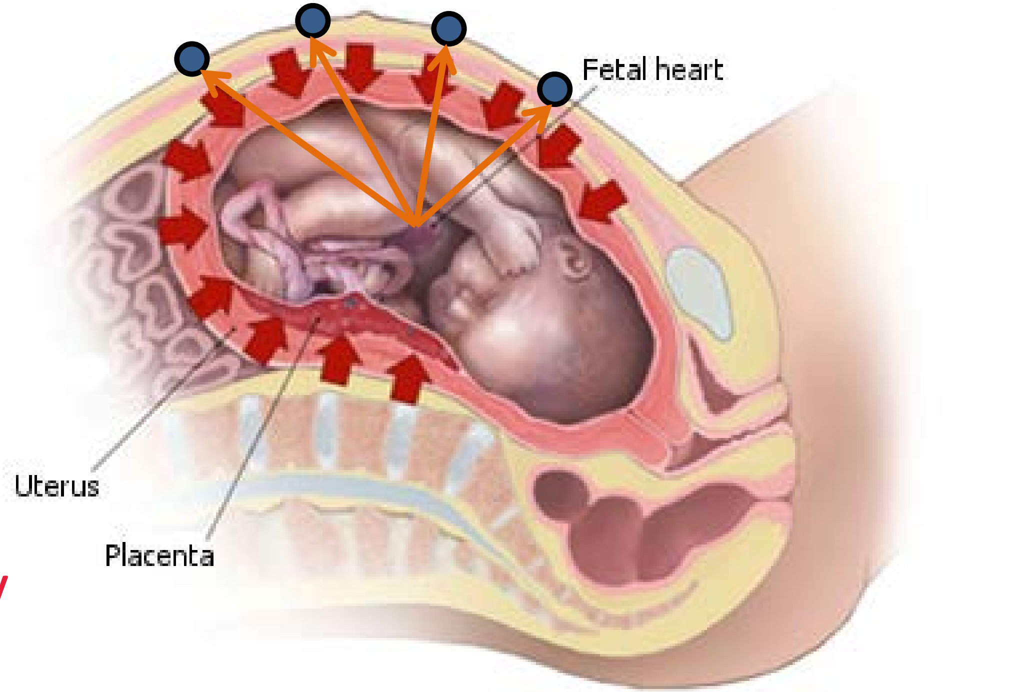
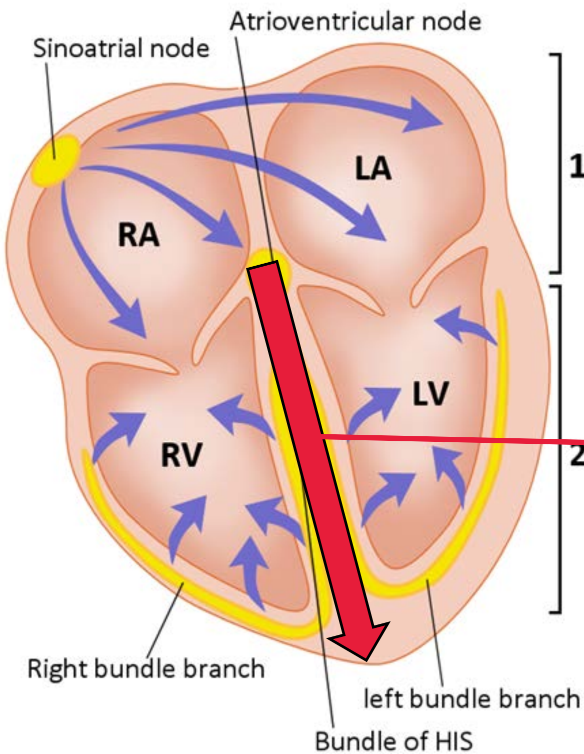
Fetal monitoring

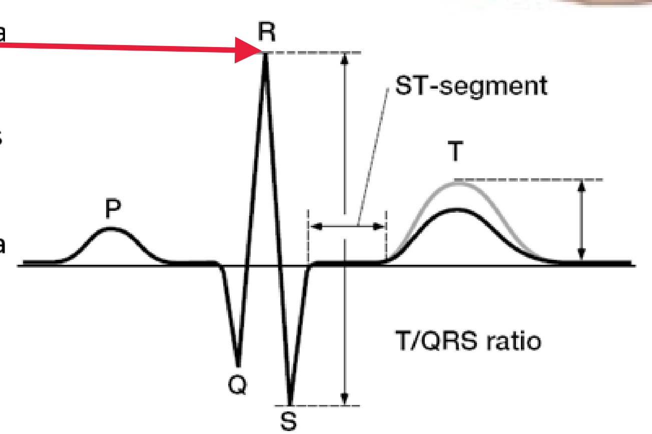
Physiology

Electrical potential in

- Fetal heart muscle
- Uterine muscles







↑ pCO_2

↓

Acidosi

↑

↓ pO_2

pCO_2 :

pO_2 :

city

→ Hea

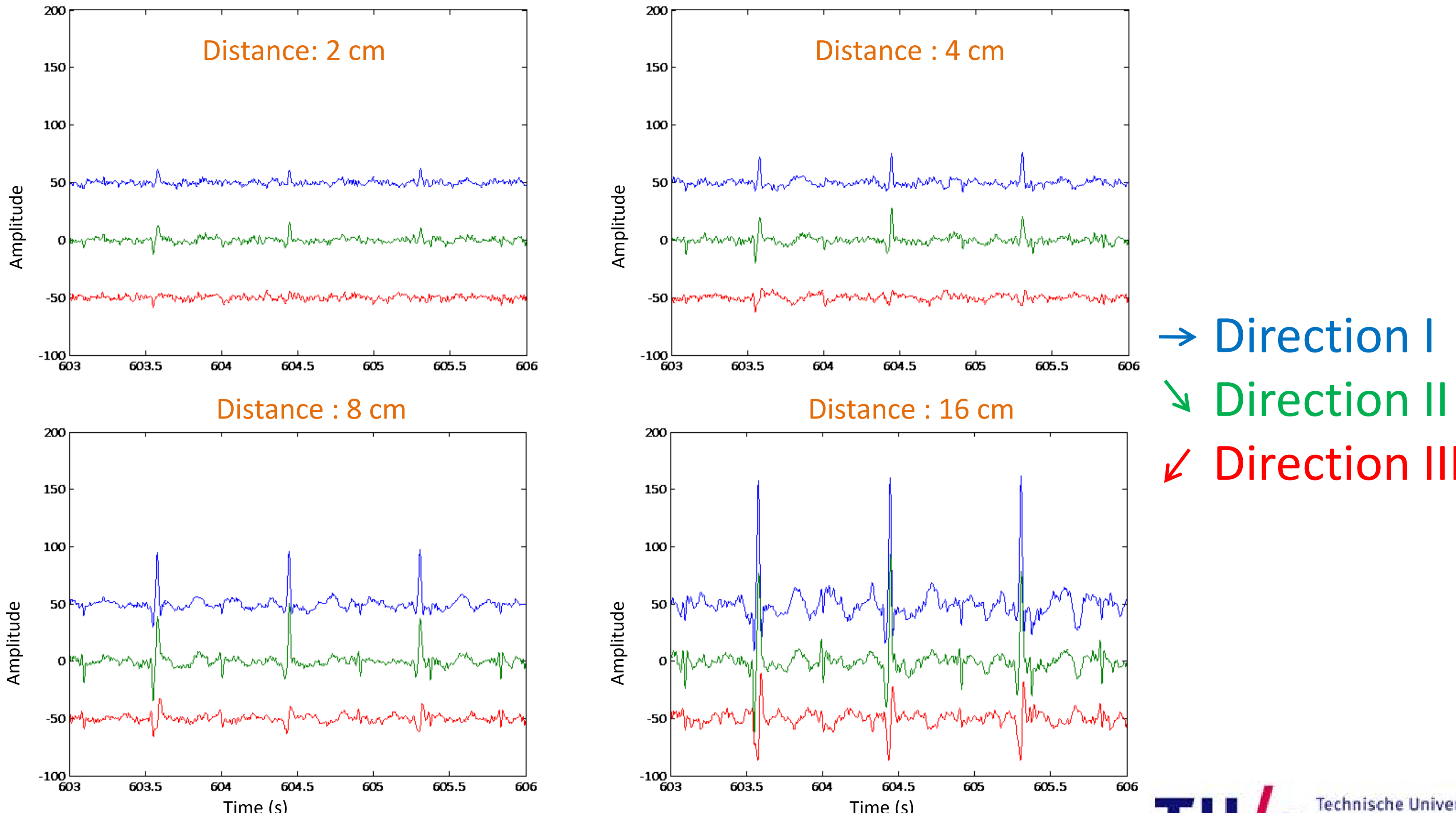
Loss

→ Hea

Abdominal measurements

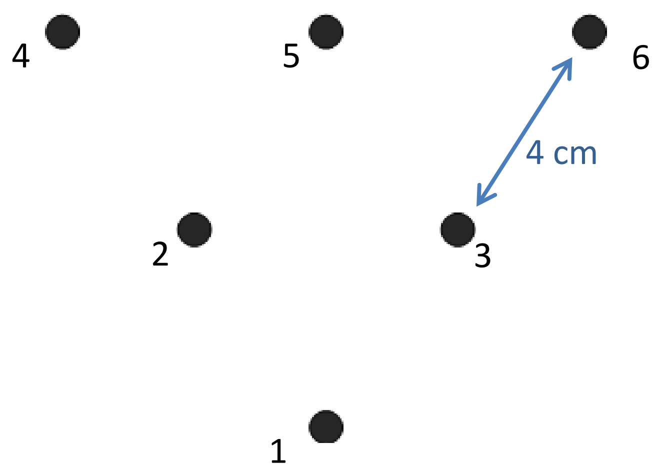
Influence of electrode distance

3 seconds of abdominal signal after filtering



Abdominal measurements

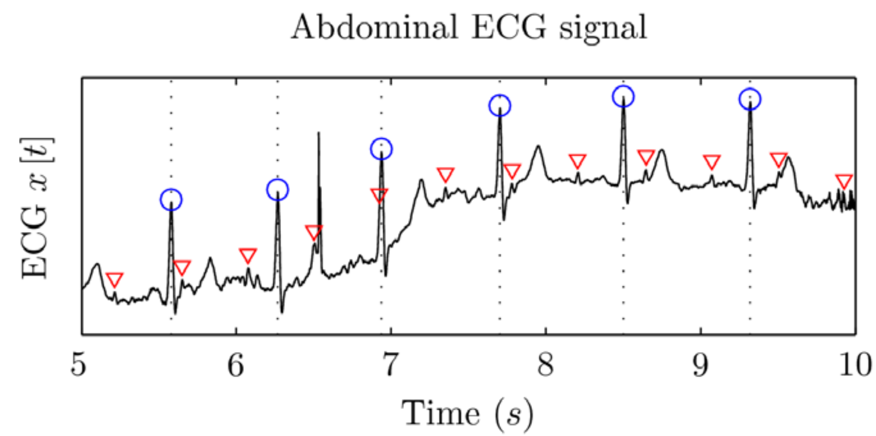
Influence of electrode distance



Abdominal measurements

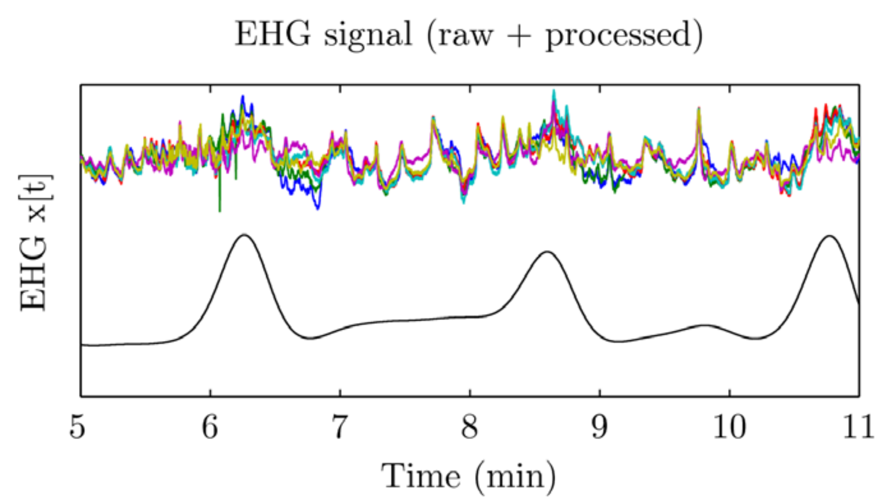
Signal characteristics

Interested in signals from 2 different sources, each with their own characteristics



ECG

- Bandwidth 1 – 70 Hz
- Maternal ECG 100 – 400 uV
- Fetal ECG < 50 uV



EHG

- Bandwidth 0.1 – 1 Hz
- Amplitude 0.5 – 5 mV
- Motion artifact in the same frequency range with amp. of several mV

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The new approach

Power optimization levels

- Top level

- **Usage scenario**: target user group and application
- **Time domain**: duty cycled operation of the system
- **Space domain**: choose sensor sites with best SNR

- Implementation level

- Right choice of system configuration

- Block level

- Power optimization of FEAMP/ADC (Smart front-end)
- Power optimization of algorithm and DSP

The new approach

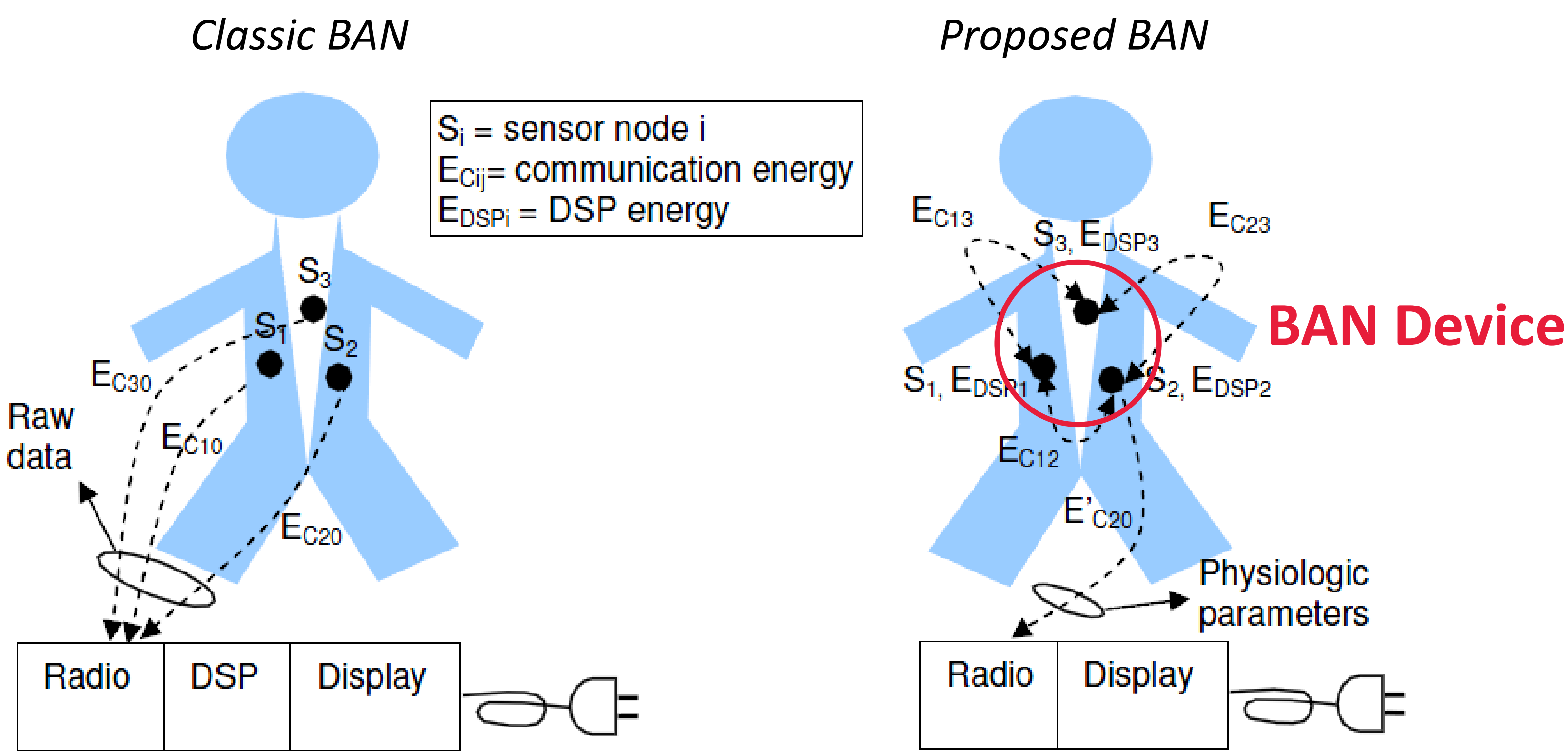
Top level optimization – Usage scenario

- **Currently:** Full day observation in hospital *(Monica)*

- **Target user group:** Women with increased risk for miscarriage
  - o Previous miscarriage
  - o High blood pressure
  - o Diabetes
  - o …
- **Target use:** Everyday use, 24/7
  - o Sitting, walking, cycling, sleeping, …

The new approach

Top level optimization – Usage scenario



- Measurement data (20bit, 1kHz): 150 nJ/bit → +/- 5mW/sensor
- Physiological data (8bit, 1Hz): 150 nJ/bit → +/- 2µW
- R/X over the body 0.1 nJ/bit *(Seong-Jun et.al.)*

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The new approach

Top level optimization – Usage scenario

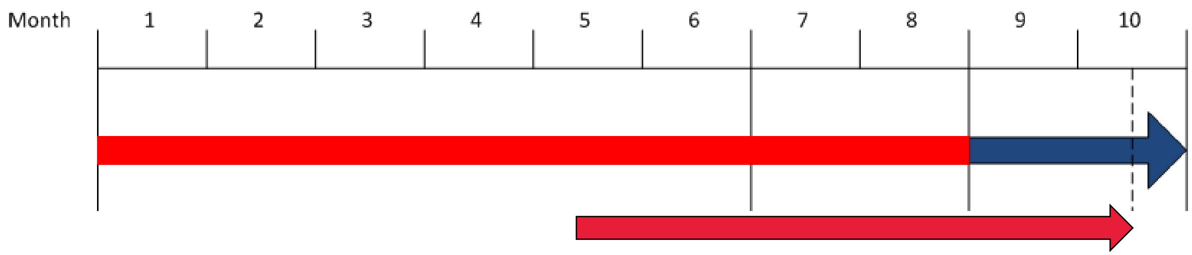
- **Currently:** Send raw data *(Monica)*

BAN Device	→	Hub	→	Server
-	raw	buffer	raw	calculations
-	raw	calculations	physiological	-
calculations	physiological	buffer	physiological	-

- **Target:** Send physiological data only
    - Local calculation use power, but give a lot of opportunities

The new approach

Top level optimization - Scenarios

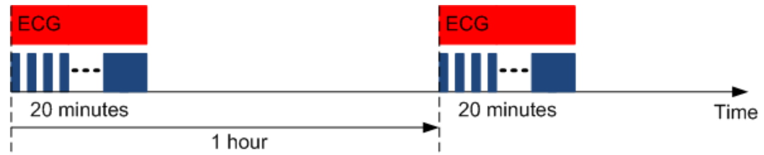


Prevent preterm delivery

Delivery monitoring

5 ~ 7 Months

8 ~ 9 Months or complicated cased

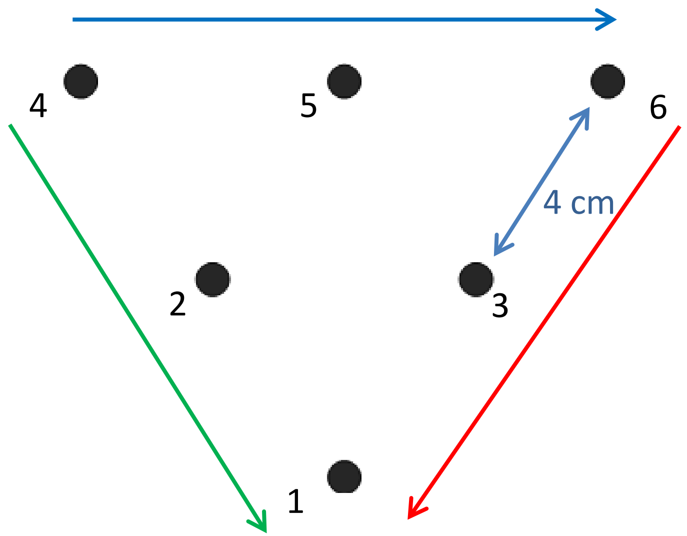


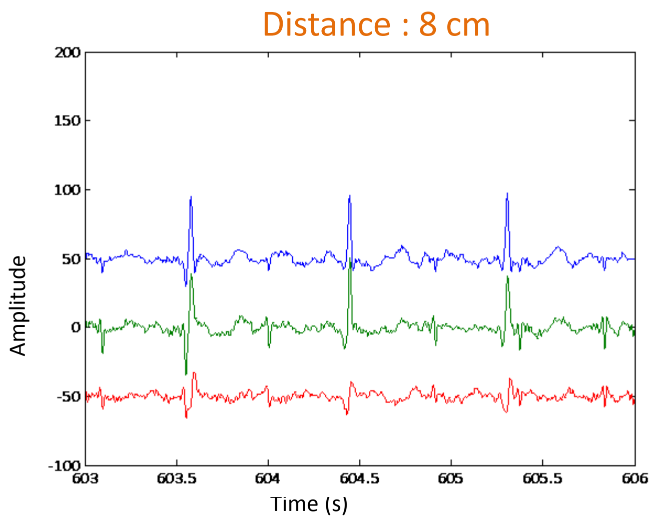
From onset of labor to delivery

- If abnormalities in fetal heart rate or uterine contractions (EHG) are detected, measures can be taken

The new approach

Top level optimization – Sensor selection





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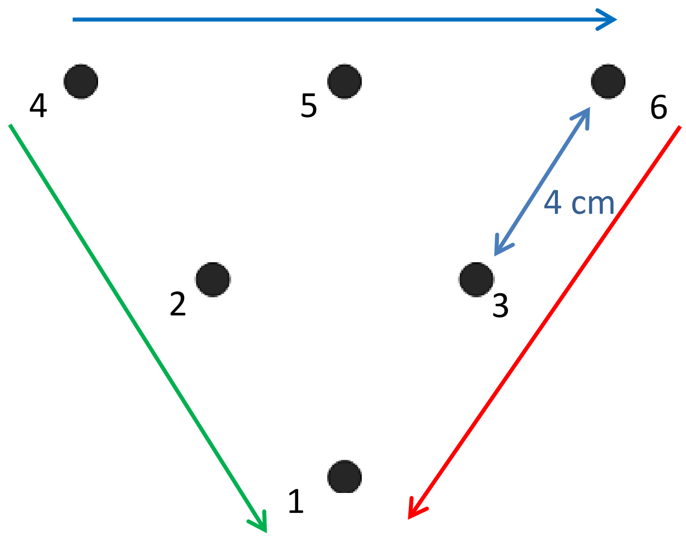
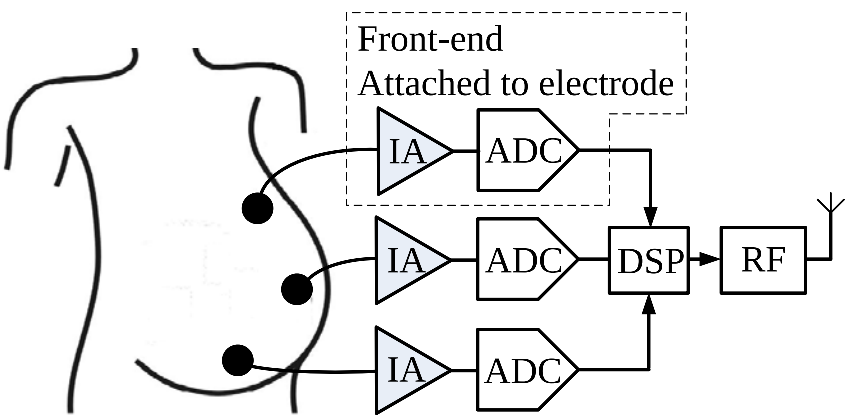
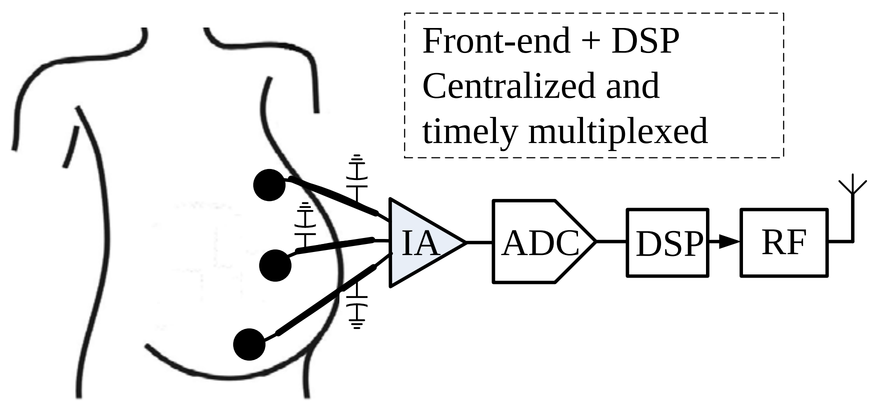
System level optimization – Implementation



Topology	Noise immunity	Analog wiring	Power consumption
Distributed FE Distributed DSP	Higher	No	Higher
Distributed FE Centralized DSP	Higher	No	Medium
Centralized FE Centralized DSP	Lower	Yes	Lower





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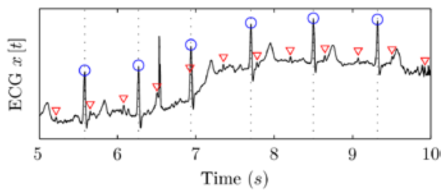
Block level optimization – Smart front-end



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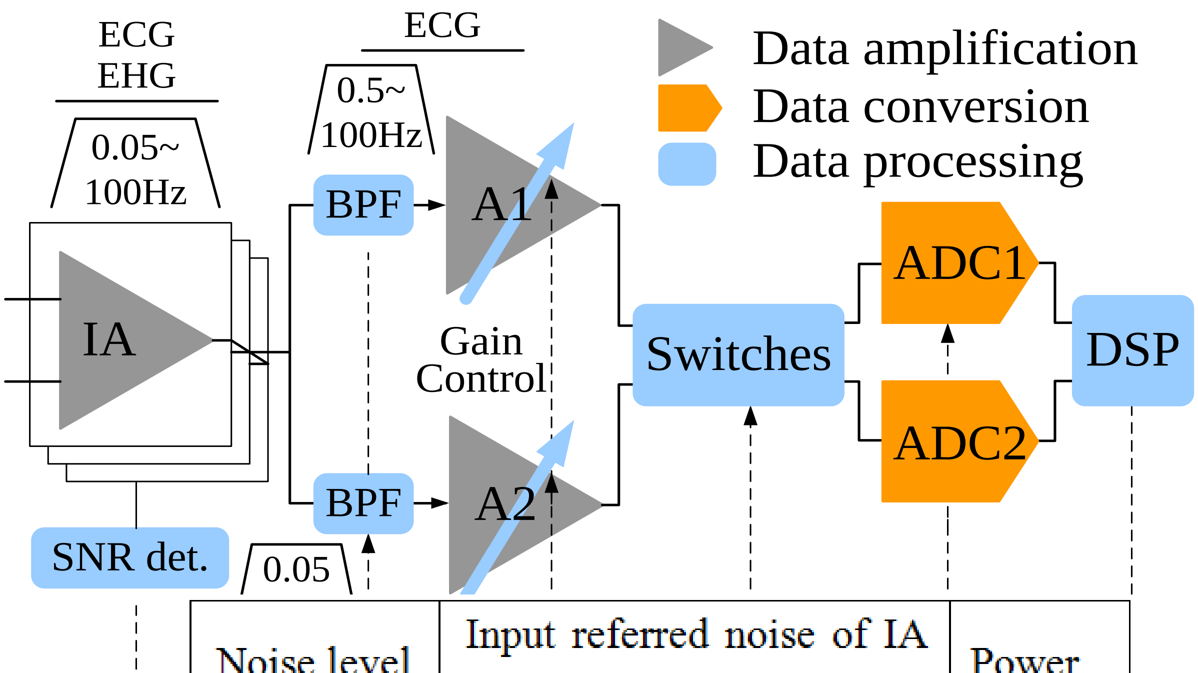
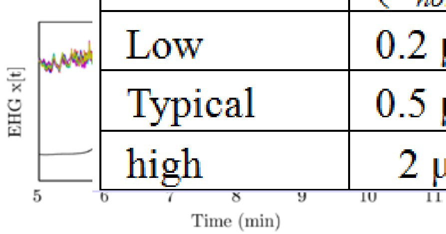


Noise level	Input referred noise of IA (V_{noise} :0.1 to 100 Hz)	Power
Low	0.2 μV_{rms}	60 μW
Typical	0.5 μV_{rms}	10 μW
high	2 μV_{rms}	1 μW



0.1 – 1 Hz

0.5 – 5 mV

in the same frequency range with amplitude of several mV

The new approach

Block level optimization – control sequence

- Every 30 seconds, the DSP detects the amplitude of the fECG signal, chooses the right sensing direction, and determines the requirement for the input referred noise.
- The IA is scaled to the required noise level; meanwhile, the relation between the amplifier gain and the ADC resolution is fixed according to the noise level.
- The gain of the AMP is adaptively changed according to the MA amplitude, and the resolution of the ADC is changed correspondingly.

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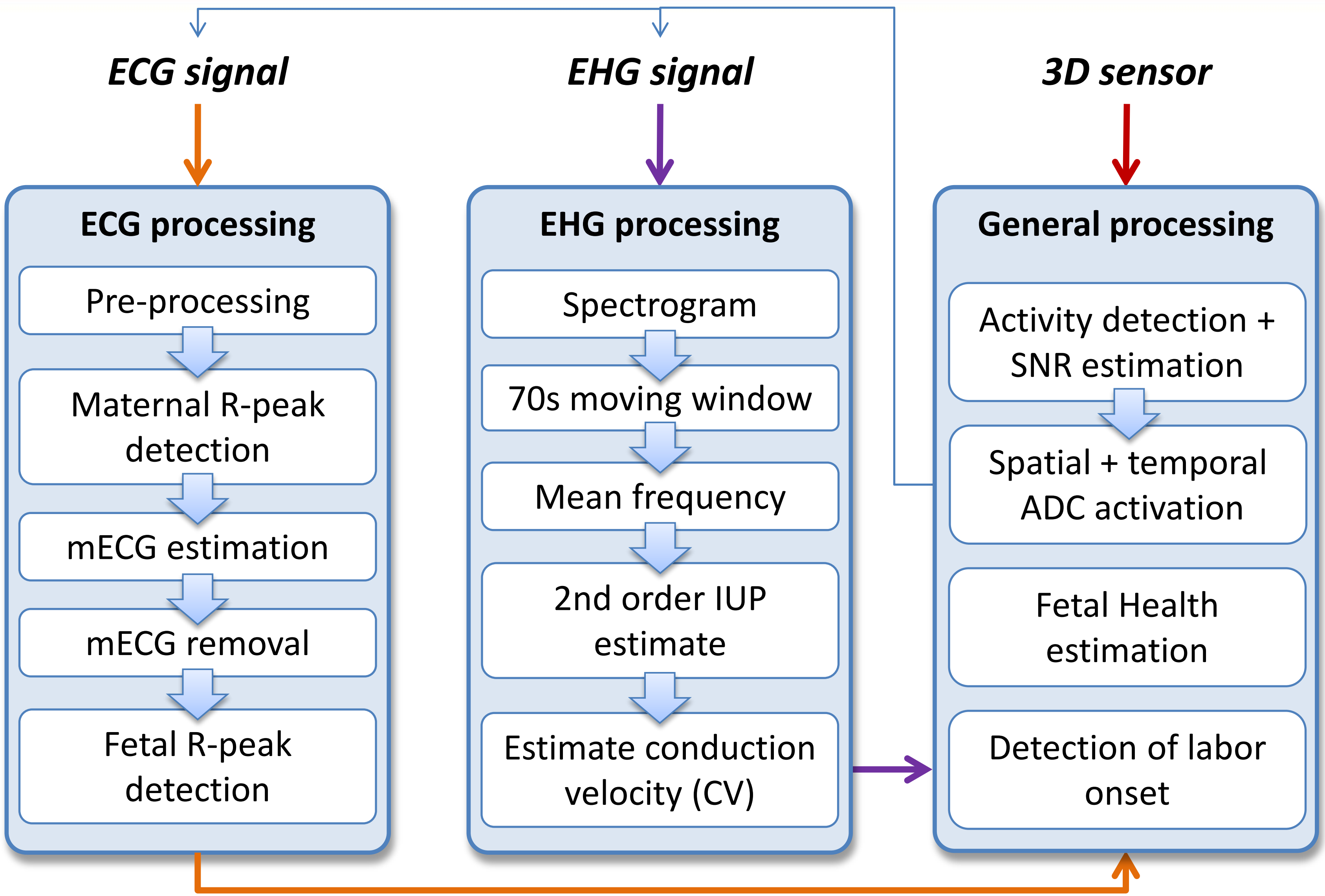
Block level optimization – Algorithms



Algorithms

Optimization process

ECG processing

1. Pre-processing
2. Maternal R-peak detection
3. mECG estimation
4. mECG removal
5. Fetal R-peak detection

Pre-processing

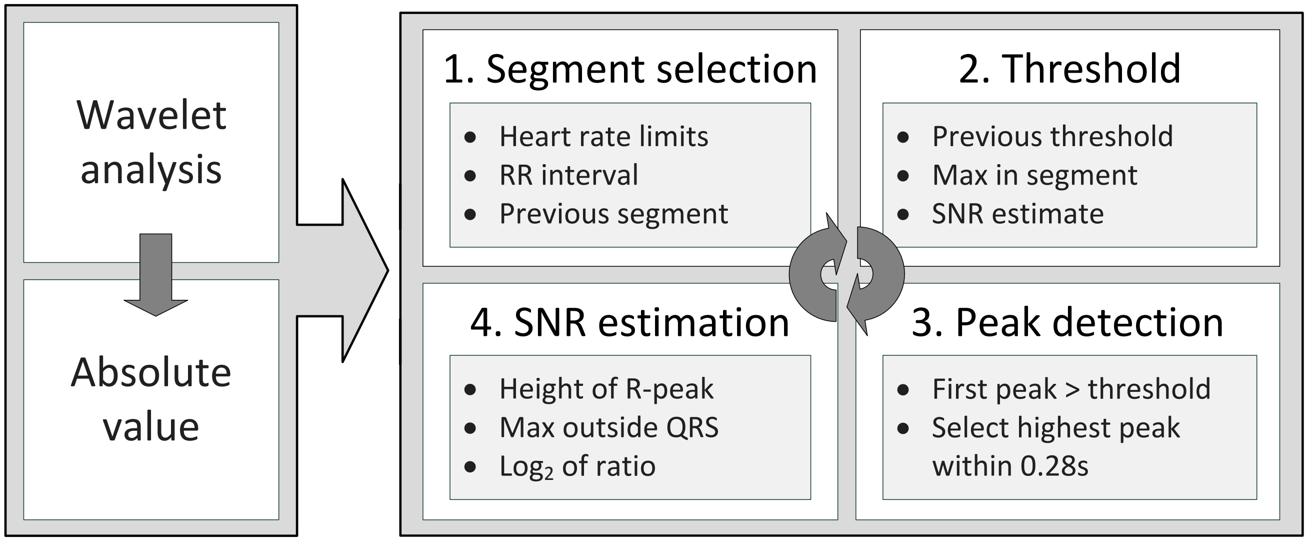
- Original by Vullings / Gritzali
- Algorithms from literature:
  FIR, IIR, Wavelet, PCA, etc.
- Own algorithm / combination

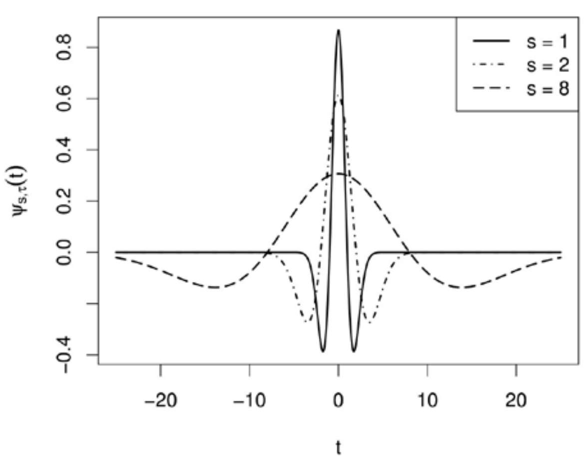
R-peak detection

- Original by Vullings / Gritzali
- Algorithms from literature:
  Li, Martinez, Romero, etc.
- Own algorithm

Algorithms

Optimization R-peak detection





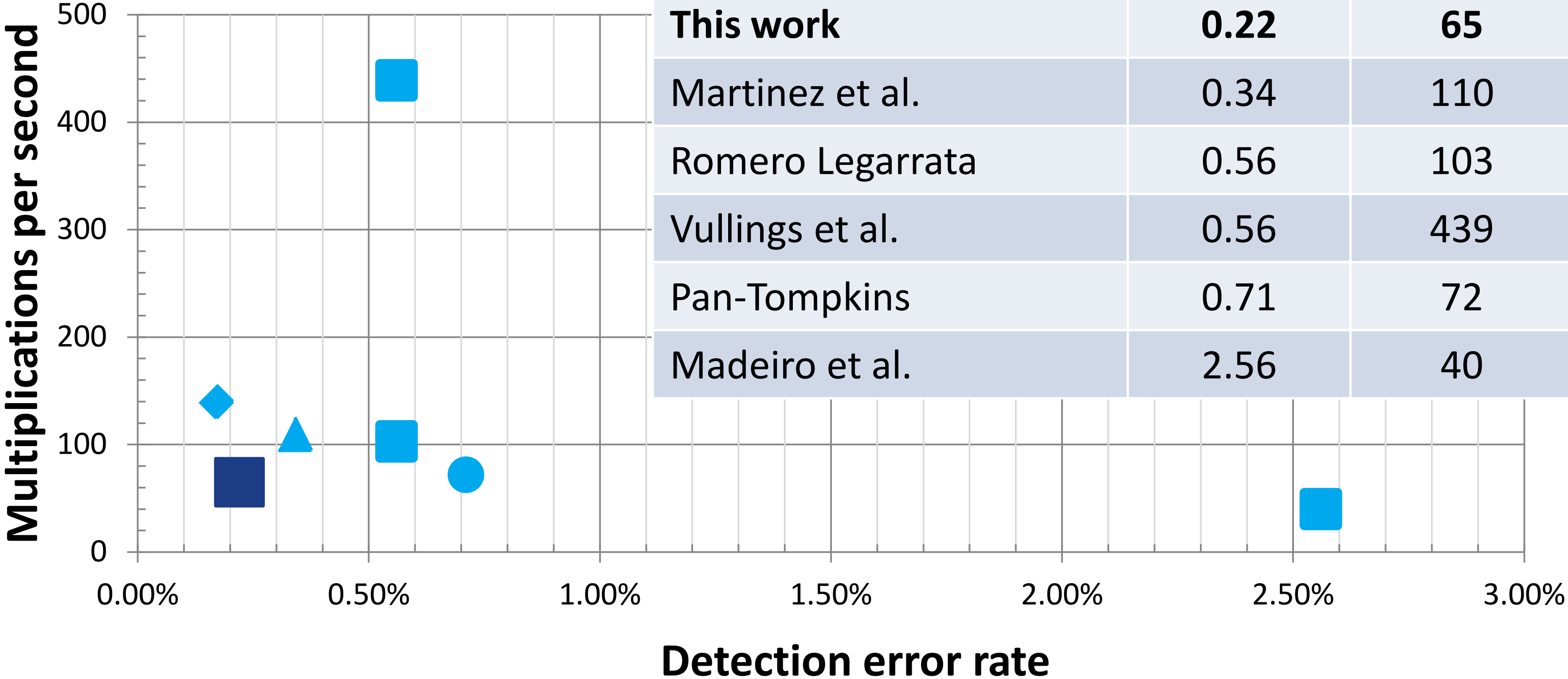
R-peak detection

- Original by Vullings / Gritzali
- Algorithms from literature:
  Li, Martinez, Romero, etc.
- **Own algorithm**

Algorithms

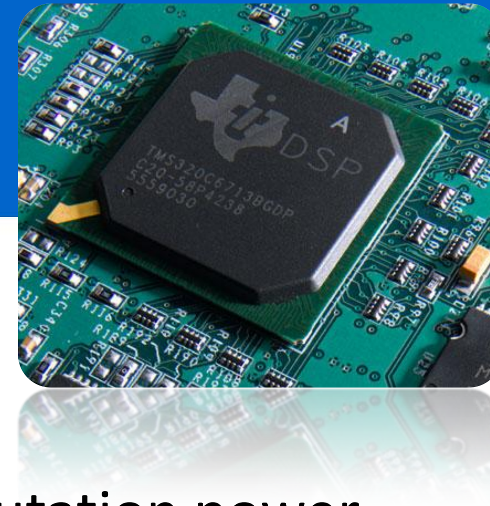
Optimization R-peak detection

MIT/BIH *(Thoraxial)*	D_e (%)	MPS[1]
Li et al.	0.17	140
This work	**0.22**	**65**
Martinez et al.	0.34	110
Romero Legarrata	0.56	103
Vullings et al.	0.56	439
Pan-Tompkins	0.71	72
Madeiro et al.	2.56	40



The new approach

Block level optimization



Choice of DSP

- Match type and instruction set
- Match algorithm complexity and computation power

Implementation on DSP

- Efficient utilization of hardware and instructions
- Conversion of algorithm to fit memory structure
- Choice of power management optimization

- *Changes to the instruction set architecture*

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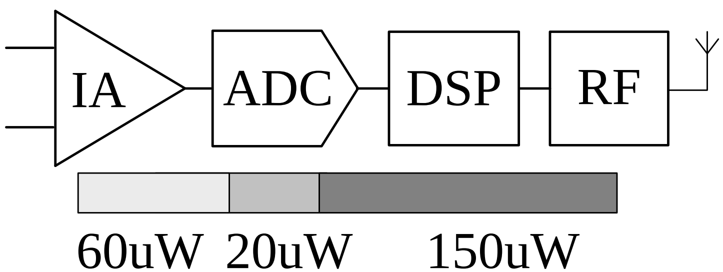
Power analysis of the new approach

- Sending on health status instead of raw data reduces **RF power** to **negligible** level
- **Smart front-end** reduces IA and ADC power significantly
- System power is **dominated by the DSP**



- Fixed parameters
- High performance front-end
- High workload in DSP

Further optimization possible

- Move parts of the algorithm to dedicated hardware

Final note

Thanks to

TU/e – SPS *Chiara Rabotti*

Massimo Mischi

TU/e – MSM *Shuang Song*

Eugenio Cantatore

Questions?

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