Controls
Electronics &
Mechatronics

BEAMS

CERN

MARCHESE project

Remote Monitoring of Health Parameters

Roberto Cittadini
BE-CEM-MRO section
roberto.cittadini@cern.ch

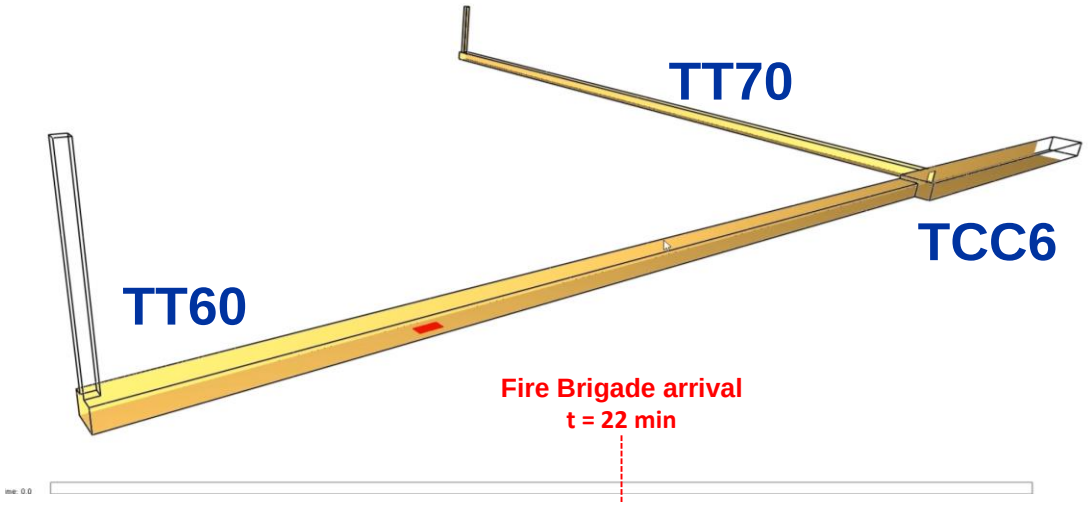
Early-Career Researchers in Medical Applications

9th November 2022

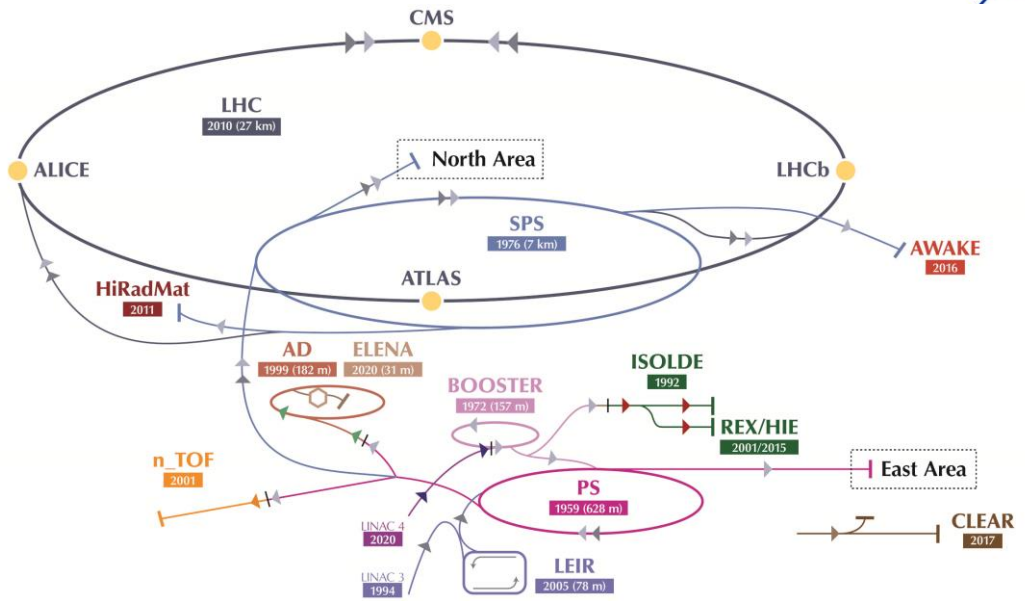
Contents

- Background and project origin
- Contactless Monitoring
- Remote Photoplethysmography
- CERN Applications
- Medical Applications
- Conclusion and future works

Background and project origin



Fire simulation: fire seat at TT60up, design fire DF5 (13MW)
PA7, TA7, TT70, **TT60,TCC6** modeled, courtesy of HSE (A. Arnalich)

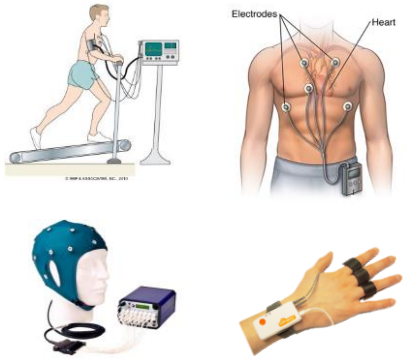


Response time of a rescue team of **CERN Fire Brigade** could take up to 22 minutes in the LHC tunnel.

The research is oriented towards the development of robotic solutions: **workers' detection** and **health contactless monitoring** during emergencies situations is important to support in search and rescue scenarios.

Contactless Monitoring

TRADITIONAL CONTACT SYSTEMS



EMERGENCY SITUATIONS

HEALTHCARE and HOSPITAL SCENARIO

ADVANTAGES

- **No-invasive** monitoring system
- **No infection**: monitoring patients at risk (COVID19)
- **Not require skin contact**: burned people, newborns
- Not affect the activities of daily living
- **Reusable device** by different users, contact-based ones need to be personal
- Ready-to-use technologies

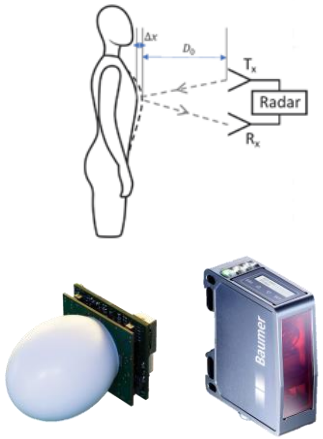
DRAWBACKS

- Not possible to detect all physiological signals in contactless way
- Person should be confined in a limited space throughout the entire monitoring session

Contactless Monitoring

MECHANICAL DISPLACEMENT

- Chest displacement for RR
- Heart contractions for HR and HRV
- Carotid artery pulsation for HR and HRV



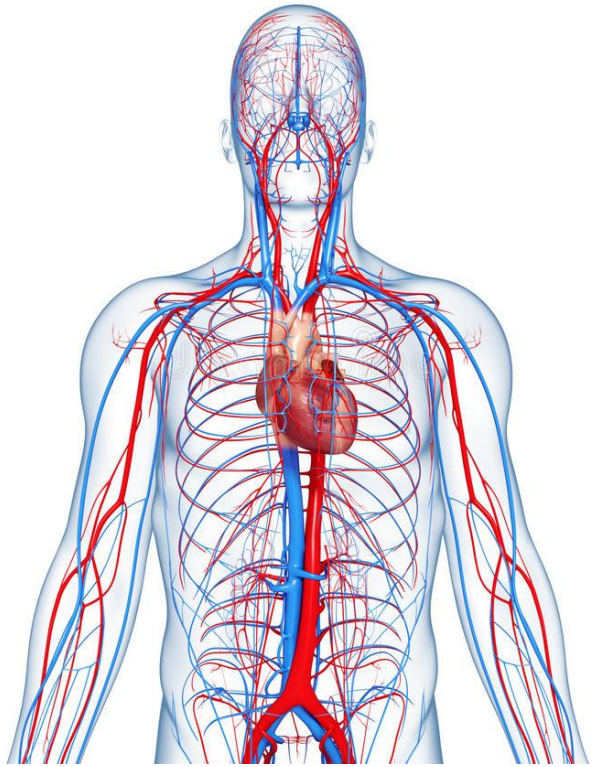
THERMOGRAPHY

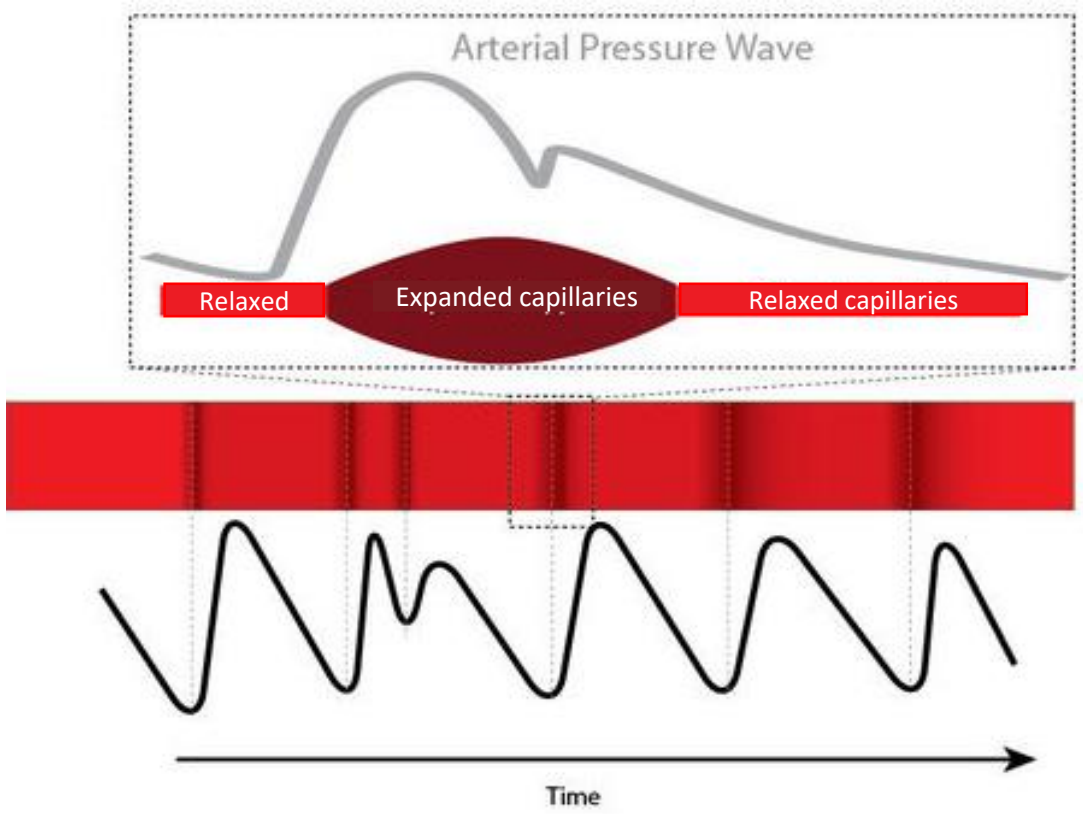
- Body Temperature distribution provides information about the human well-being

PHOTOPLETHYSMOGRAPHY

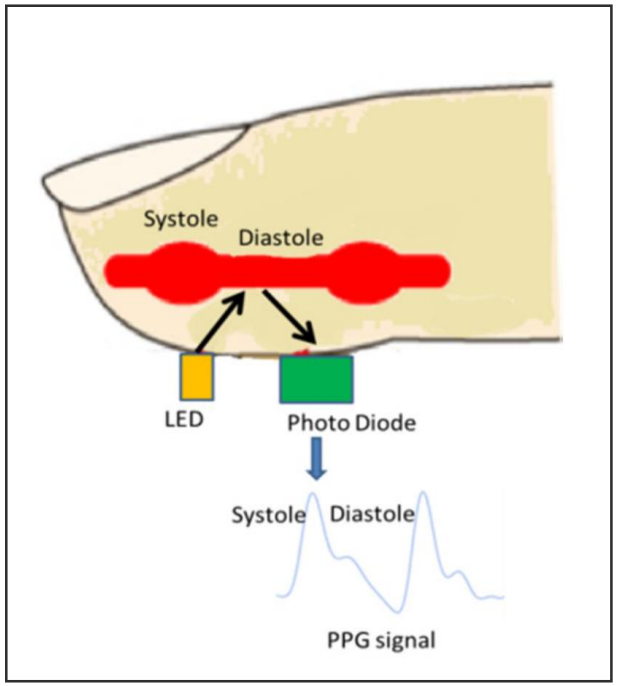
- Optical technique used to detect volumetric changes in the blood in the peripheral circulation.
- Blood volume changes in microvascular tissue (i.e. at cheeks and forehead level)

PhotoPlethysmoGraphy (PPG)

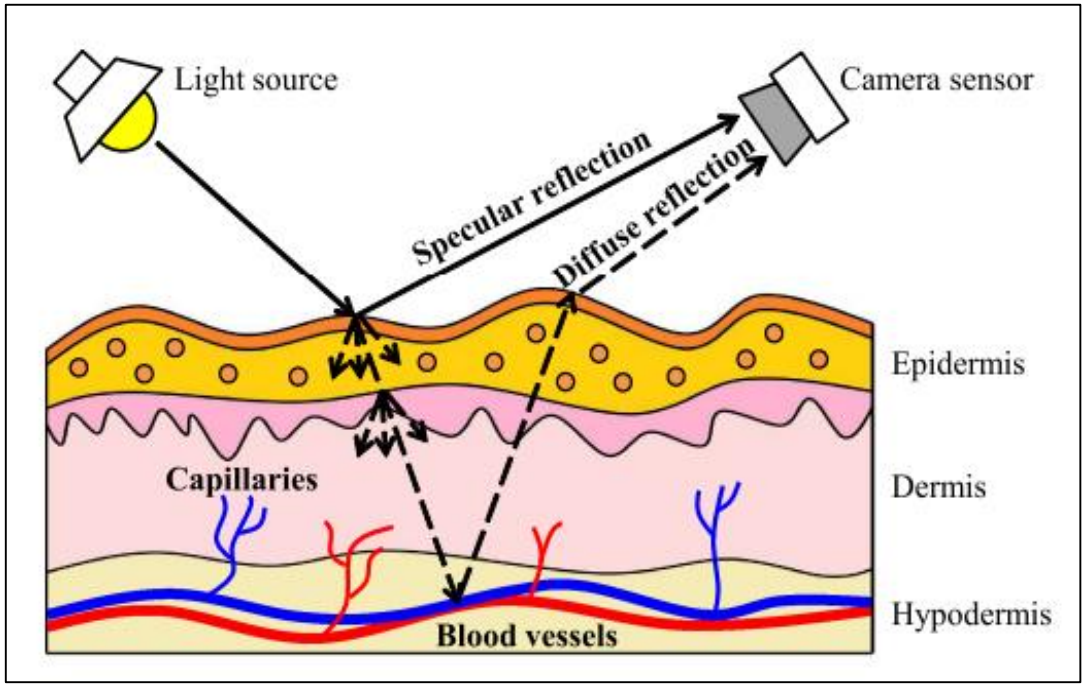




Contact PPG vs remote PPG

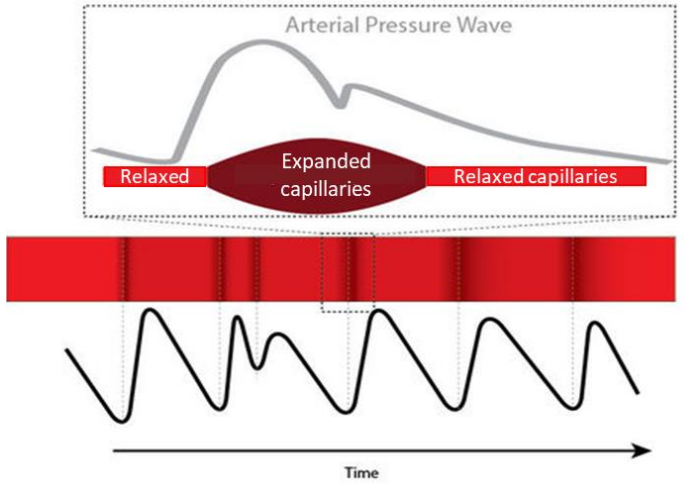


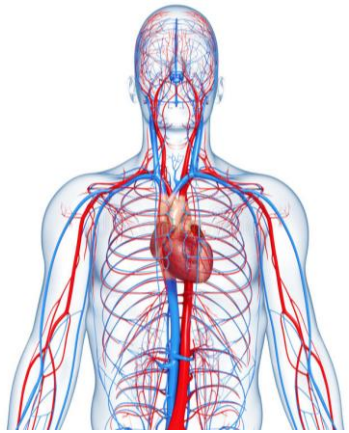
CONTACT PPG

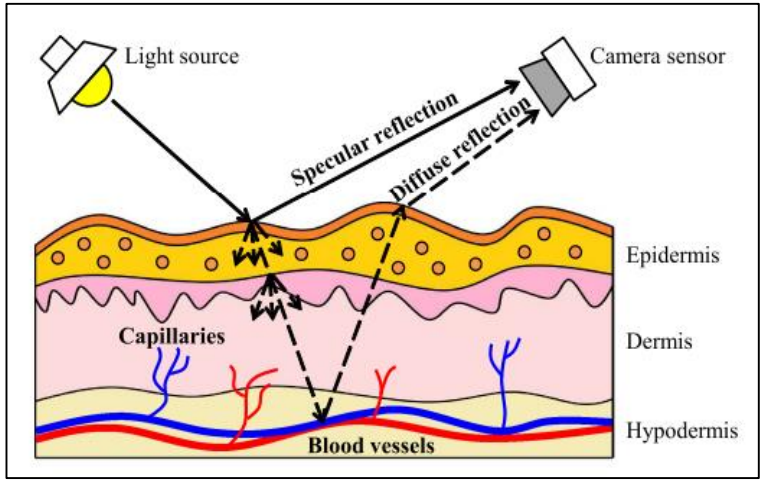


REMOTE PPG or NO-CONTACT PPG

Remote PPG: Dichromatic model







$$C_k(t) = I(t) \cdot [v_s(t) + v_d(t)] + v_n(t)$$

SPECULAR REFLECTION

$$v_s(t) = u_s \cdot (s_0 + s(t))$$

- $\boldsymbol{u_s}$ = unit color vector of the light spectrum
- $\boldsymbol{s_0}$ = stationary part of specular reflection
- $\boldsymbol{s(t)}$ = varyng part of specular reflection (motion)

DIFFUSE REFLECTION

$$v_d(t) = u_d \cdot d_0 + u_p \cdot p(t)$$

- $\boldsymbol{u_d}$ = unit color vector of the skin tissue
- $\boldsymbol{d_0}$ = stationary reflection of diffuse reflection
- $\boldsymbol{u_p}$ = pulsatile coeff in RGB channels
- $\boldsymbol{p(t)}$ = pulse signal

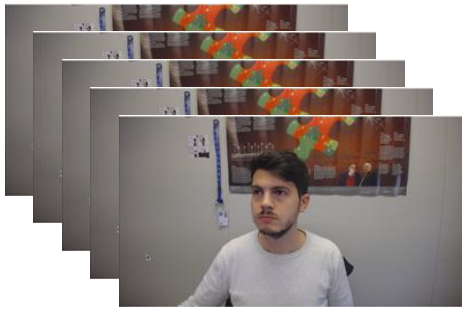
DICHROMATIC MODEL $\rightarrow$ $C_k(t) \sim I_0(1 + i(t)) \cdot [u_c \cdot c_0 + u_s \cdot s(t) + u_p \cdot p(t)]$

Constant Specular **Pulse**

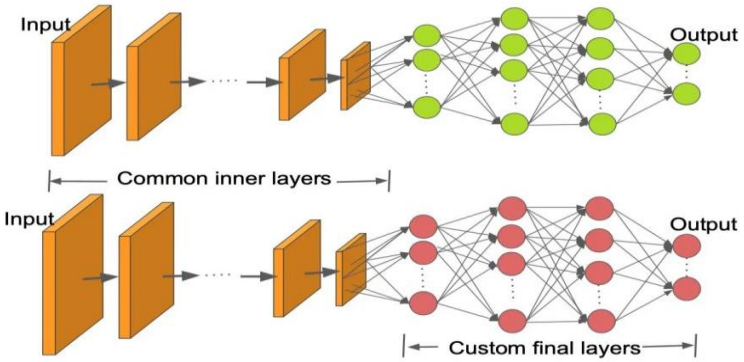
Remote PPG: Video pre-processing

30 FPS

30 images/second
Logitech 1080p FULL HD
GPU NVIDIA GTX 1080p

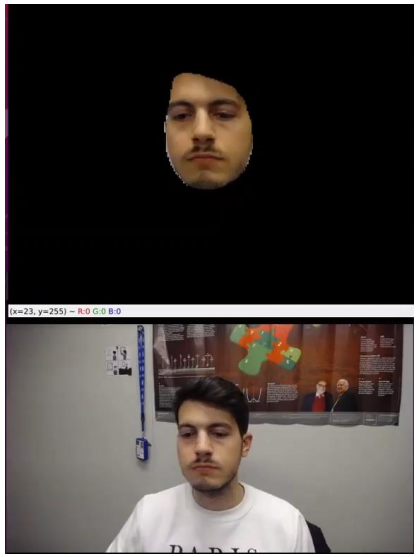


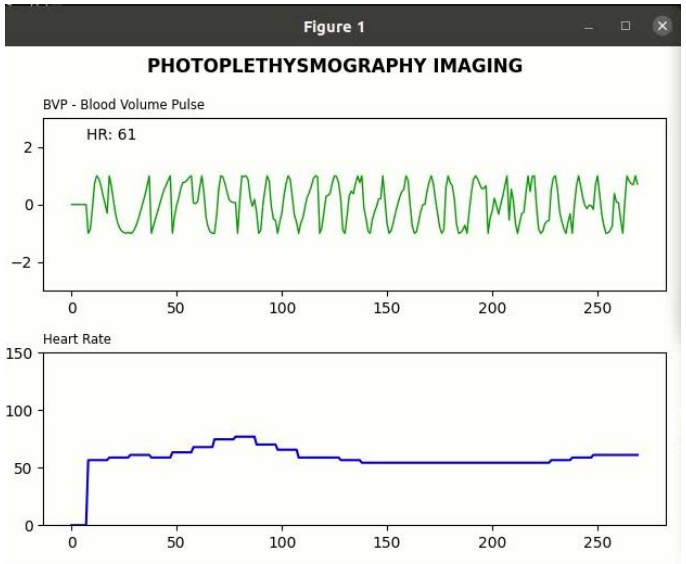
NEURAL NETWORK

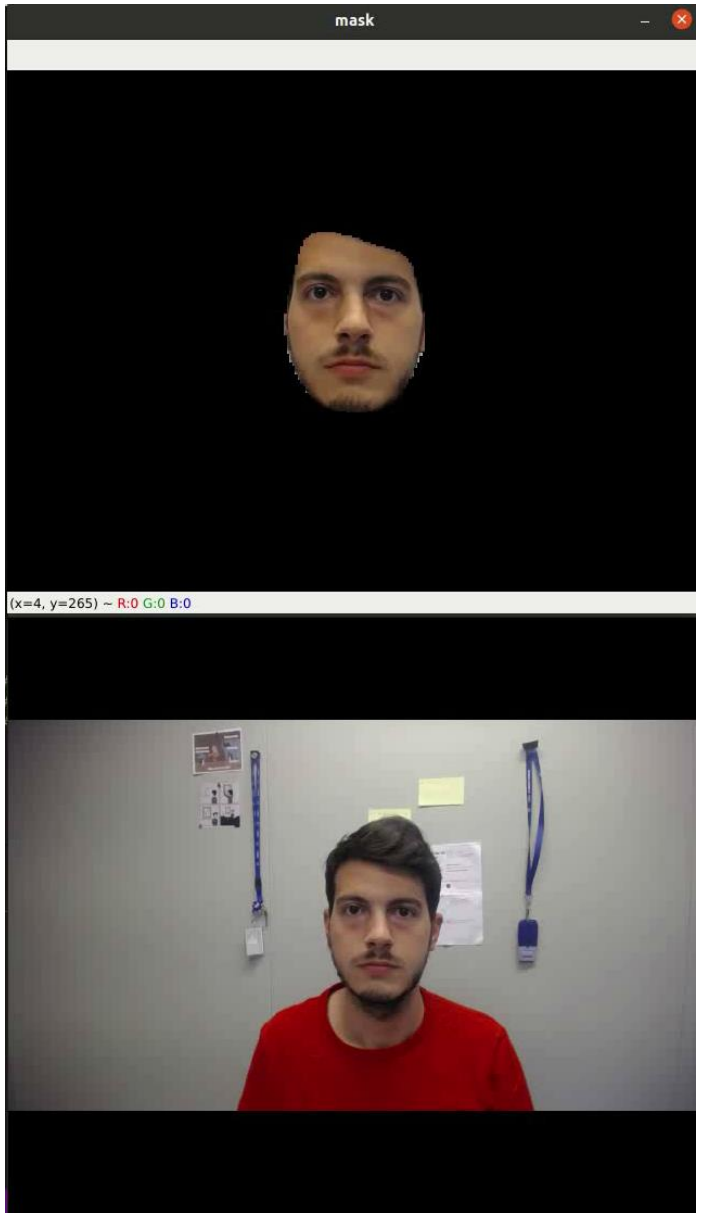


SEPARATION of SKIN PIXELS from NO-SKIN PIXELS

REAL TIME



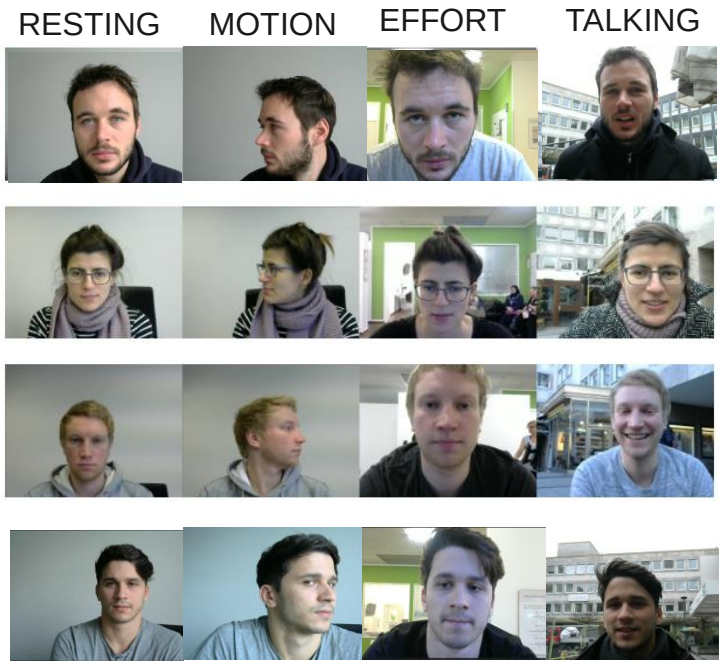


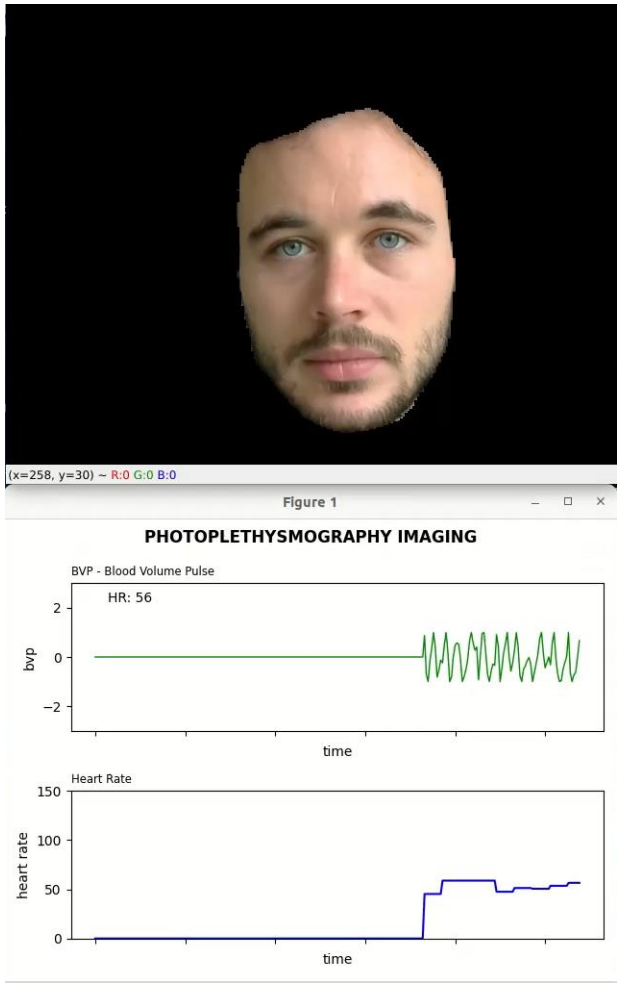



```
FPS: 30.15244789362723 - your Heart Rate is 54
FPS: 30.176730443624784 - your Heart Rate is 54
FPS: 29.993199459865966 - your Heart Rate is 54
FPS: 30.127259410614457 - your Heart Rate is 54
FPS: 29.754511151694206 - your Heart Rate is 54
FPS: 30.525815272766796 - your Heart Rate is 54
FPS: 30.09615865280778 - your Heart Rate is 54
FPS: 30.00694674141071 - your Heart Rate is 56
FPS: 30.103675746000043 - your Heart Rate is 58
FPS: 30.11694061634009 - your Heart Rate is 61
FPS: 29.781652546534897 - your Heart Rate is 61
FPS: 30.385103636796103 - your Heart Rate is 61
```

Remote PPG: available databases

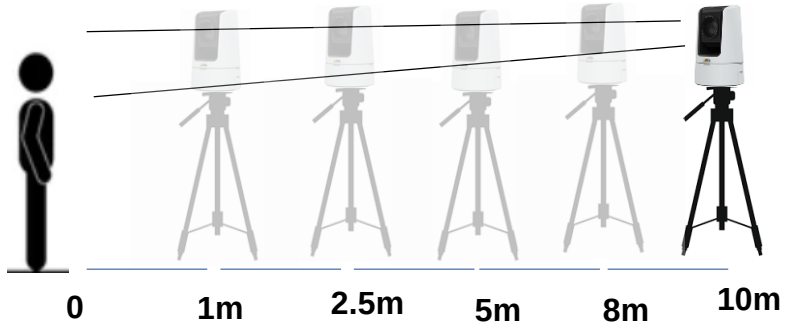
DATABASE

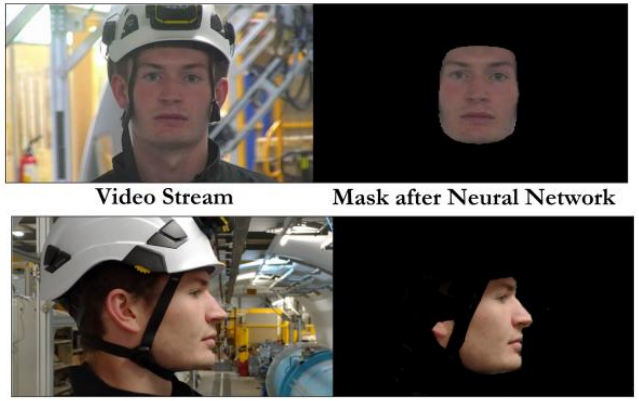


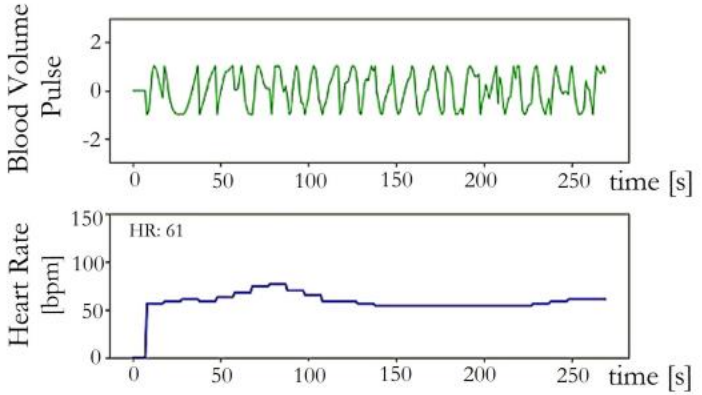


Experiment in the LHC mock-up

EXPERIMENTAL SETUP







EXPERIMENTAL PROTOCOL: use 1x to 30x optical zoom of PTZ camera to measure heart rate for an interval time of 90 s at different distances fixed, verified with Shimmer3 ECG as ground-truth sensor.

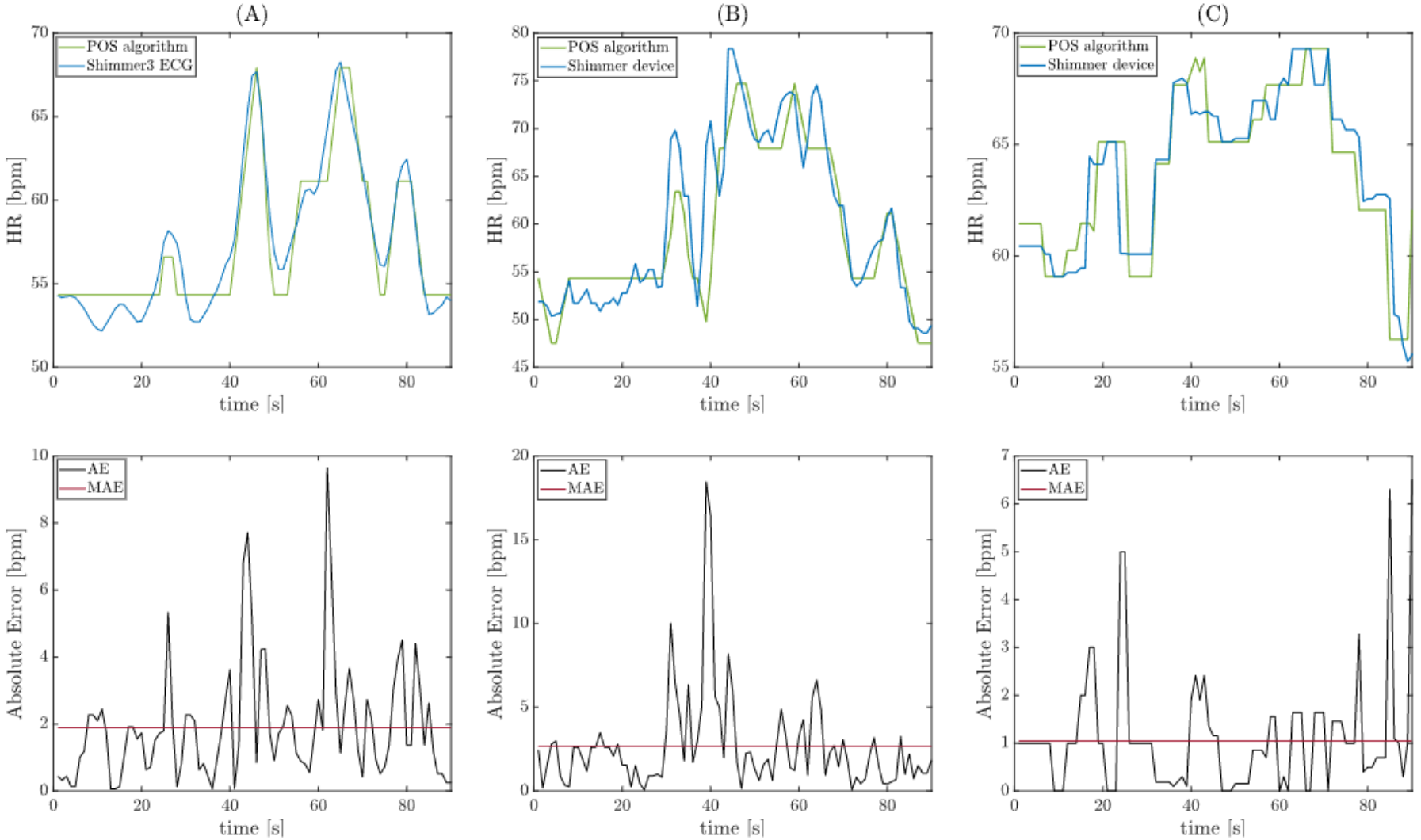
EVALUATION METRICS

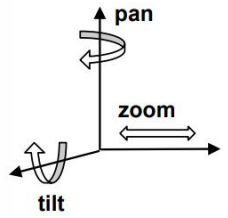
- Absolute Error (AE):
- Mean Absolute Error (MAE):

$$AE(i) = |HR_{POS}(i) - HR_{true}(i)|$$

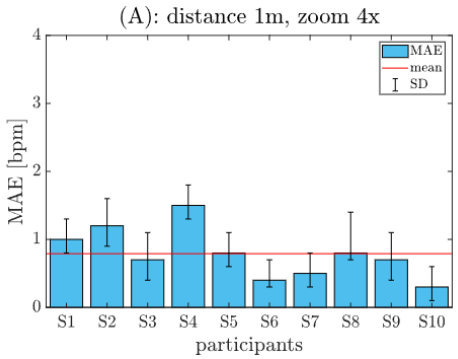
$$MAE = \sum_{i=1}^{N} AE(i)$$

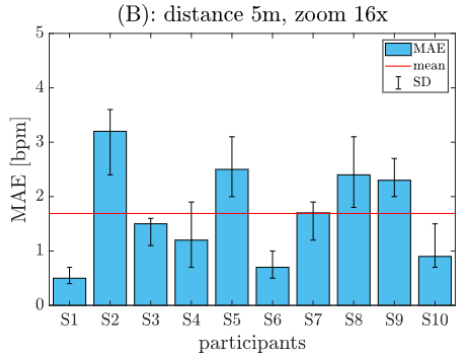
Remote PPG: comparison with benchmark device

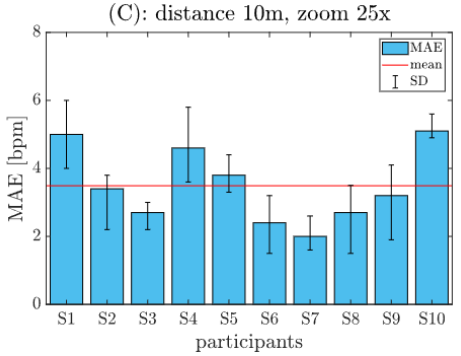


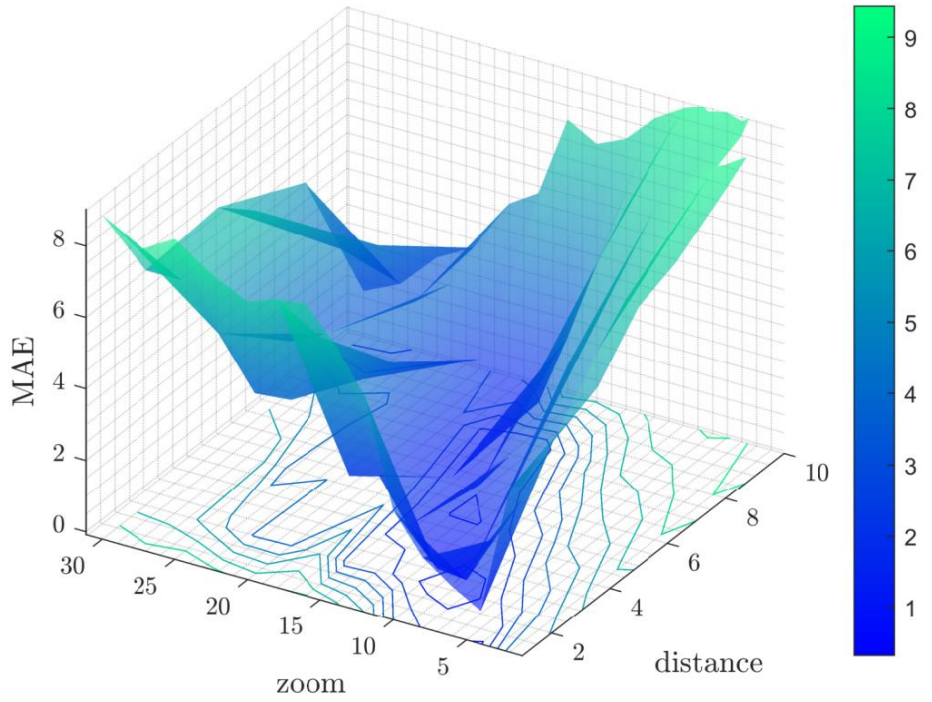


Remote PPG: comparison with benchmark device









STATISTICAL ANALYSIS

distance-zoom	PCC	p-value
d = 1m, zoom = 4x	ρ = 0.92	p < 0.0001
d = 1m, zoom = 6x	ρ = 0.92	p = 0.0009
d = 1m, zoom = 8x	ρ = 0.92	p = 0.0012
d = 2.5m, zoom = 6x	ρ = 0.92	p = 0.0004
d = 2.5m, zoom = 8x	ρ = 0.94	p = 0.0007
d = 2.5m, zoom = 10x	ρ = 0.89	p < 0.0001
d = 2.5m, zoom = 12x	ρ = 0.94	p < 0.0001
d = 5m, zoom = 12x	ρ = 0.90	p = 0.0014
d = 5m, zoom = 14x	ρ = 0.87	p < 0.0001
d = 5m, zoom = 16x	ρ = 0.91	p = 0.0005
d = 8m, zoom = 14x	ρ = 0.91	p < 0.0001
d = 8m, zoom = 16x	ρ = 0.96	p = 0.0002
d = 8m, zoom = 18x	ρ = 0.92	p = 0.0008
d = 10m, zoom = 30x	ρ = 0.92	p = 0.0004

EVALUATION METRICS

- AE = Absolute Error
- MAE = Mean Absolute Error

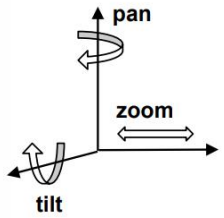
PEARSON CORRELATION COEFFICIENT

$$\rho = \frac{\sum_i (HR_{POS}(i) - \mu)(HR_{true}(i) - \hat{\mu})}{\sqrt{\sum_i (HR_{POS}(i) - \mu)^2} \sqrt{\sum_i (HR_{true}(i) - \hat{\mu})^2}}$$

Applications

CERN Applications: VISUAL INSPECTION IN HARSH ENVIRONMENT

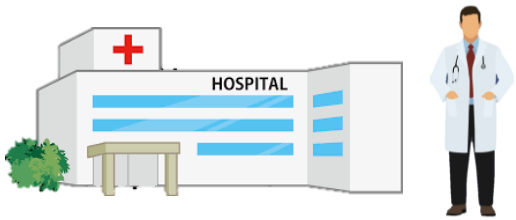
- Contactless Monitoring System
- Vital parameters check
- Human presence
- Workers' localization
- Support in harsh environment
- Search and Rescue scenario



Medical Applications

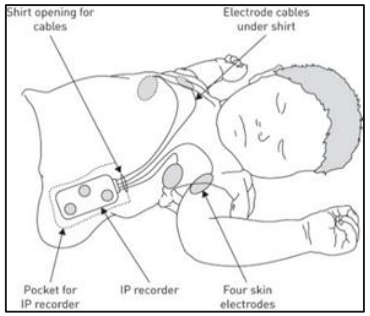
In contact with Medical Staff in the Hospital

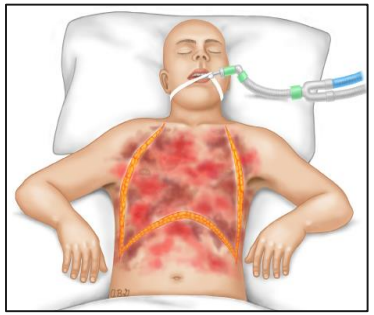
- **Understand which are the needs of the real scenario**
- **Develop technologies useful**



NEWBORN and PATIENTS WITH BURNS

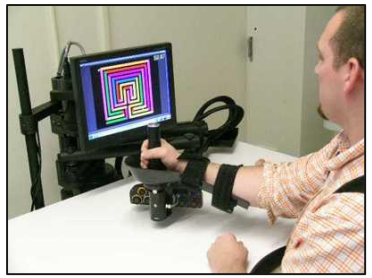
- Fragile skin
- No abrasions and damage of epidermis
- Continuous and constant monitoring





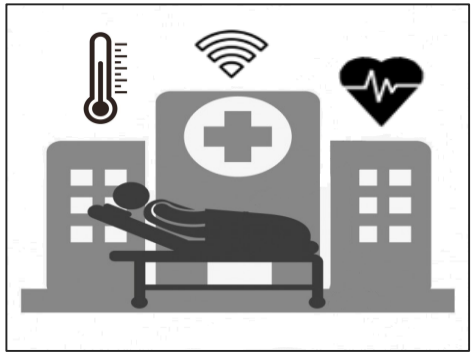
ASSISTIVE ROBOTIC REHABILITATION

- adjust the exercise level (increase or decrease) according to the patient's physiological response
- Exploit residual patient capabilities (assistance-as-needed)



SMART HOSPITAL ROOM

- Hospital room for remote monitoring
- Avoid medical staff infections
- Hospitalization more comfortable for patients
- Group or single patient monitoring

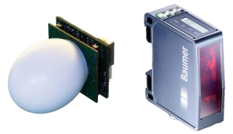


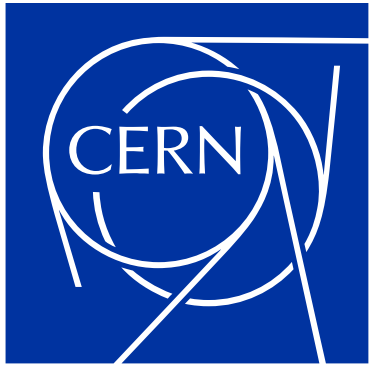
Conclusion

- Complete development of **remote PPG system** ready-to-use via webcam
- An experiment was conducted in order to evaluate optimal configuration in terms of distance and camera zoom
- Good correlation between algorithm and benchmark device (PCC and p-value)
- Mobile camera lens implementation for remote PPG system more versatile: adapt the technology to the human and not vice versa

FUTURE WORKS

- Continue in working on limits: illumination, body motions, multiple detection
- Explore other contactless monitoring methods to extend the system (radars, laser distance)
- Continue in getting knowledge and experiences with medical staff





Thank you for your attention!

beams.cern