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University of Applied Sciences and Arts

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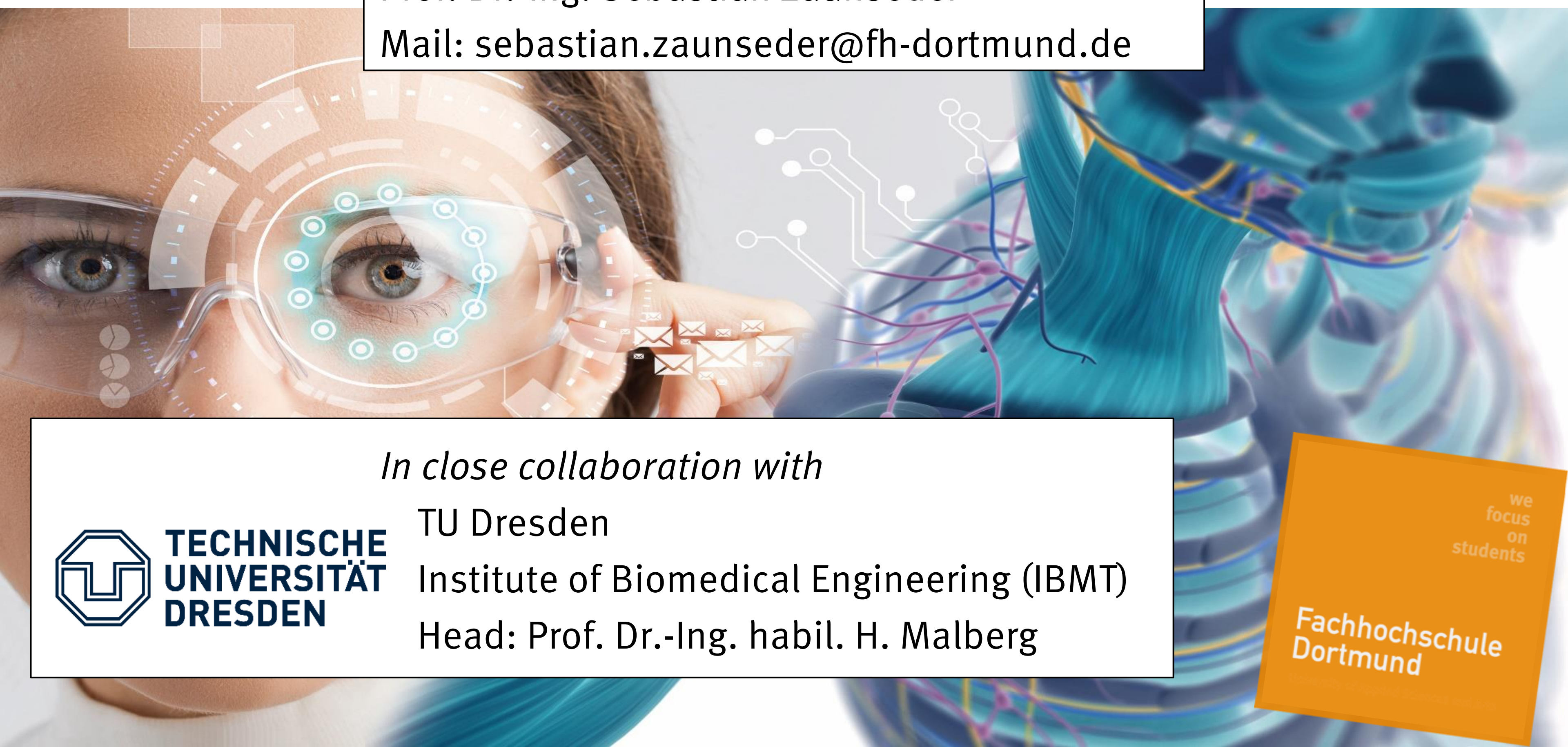
From single biosignal measurement to contactless multimodal physiological measurement technologies

Prof. Dr.-Ing. Sebastian Zaunseder
Mail: sebastian.zaunseder@fh-dortmund.de



In close collaboration with

TECHNISCHE UNIVERSITÄT DRESDEN

TU Dresden
Institute of Biomedical Engineering (IBMT)
Head: Prof. Dr.-Ing. habil. H. Malberg

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Background – biosignal measurement status quo

[HP1]

Topic

Contactless measurement techniques

- Common measurement techniques are invasive or require skin contact

→ Burden to patients and medical staff

→ Restricted applicability

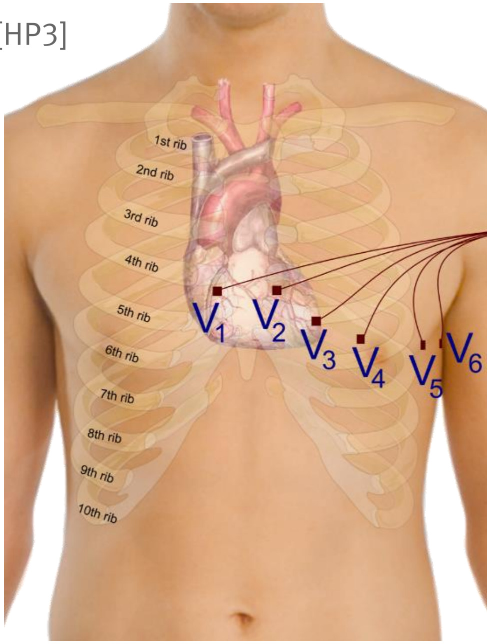
→ Interest in novel measurement techniques

[HP2]

Background – definitions and focus

- Definition of „contactless“
  - Conventional measurement techniques
    - Invasive or skin contact required
    - Patient preparation required
    - Professional assistance required
  - Contactless measurement techniques
    - No patient preparation
    - No direct skin contact
    - Not fixed to the body
    - Variable distance
- Focus here: cardio-respiratory signals (current works focus most often on heart rate and respiratory rate)

[HP3]



[HP6]

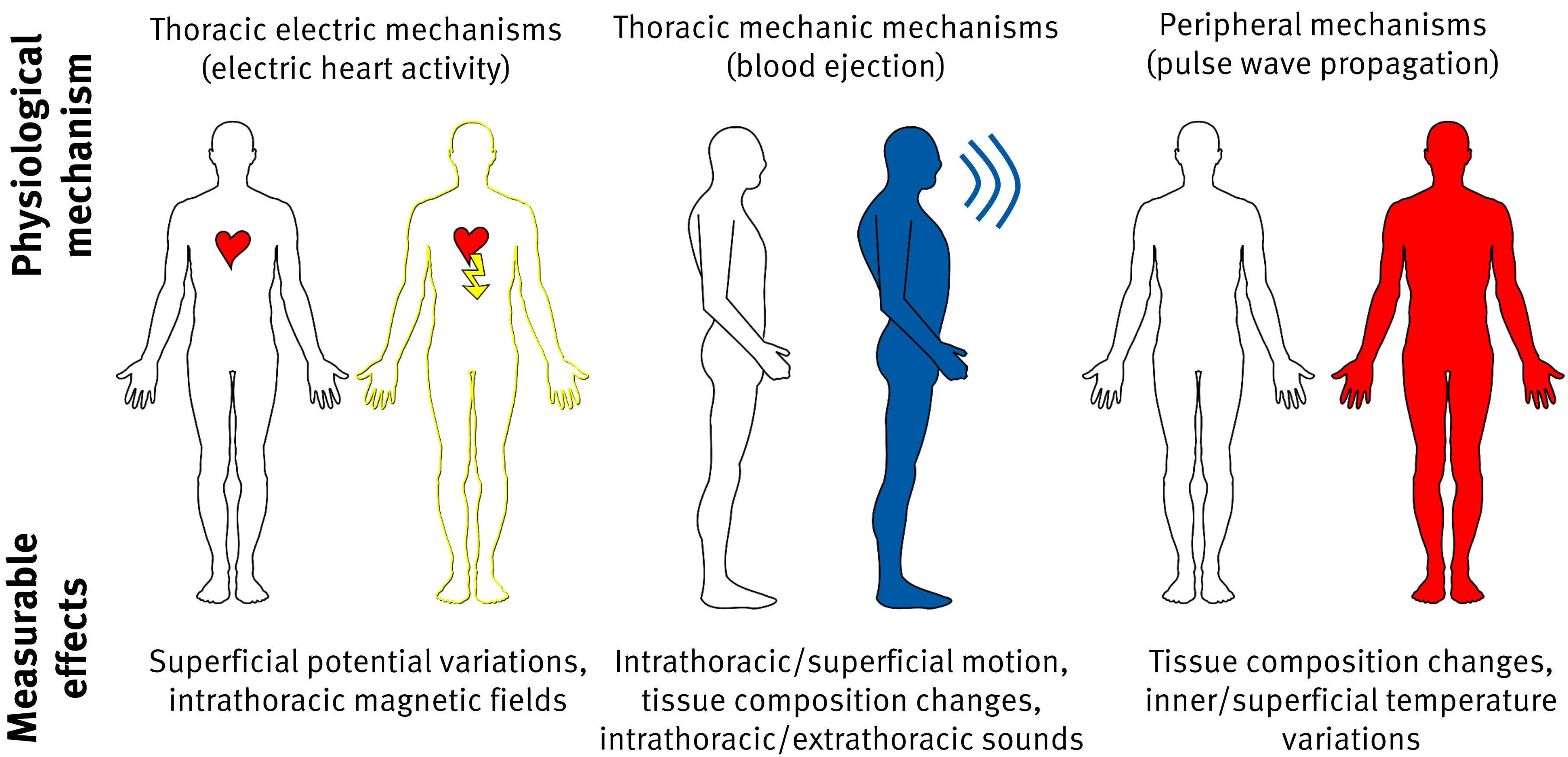
[HP4]

[HP5]

Contents

- Basic physiology
- Contactless measurement techniques
- Sensor data fusion – multimodal analyses
- Valuation – current state, limitations and future directions
- Summary

Basic physiology – cardiovascular activity

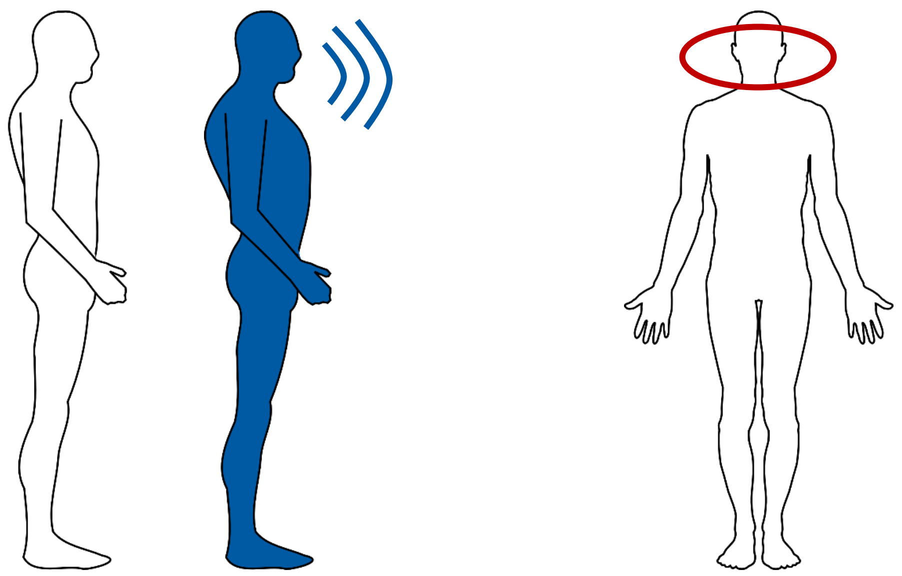


Basic physiology - respiration

Physiological mechanism

Thoracic mechanic mechanisms
(ventilation drive and ventilation)

Peripheral mechanisms
(air flow)



→ (Partially)
qualitatively similar effects compared to the effects of the cardiovascular activity

Measurable effects

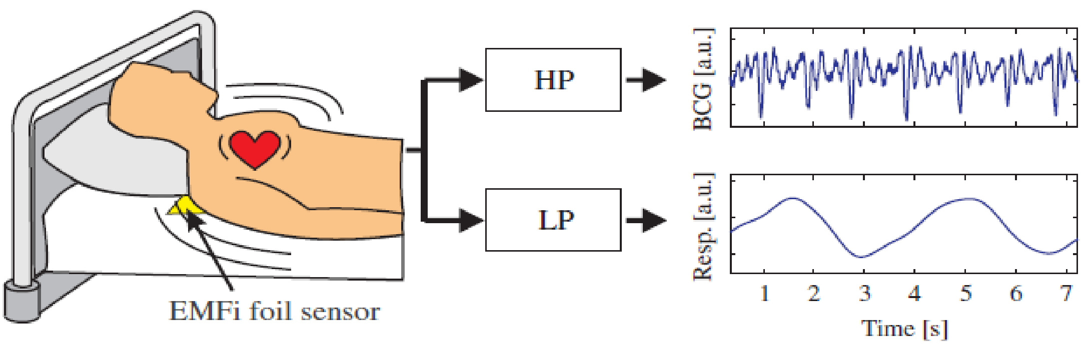
Intrathoracic/superficial motion, tissue composition changes, intrathoracic/extrathoracic sounds

Superficial/air temperature variations

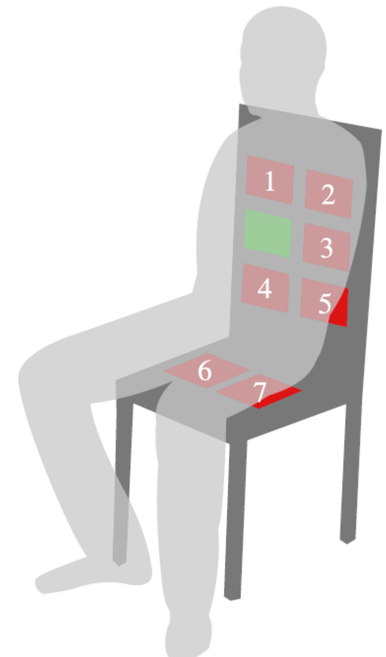
Contactless measurement techniques

Contactless measurements – overview

- Mechanical (ballistocardiographic)
- **Radar-based**
- Acoustic
- Ultra-sound based
- **Optical**
- **Thermal**
- **Electrical**
- Magnetic



[Brueser2013]



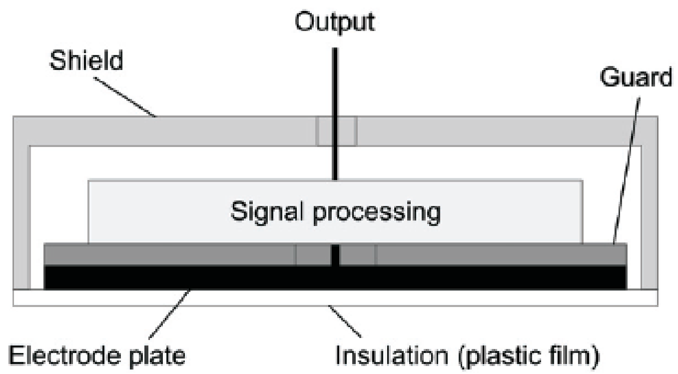
[Wedekind2018]

→ Review papers (amongst others): [Brueser2015], [Zaunseder2017], [Kranjec2014]

Contactless measurements – capacitive ECG

- Background
  - Measurement principle analogous to conventional ECG → superficial electrical potentials are acquired
  - No galvanic connection to the skin required
  - Shielding of fundamental importance
  - Focus on cardiac signals (respiration possible)

→ measurement via clothes and integration possible

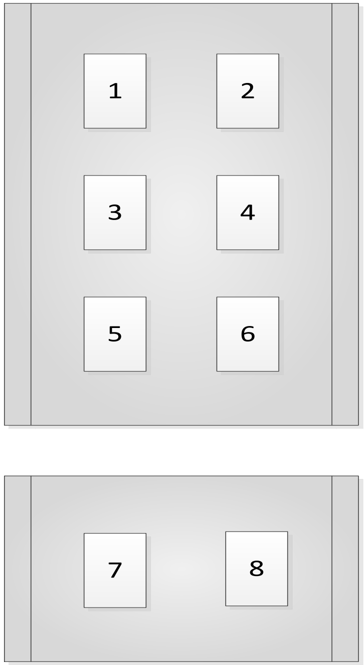


[Oehler2008]

[Aleksandrowicz2007]

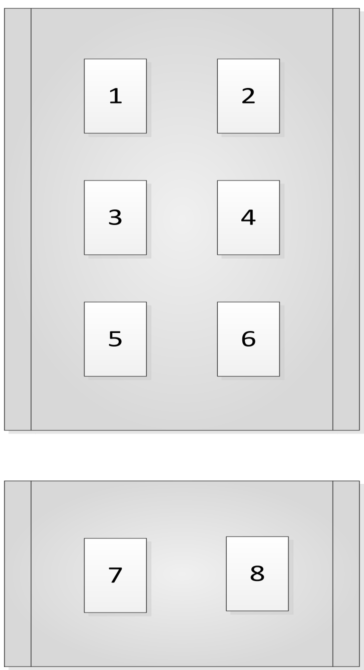
Contactless measurements – capacitive ECG

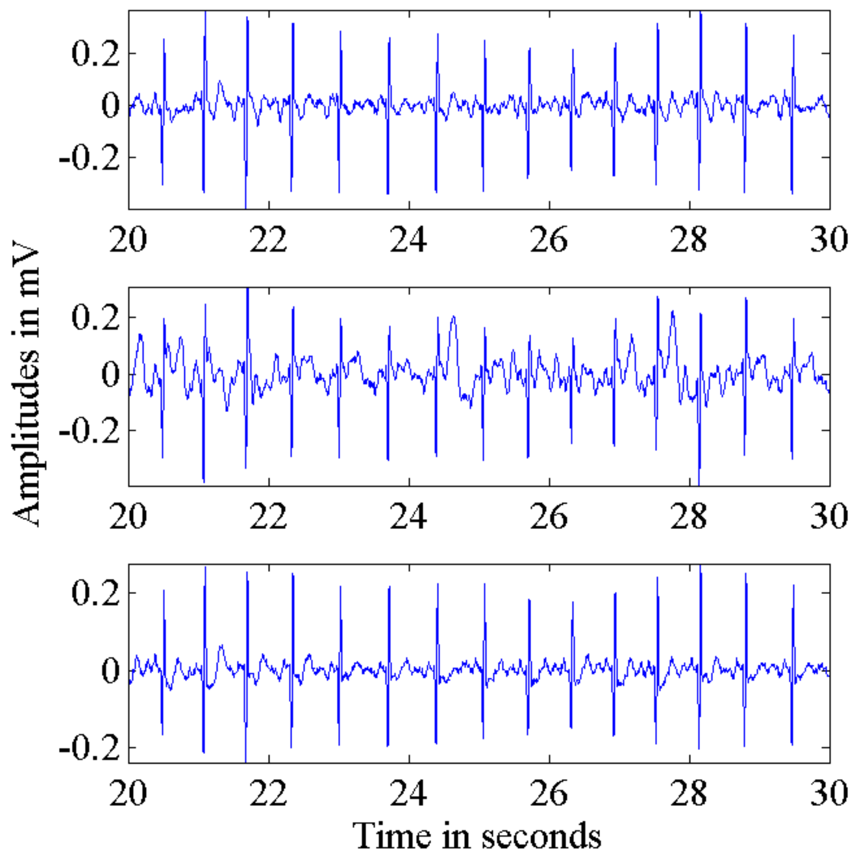
- Implementation at IBMT



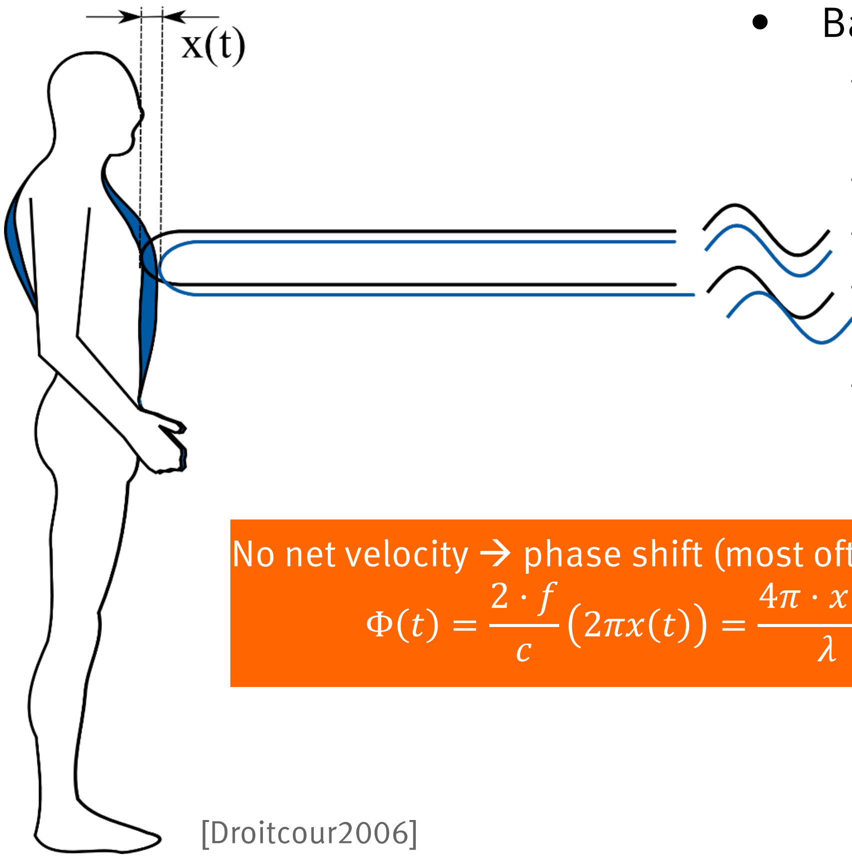
Contactless measurements – capacitive ECG

- Implementation at IBMT





Contactless measurements – radar-based acquisition



[Droitcour2006]

- Background
  - First approaches date back more than 30 years; recent revival due to hardware improvements
  - Technique exploits motion
  - In principle phase and frequency shits usable
  - Phase modulation in proportion to the time-varying position of the target
  - Filters can be used to separate respiration and cardiovascular activity

No net velocity → phase shift (most often used)

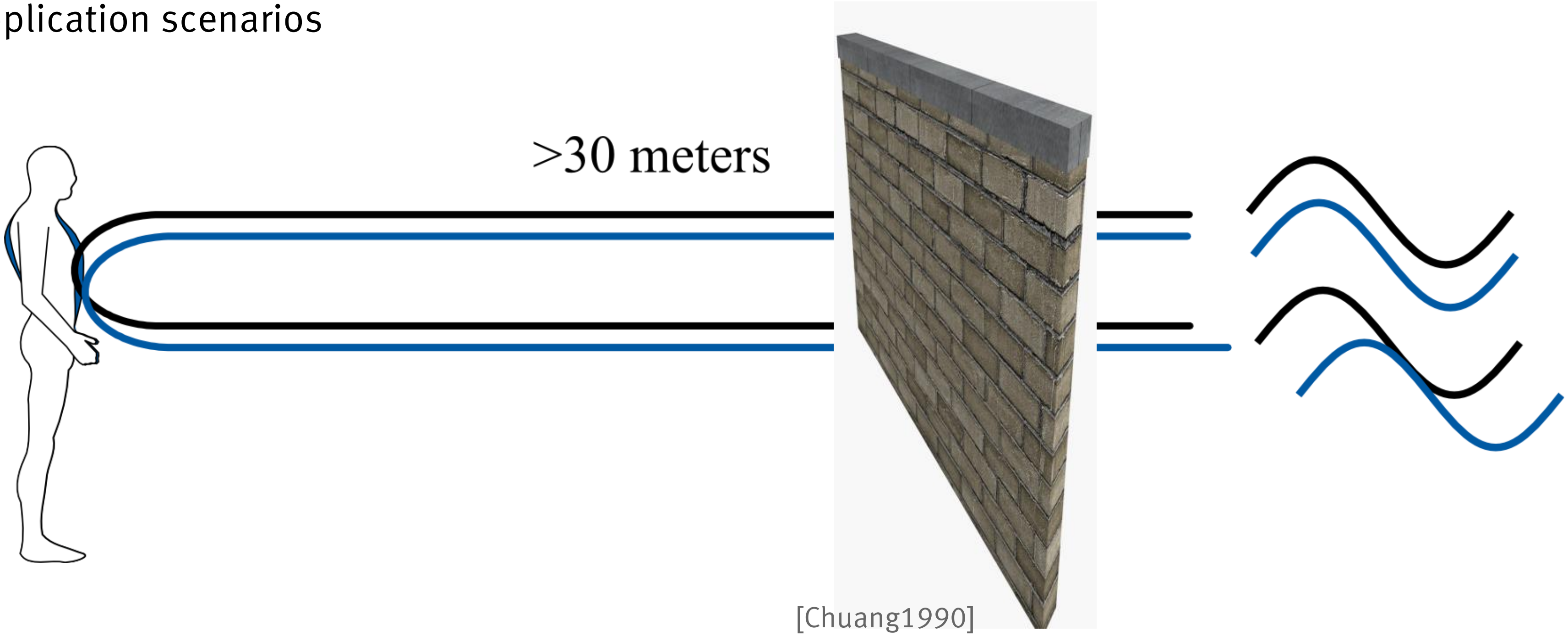
$$\Phi(t) = \frac{2 \cdot f}{c}\left(2\pi x(t)\right) = \frac{4\pi \cdot x(t)}{\lambda}$$

Velocity → frequency shift

$$f_d(t) = \frac{2 \cdot f}{c} v(t) = \frac{2v(t)}{\lambda}$$

Contactless measurements – radar-based acquisition

- Application scenarios

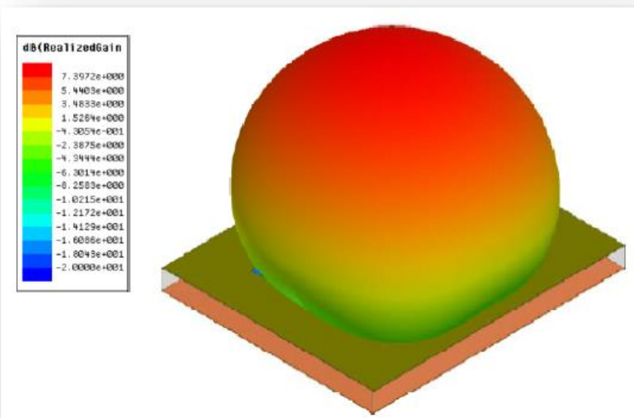


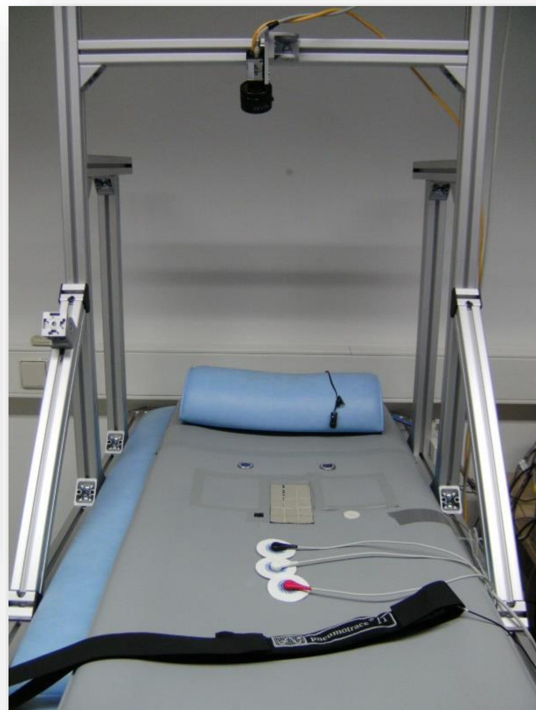
[Chuang1990]

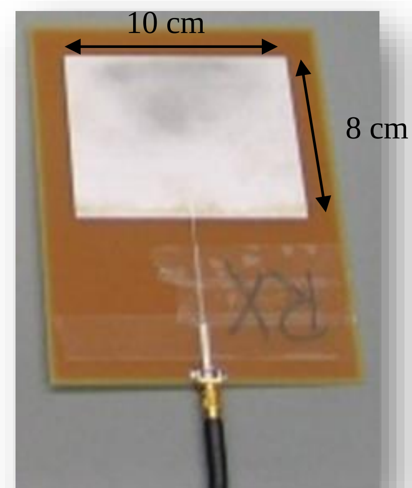
Contactless measurements – radar-based acquisition

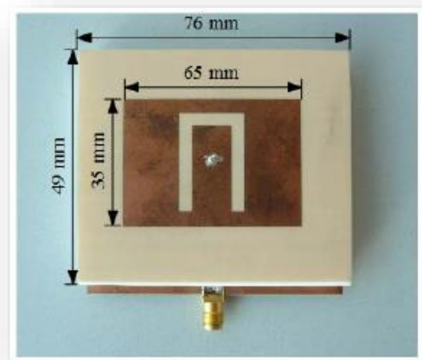
[Henning2013]

- Implementation at IBMT



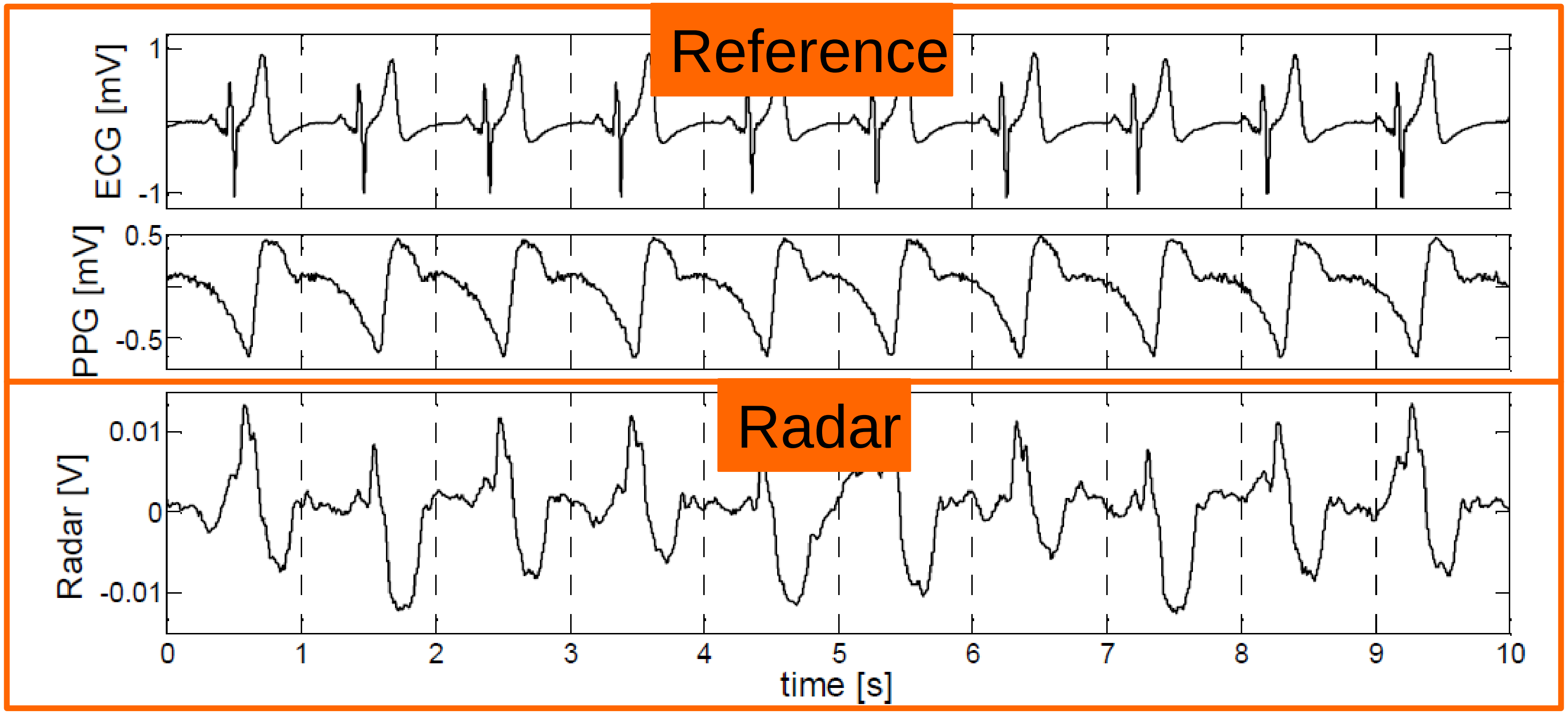






Contactless measurements – radar-based acquisition

- Implementation at IBMT



Contactless measurements – thermography

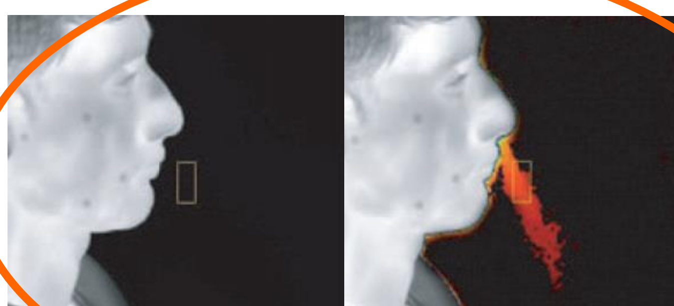
- Background
  - Thermal cameras are used to capture temperature variations
  - Temperature difference through oronasal airflow or superficial blood flow

Cardiovascular monitoring

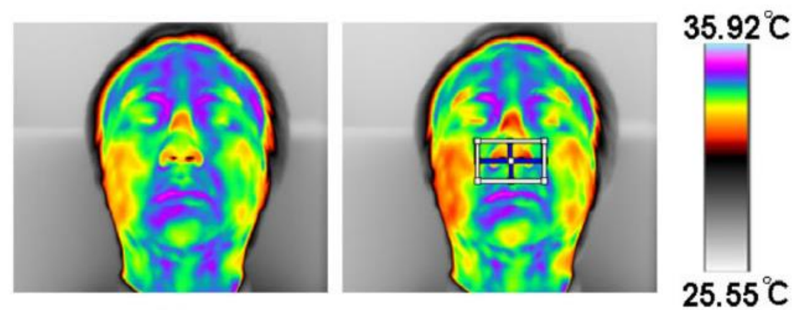
[Sun2005]

Active cooling required → costly systems

Respiratory monitoring



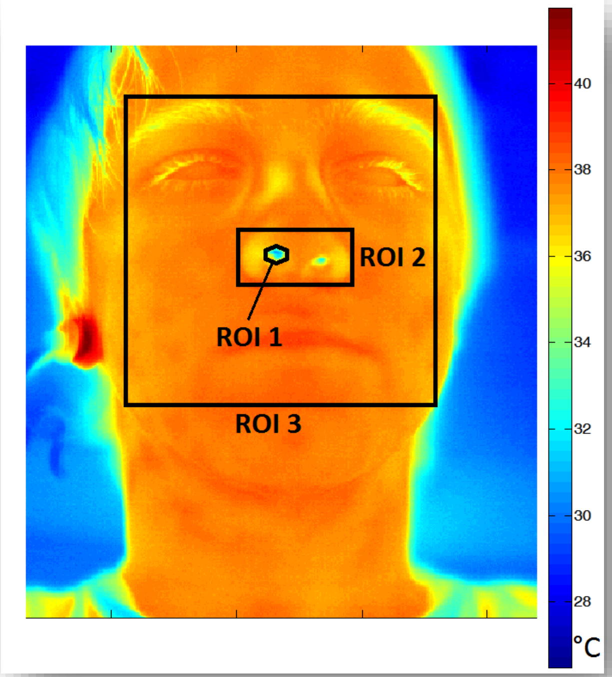
[Murthy2004]



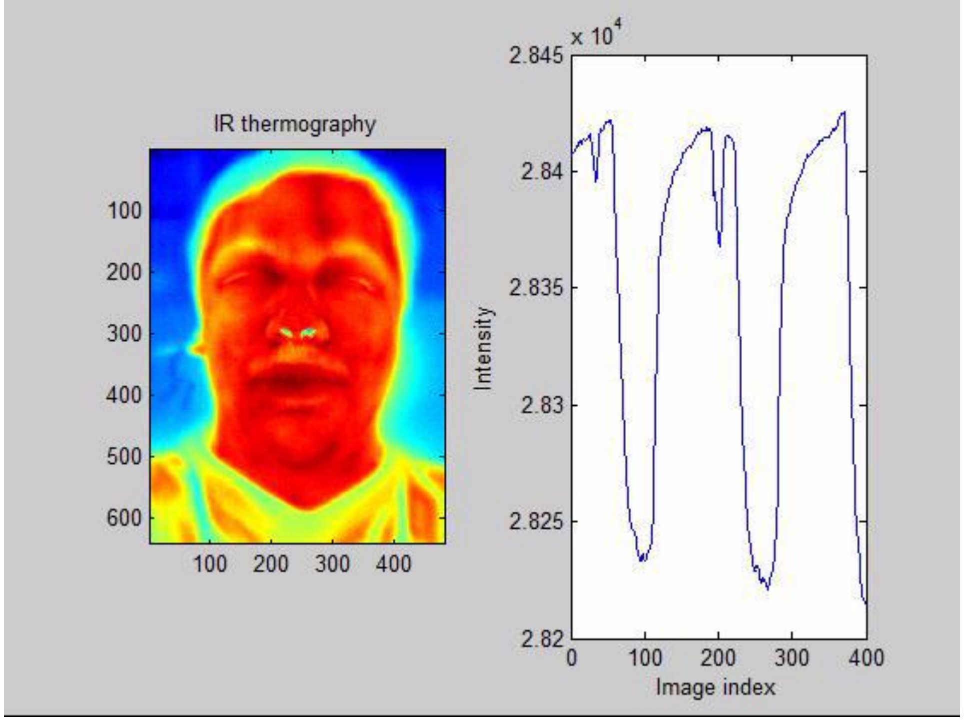
[Fei2010]

Contactless measurements – thermography

- Implementation at IBMT

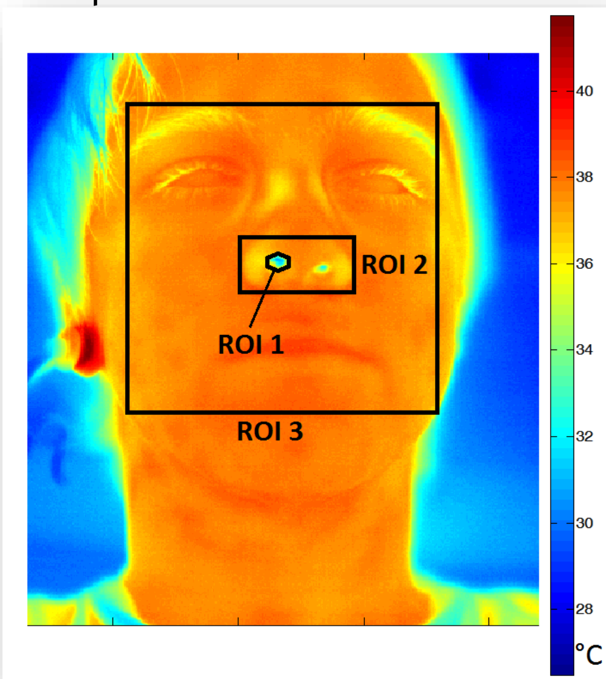


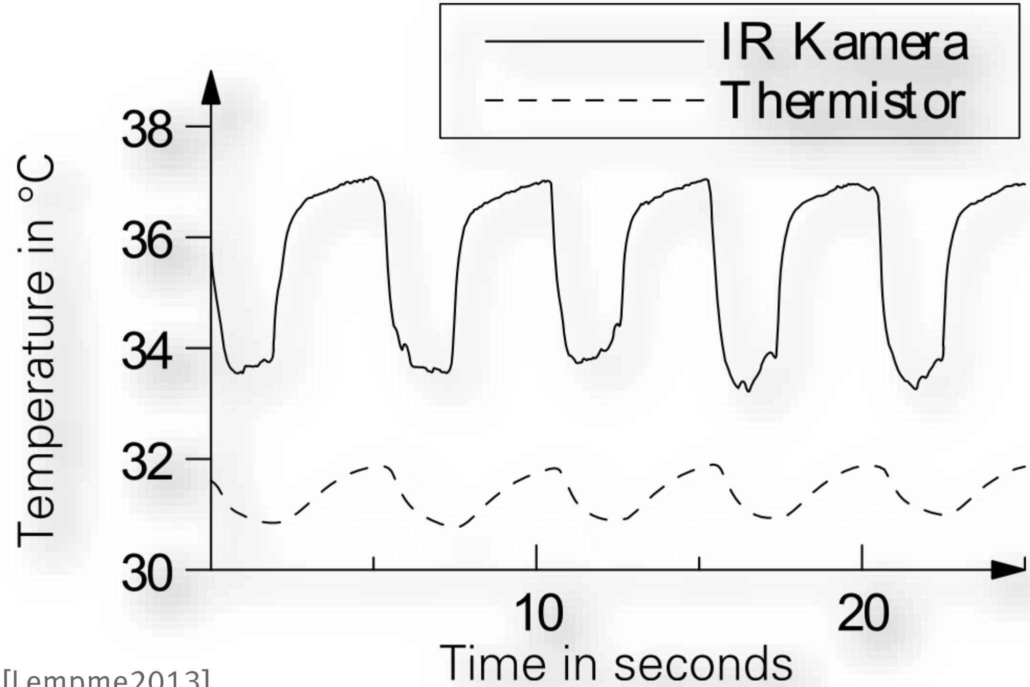
[Lempe2013]



Contactless measurements – thermography

- Implementation at IBMT



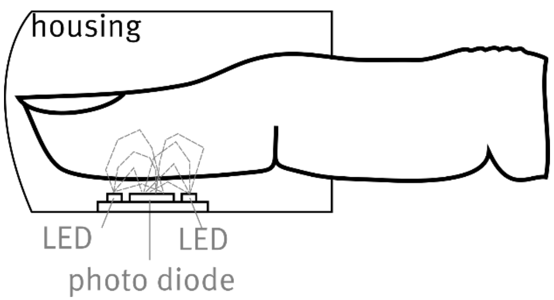


[Lempme2013]

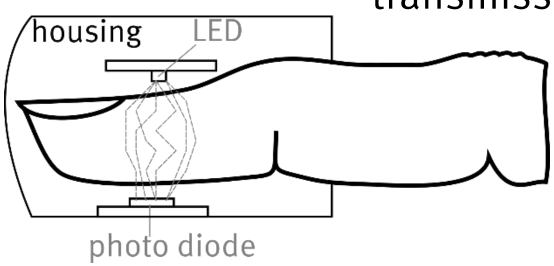
Contactless measurements – iPPG

- Background
  - Measurement analogue to photoplethysmography (PPG)
  - Various respiratory/cardiovascular parameters available

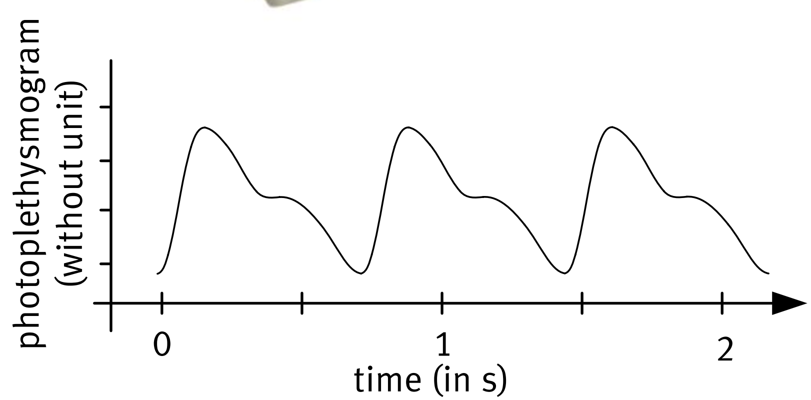
reflective PPG



transmissive PPG

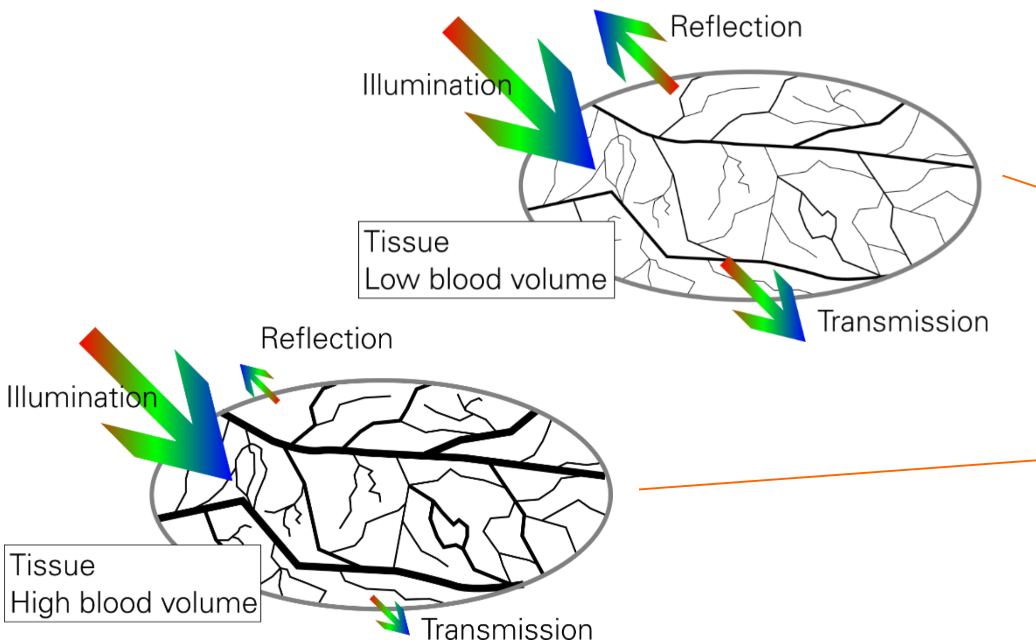


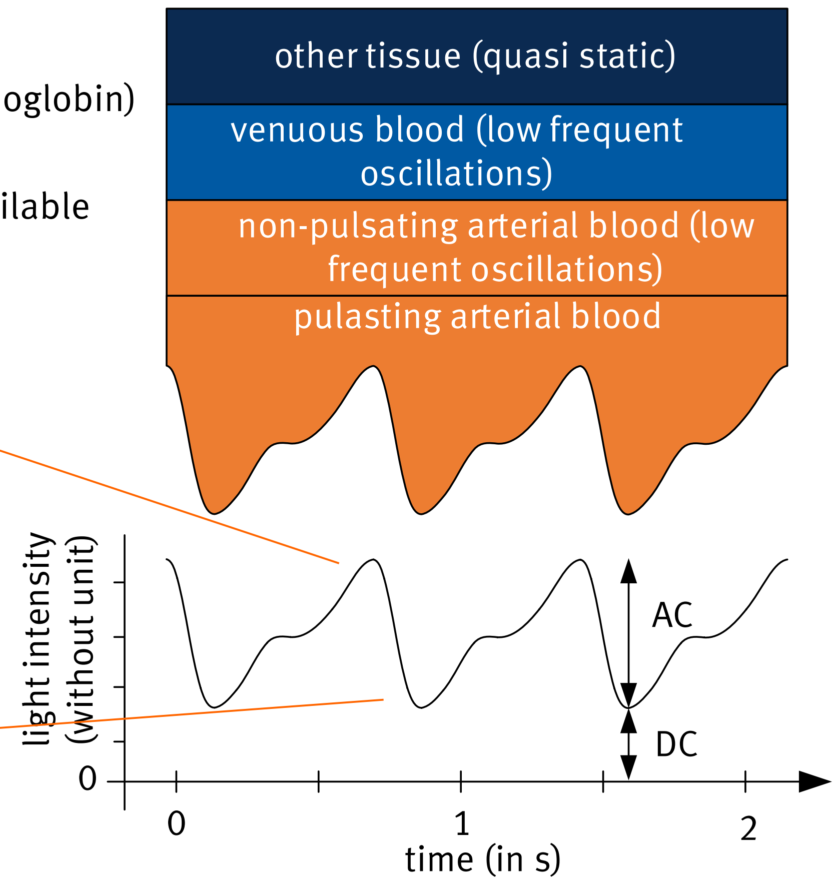
[HP4]



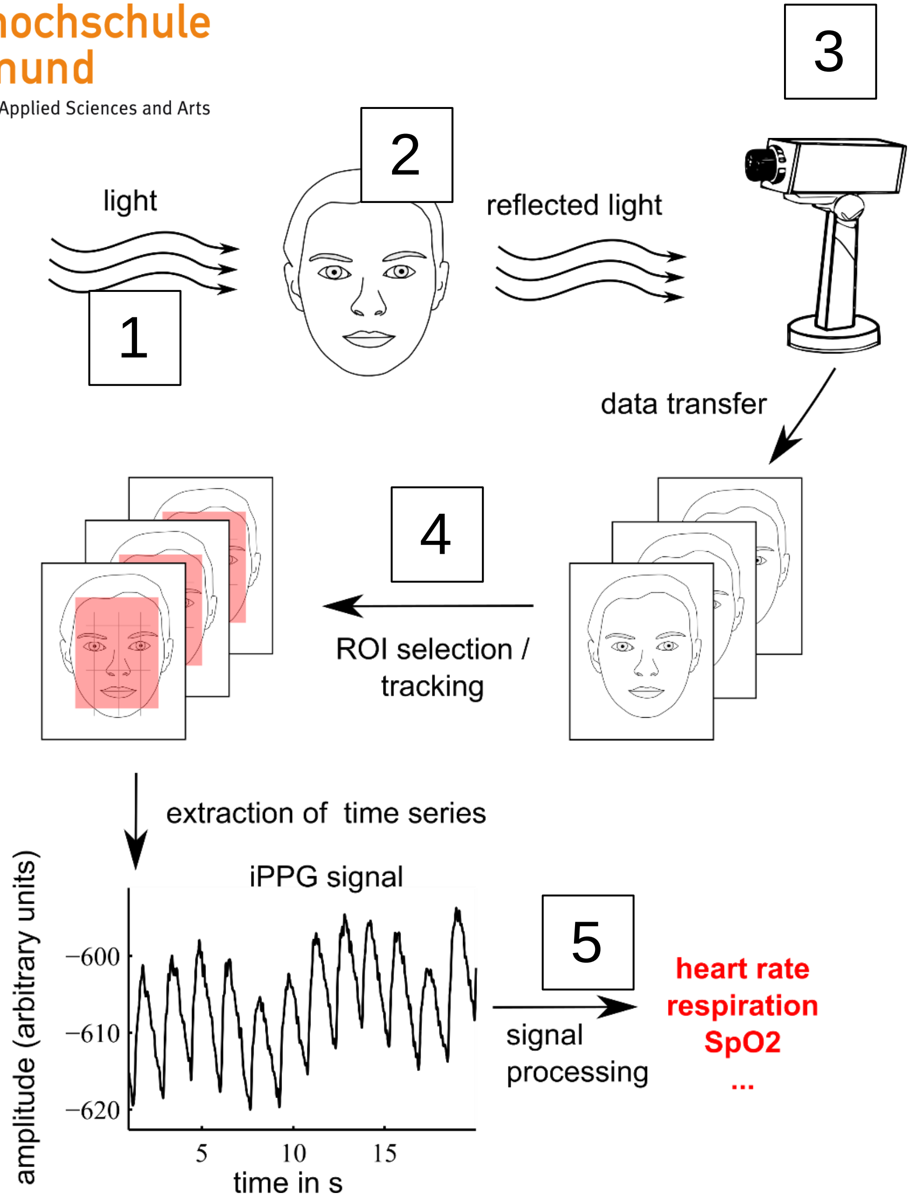
Contactless measurements – iPPG

- Background
  - Basis is tissue light interaction (absorption by hemoglobin)
  - Can be captures by cameras → imaging PPG
  - Various respiratory/cardiovascular parameters available



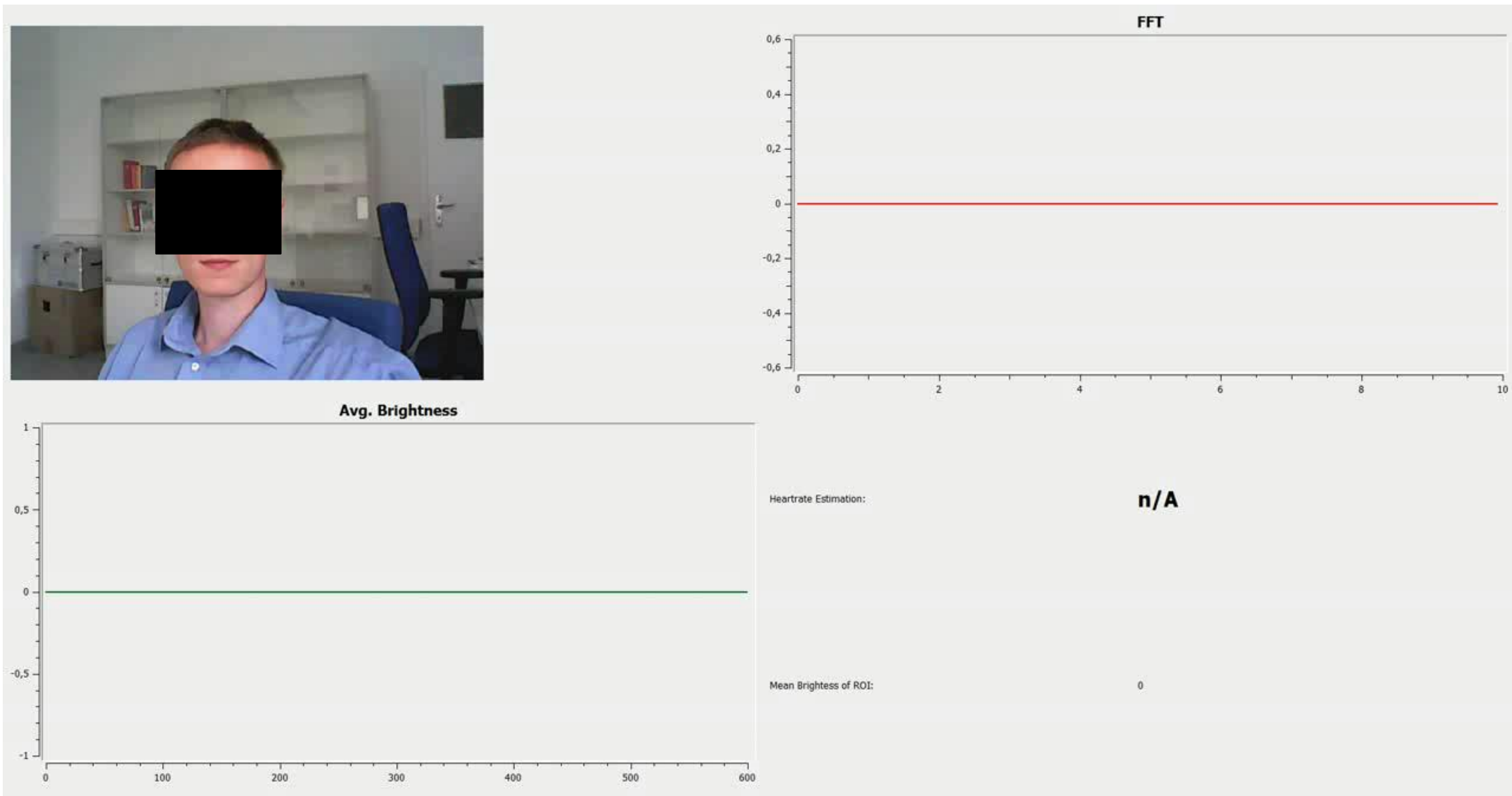


Contactless measurements – iPPG



1. Illumination
   - Ambient light/ artificial illumination (400 nm … 1000 nm)
2. Measurement areas
   - Skin
   - Most often facial area
3. Cameras
   - Webcams to high end cameras
   - Wavelengths (400 nm … 1000 nm)
4. ROIs
   - Automated/manual ROIs
   - Static/dynamic ROIs (→ essential for distance cbPPG)
5. Signal processing
   - Crucial aspect
   - Subject to many works
   - Filtering, Source separation, time-frequency transforms, …

Contactless measurements – iPPG

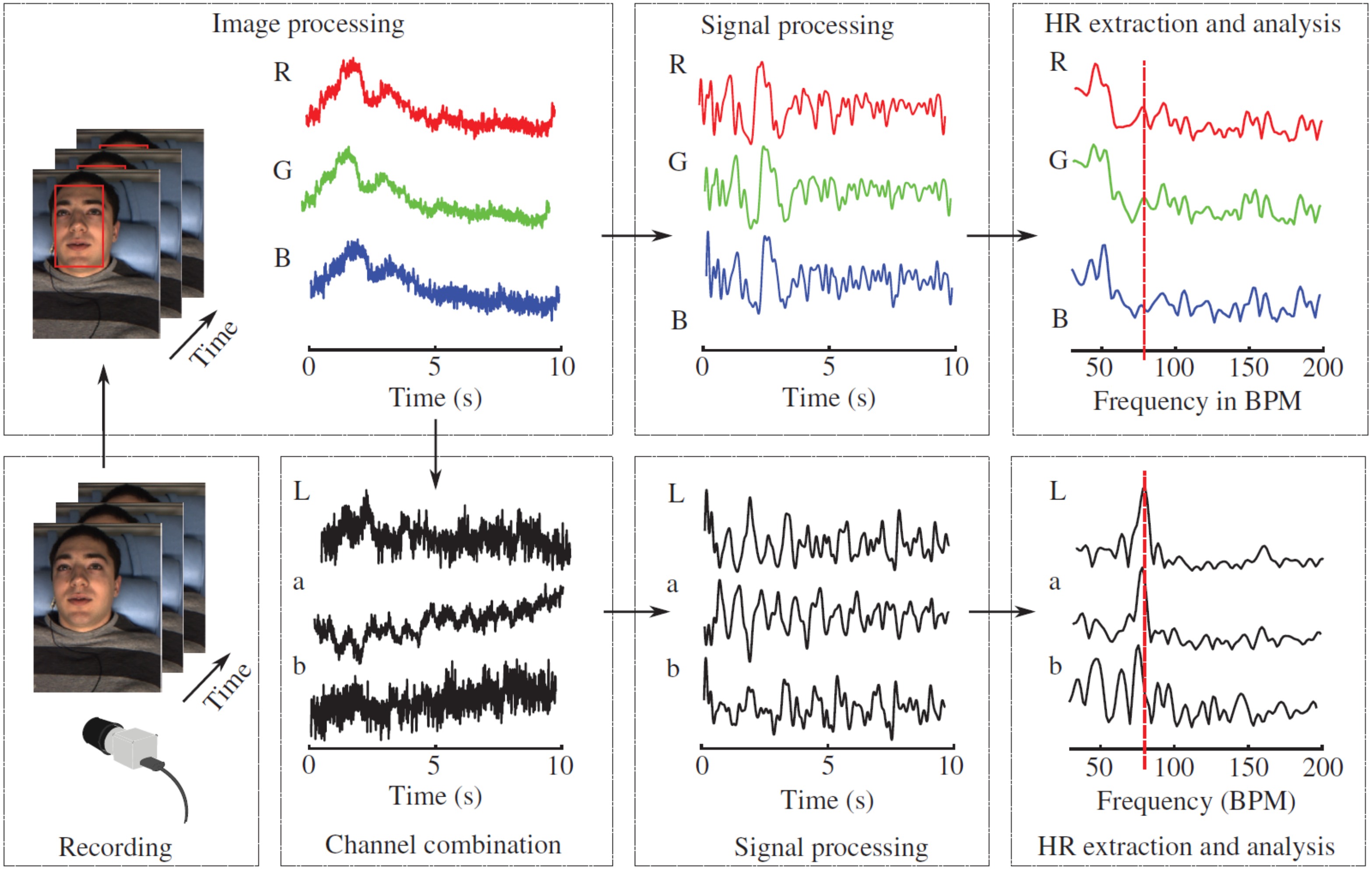


Sensor data fusion (SDF) – multimodal analyses

Sensor data fusion - background

- Sensor data fusion (SDF) = combination of data from different sensors
  - Homogeneous SDF = combination of „comparable“ data, e.g. multiple leads of a single modality
  - Heterogeneous SDF = combination of multiple modalities, e.g. iPPG and radar
- Potential benefits
  - Make analysis more robust (by redundant measurements / measurement systems)
  - Create a more comprehensive view (by considering different parameters accessible from different modalities)
  - Derive additional parameters by combination of different modalities

Sensor data fusion - realizations



[Zaunseder2018]

Improvement of signal quality by color channel combination

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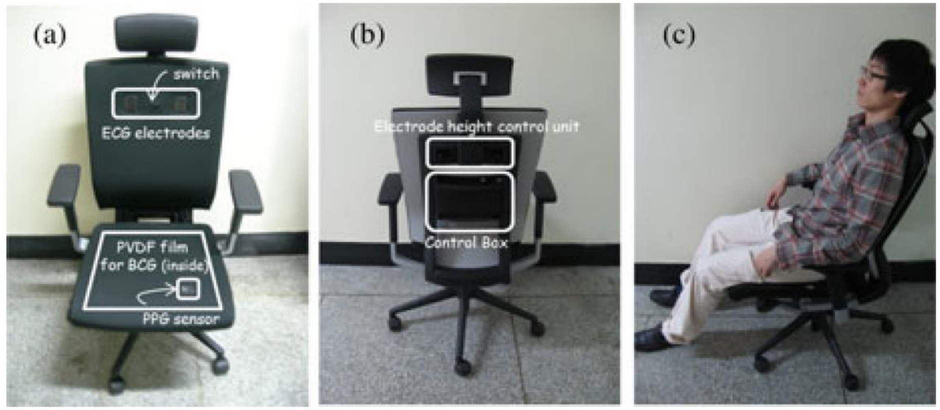
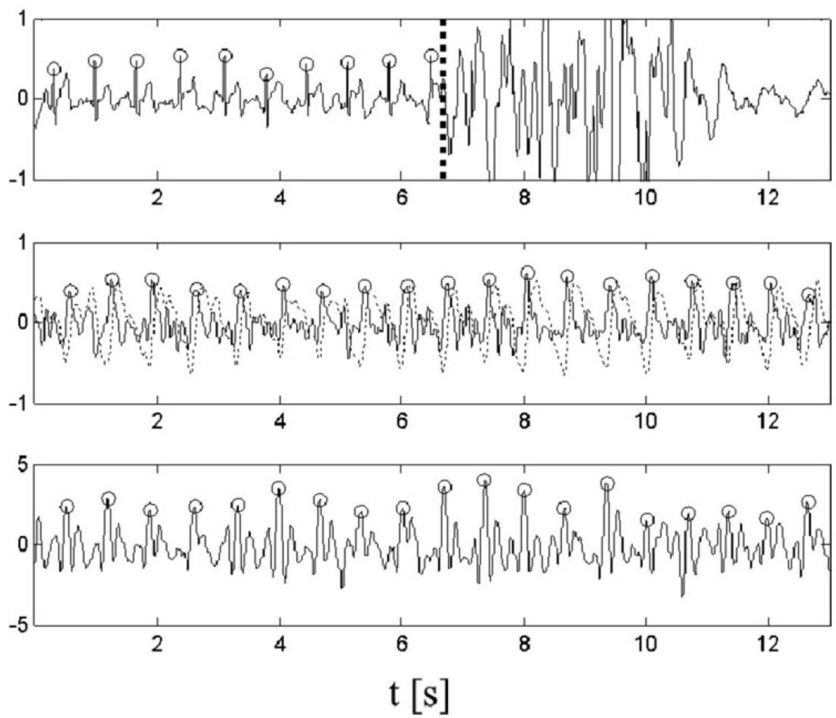
Sensor data fusion - realizations



Capacitive ECG

PPG through clothes

Ballistocardiographic signal



[Baek2012]

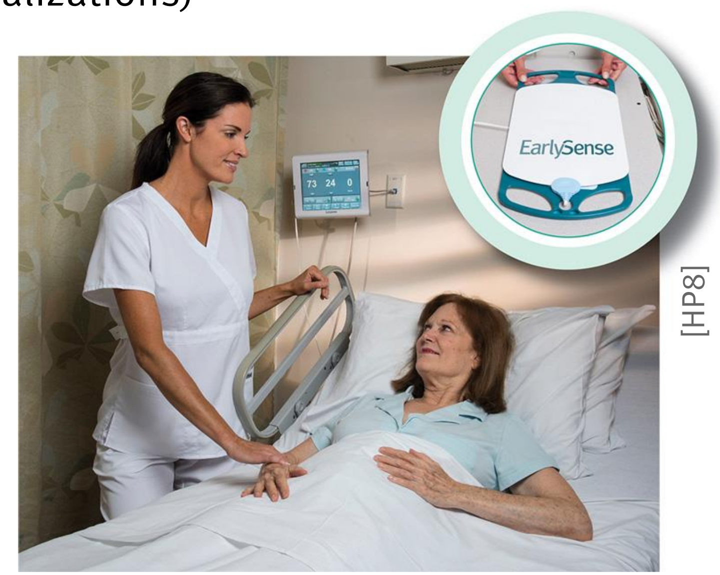
Derivation of pulse transit time as blood pressure correlate by PPG, ballistocardiographic signal and capacitive ECG

Valuation – current state, future directions and limitations

Valuation – current state

- Various solutions for contactless measurements in research
- Practical use cases still limited (→ e.g. in Germany difficult situation of health insurances)
- Only few „real applications“ (commercial realizations)

[HP7]



[HP8]

Ballistocardiographic monitoring under a mattress by earlysense (respiration, heart rate)

Valuation– current state

[Weinreich2014]

Radar-based sleep monitoring (respiratory monitoring to determine sleep related breathing disorders)

BUT: difficult to establish

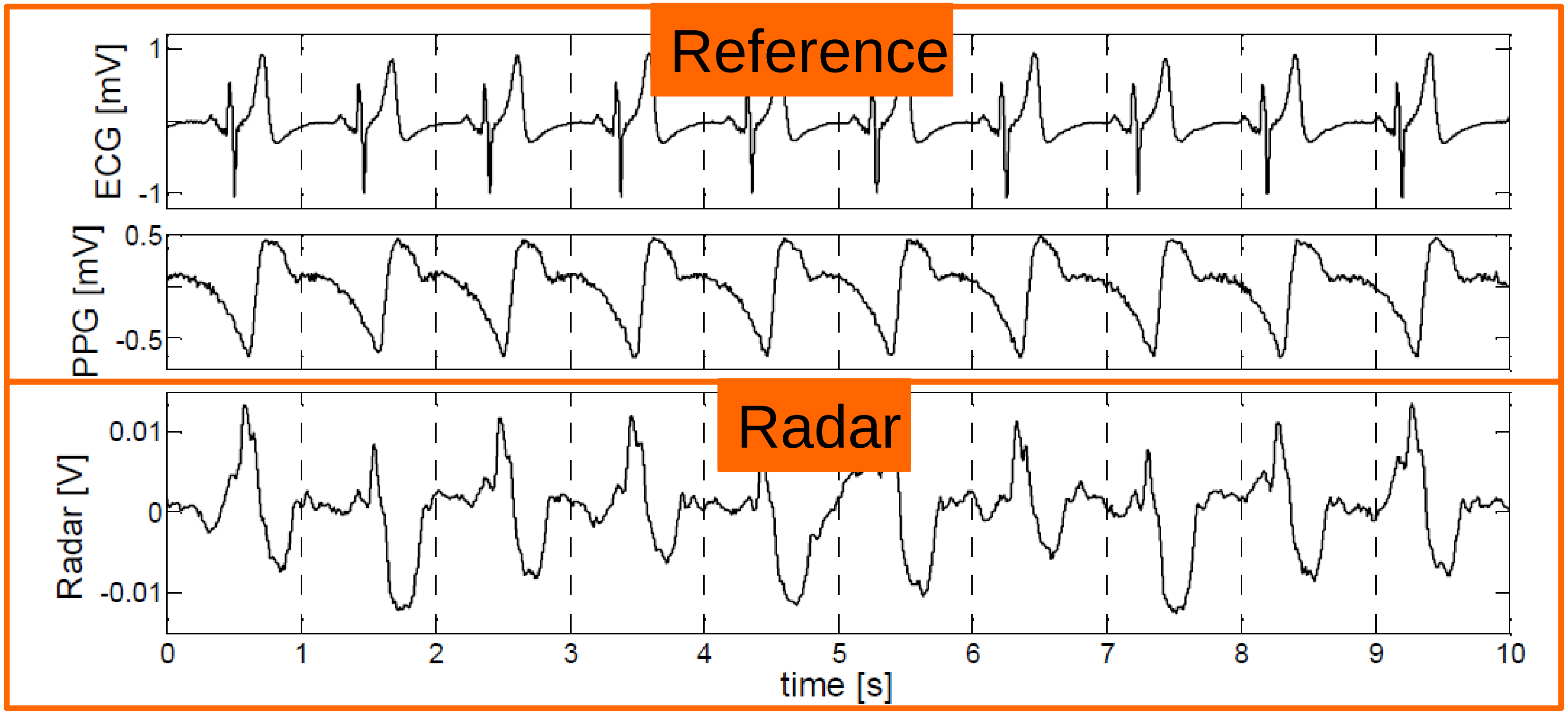
! Systems are often intended to replace existing solutions → difficult to obtain sufficient quality (compared to reference techniques) !

Future directions: exploit added value of novel techniques

1. **Novel applications (e.g. domestic area → see Friday lecture)**
2. **Novel parameters**

Valuation – future directions

- Radar-based measurements at IBMT



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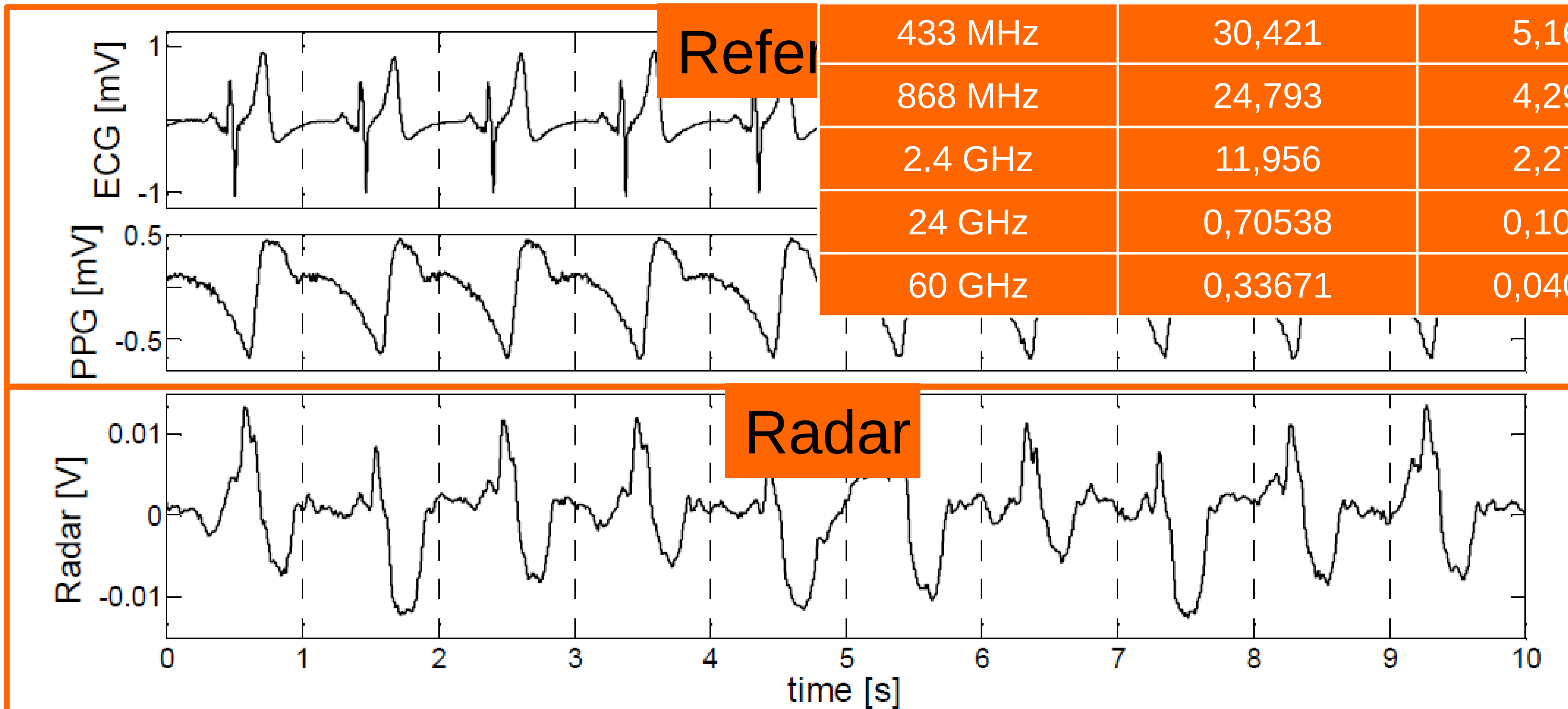
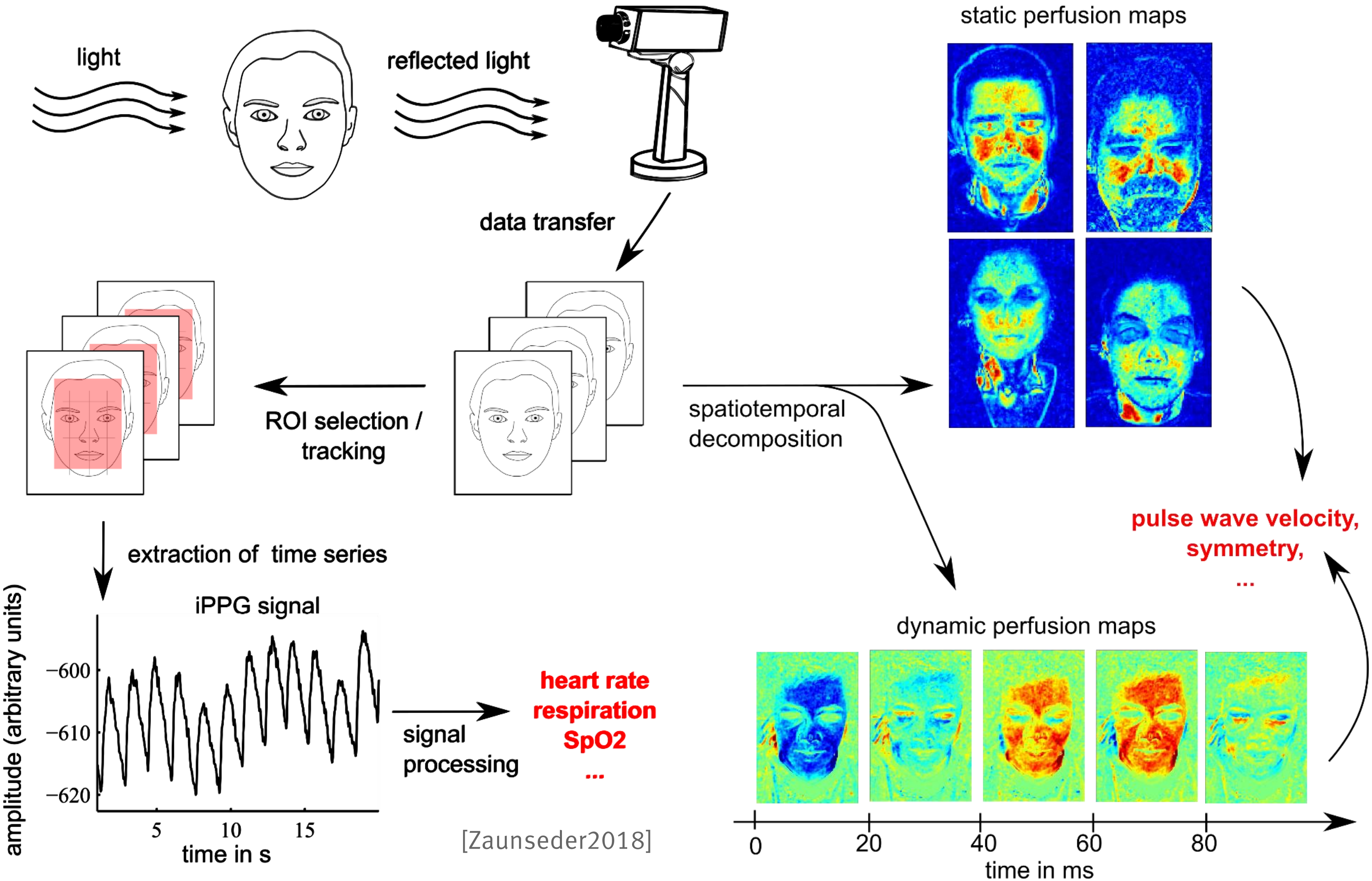
Valuation – future directions

- Radar-based measurements at IBMT

Frequency	Penetration depth (in cm)	
	Fat	Muscle
433 MHz	30,421	5,1692
868 MHz	24,793	4,2904
2.4 GHz	11,956	2,2785
24 GHz	0,70538	0,10086
60 GHz	0,33671	0,040973



Valuation – future directions



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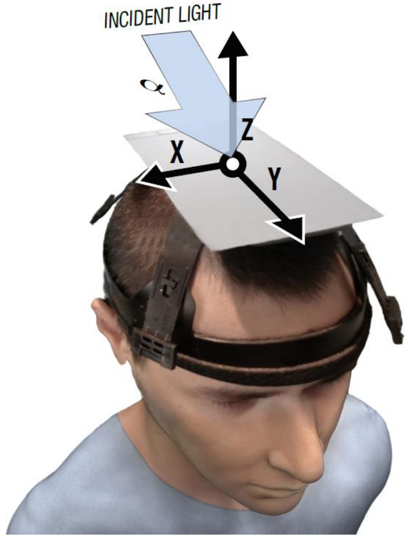
Valuation – future directions

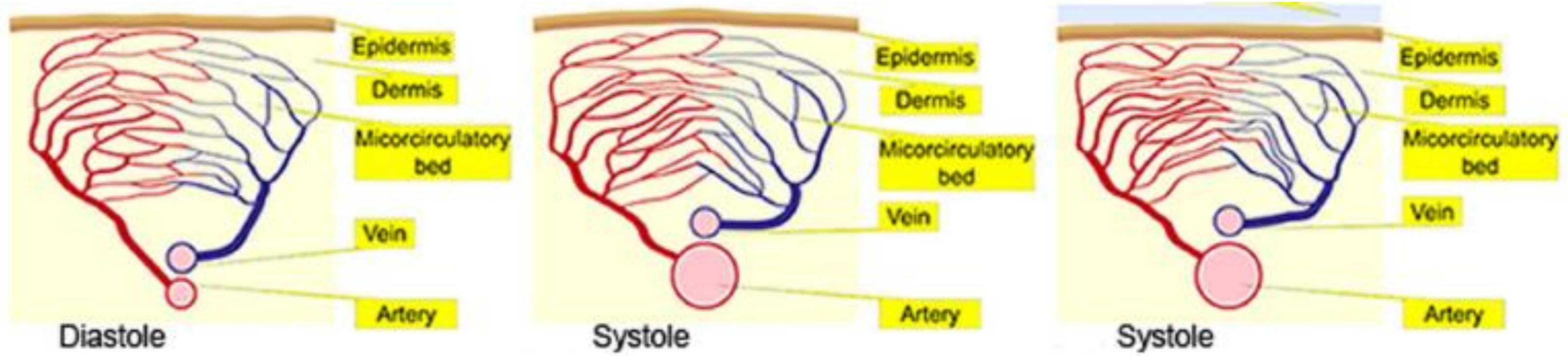
Cyclic variations due to heart rate and spatio-temporal perfusion characteristics (Videos in 5-fold slow motion)

Valuation – future directions

- Different theories on iPPG signals' background (a ballistocardiographic component must at least be considered)
- Most analyses do not account for impairing factors
- Future work required → particularly fusion of information for a reliable state estimate is necessary → network physiology approach might be beneficial



[Moco2016]

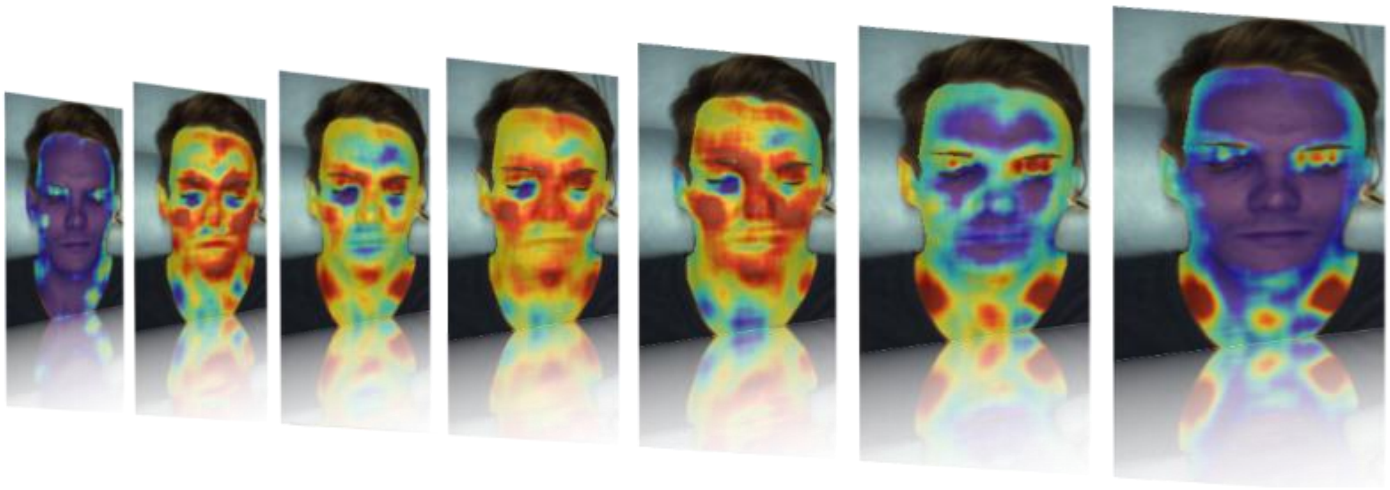


[Kamshilin2015]

Summary

Summary

- Different techniques for contactless measurements available
- Contents (partially) redundant and (partially) complementary → approaches of sensor data fusion applicable
- Few „real applications“
- Understanding partially lacking → risk of misinterpretation
- Full potential not yet exploited
- Future works will have to incorporate und fuse more information



Thank you for your interest

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[HP4] https://discountcardiology.com/Generic-BCI-Finger-Clip-Sensor.html , 16.07.2019
[HP5] https://www.biocomtech.com/products/heart-rhythm-scanner_hardware , 16.07.2019
[HP6] https://www.ambu.com/products/cardiology/ecg-electrodes/product/ambu-bluesensor-l , 16.07.2019
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