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Open Innovation by IMEC and TNO

BODY SENSORS FOR THE FUTURE OF MEDICINE

WILL YOU STILL NEED YOUR DOCTOR?

hSITE Annual Meeting | Montreal | 4-5 June 2012

JULIEN PENDERS
Program Manager Body Area Networks
imec / Holst Centre
contact: Julien.Penders@imec-nl.nl

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What will the doctor of the future look like?

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Managing STRESS

30-40%

Report their job as stressful (US)

$42-300B

Cost associated to stress-related disorders (US)

40M

Affected by work related stress (EU)

4/10

Leading causes of death directly related to stress

25%

Extended sickness absence are related to stress (EU)

3/10

Leading causes of death indirectly related to stress

STRESS TREATMENT TODAY

TREATMENT today is about reducing the SYMPTOMS through Antidepressant DRUGS

or

semi-empirically by COUNSELING (stress therapy)

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STRESS MANAGEMENT TOMORROW
A smart phone app that reduces stress?

IT STARTS WITH MEASURING STRESS

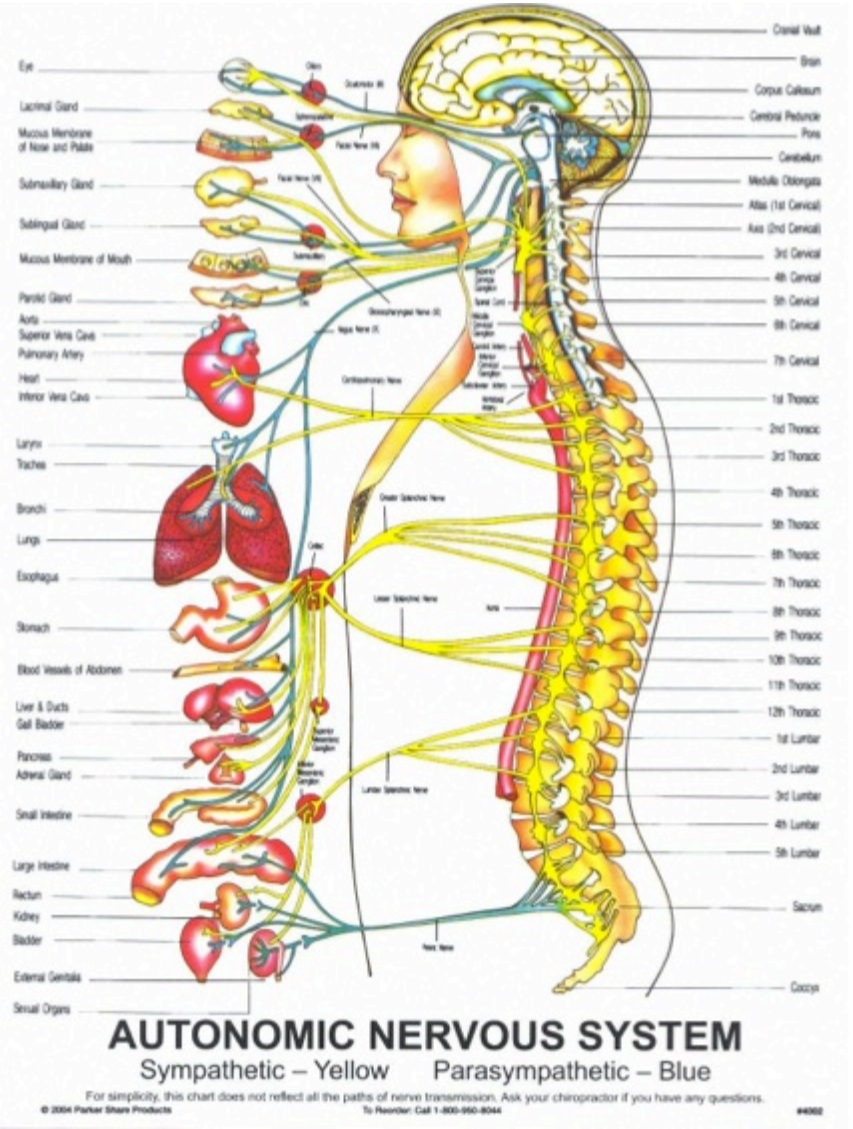
By monitoring the Autonomic Nervous System

The ANS system

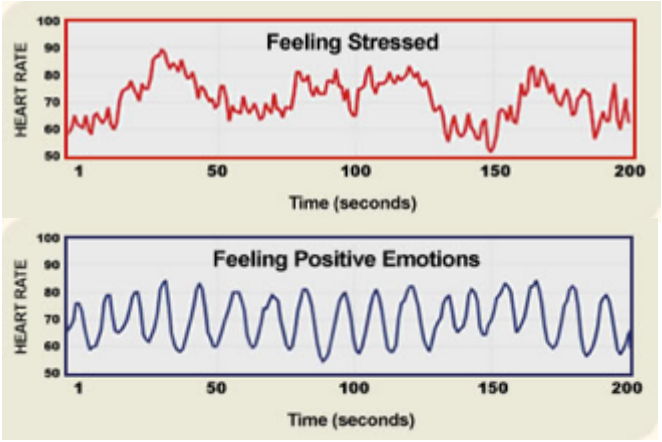
- Is responsible for maintaining homeostasis in the body
- Helps people adapt to changes in their environment
- Adjusts or modifies some functions in response to stress
- Is an unconscious control mechanism

The ANS affects regulation of

- heart rate, respiration rate, salivation, perspiration, diameter of the pupils



MONITORING STRESS



HeartMath's emWave

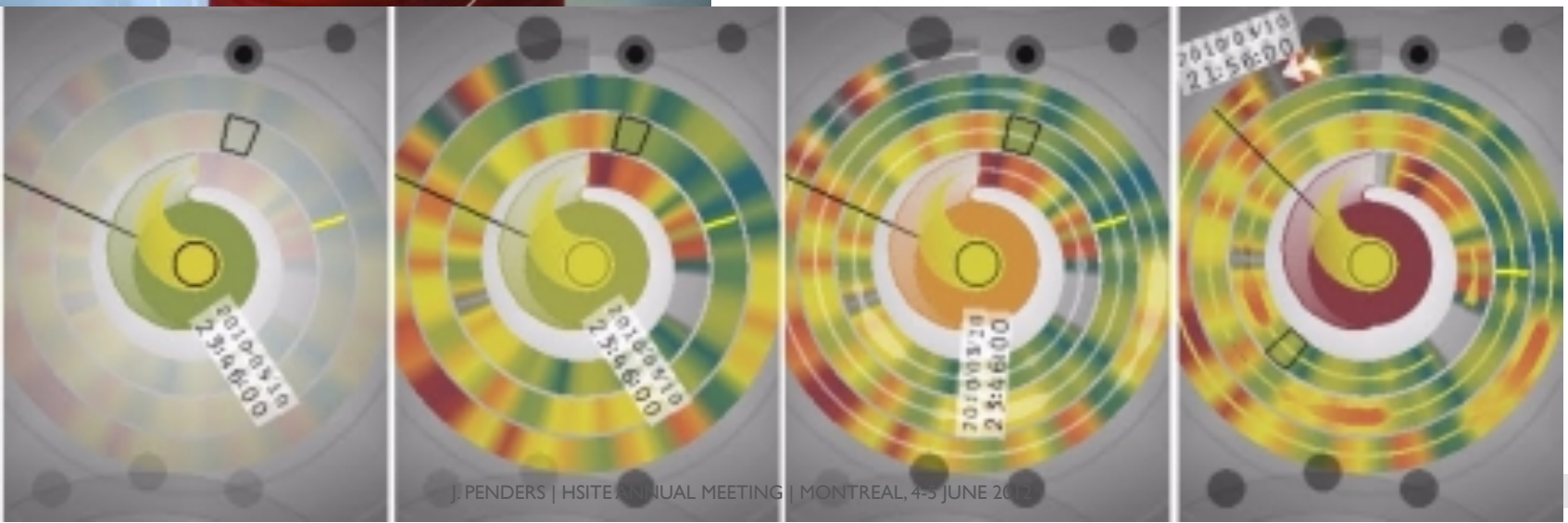
EXMOVERE

affectiva

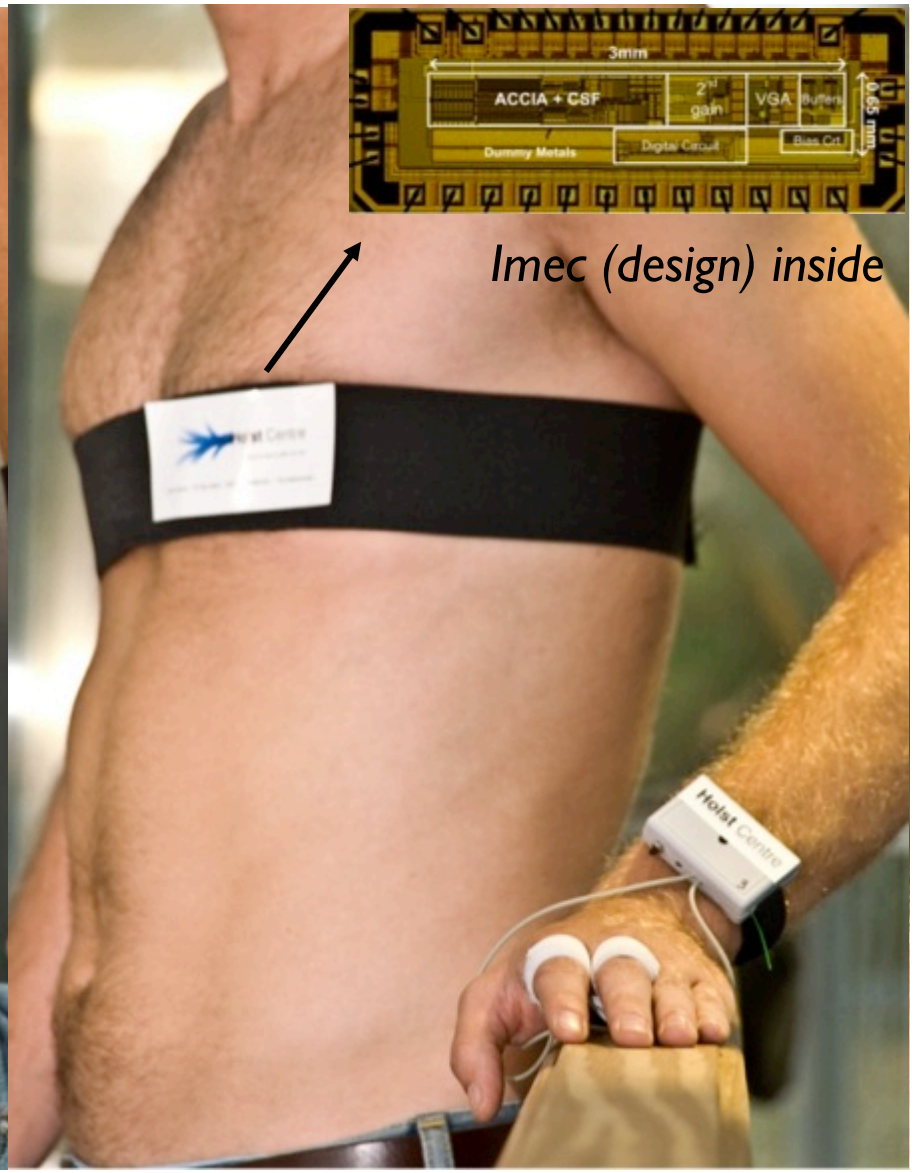
© IMEC 2012

MONITORING STRESS

K.Hook
Swedish Institute of Computer Science

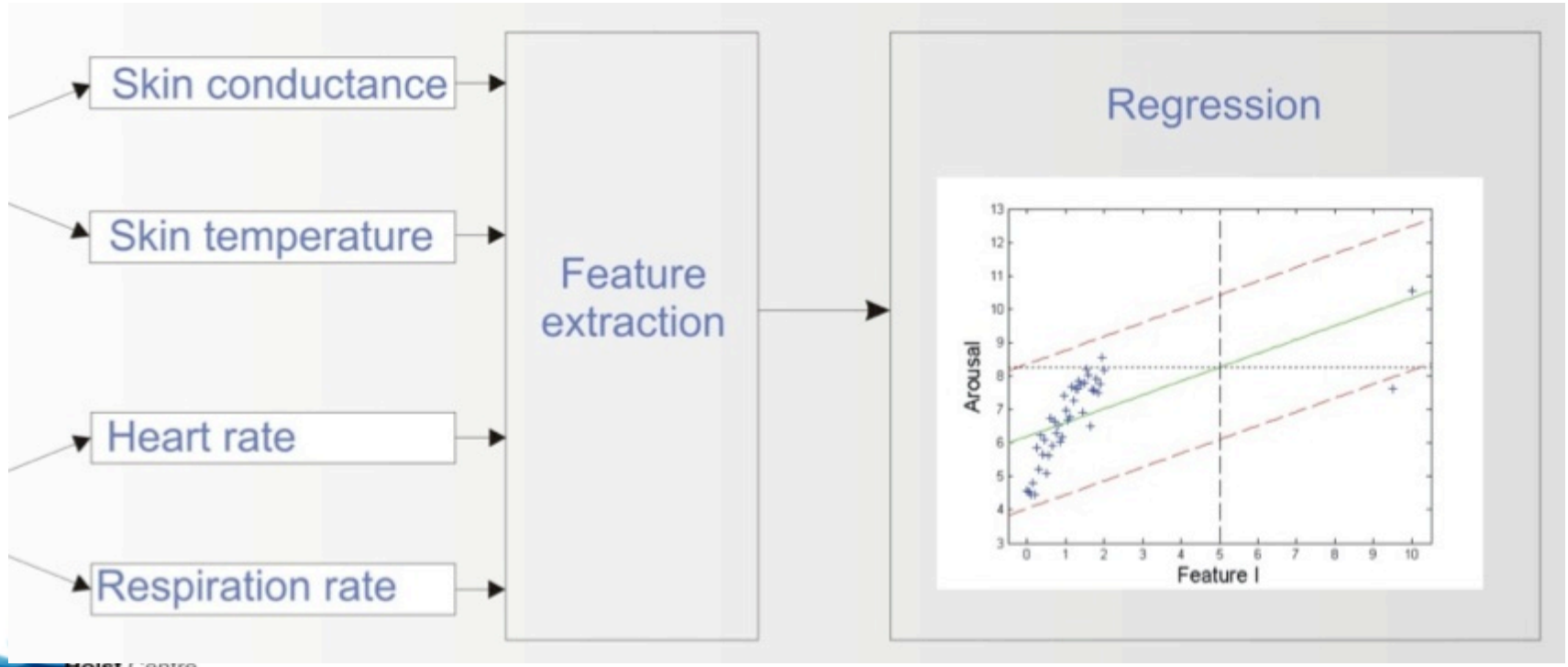


ANS MONITORING AT IMEC



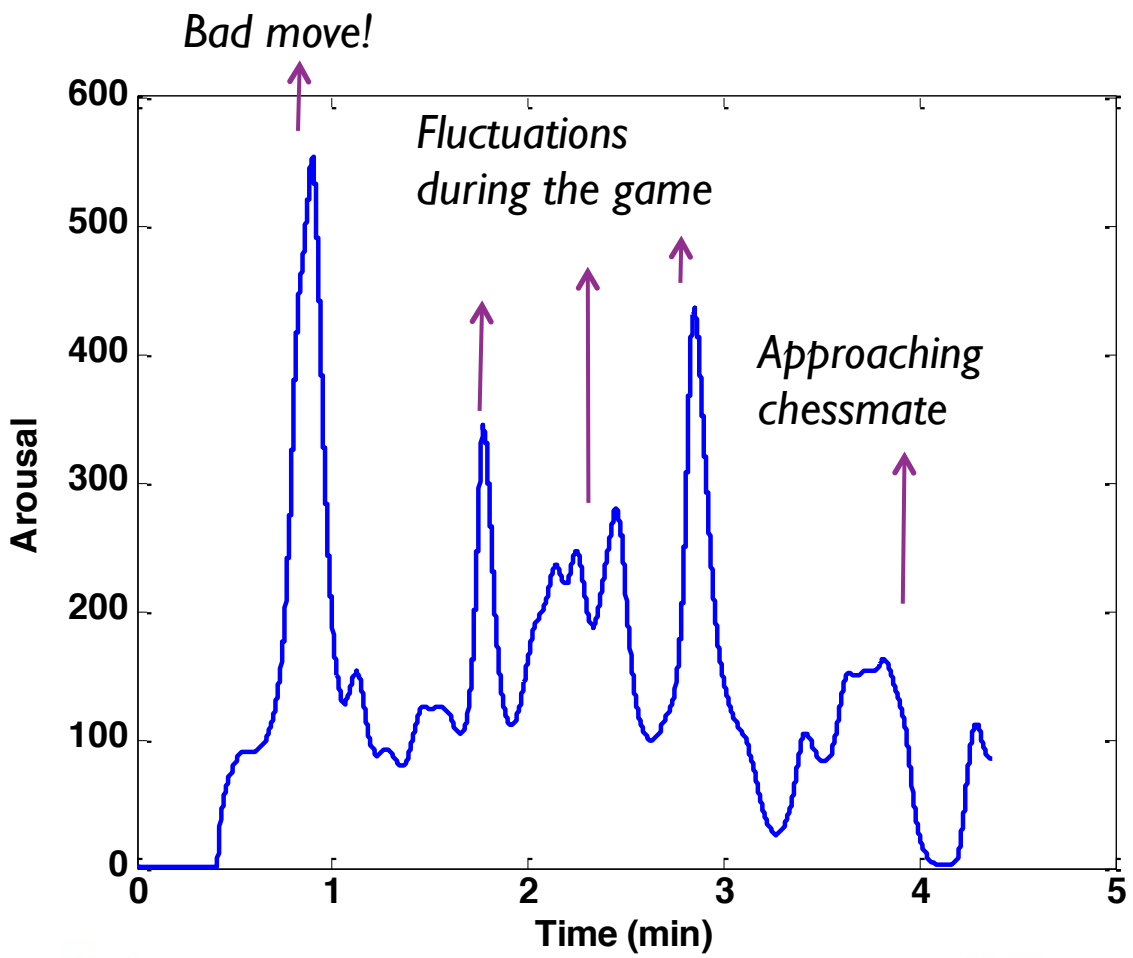
REAL-TIME AROUSAL MONITORING
Extracting arousal from physiological responses

- Data processing with real-time sensor fusion and pattern recognition
- Real-time feature extraction from physiological signals
- Regression analysis combines the features into an estimation of ***arousal***



Grundlehner et al, BSN 2009

REAL-TIME AROUSAL MONITORING
Use-case: chess players



Can we gauge the arousal of a chess player?

- Test game against a computer
- Player commenting his game afterwards

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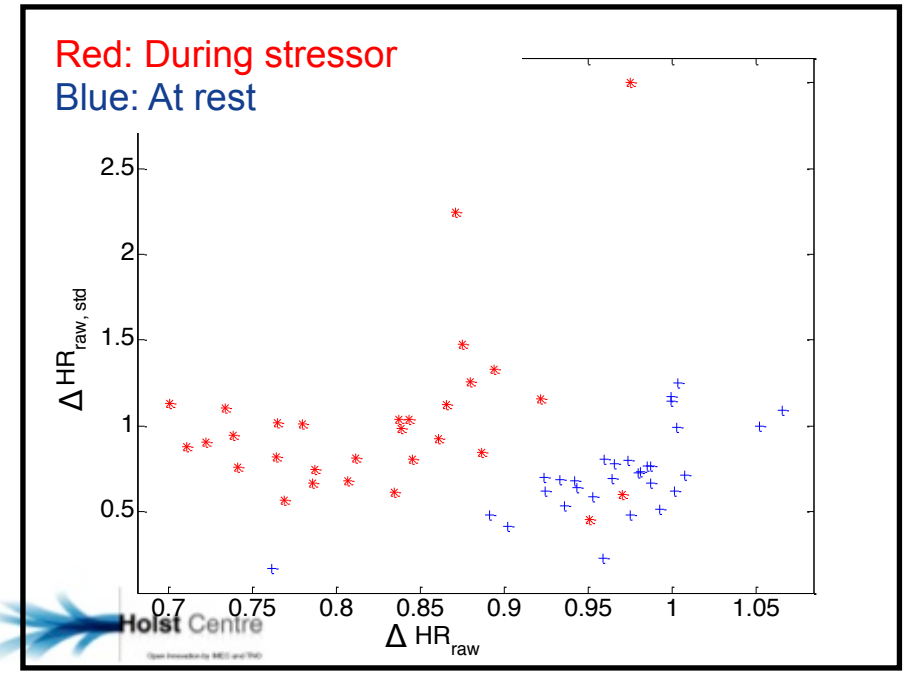
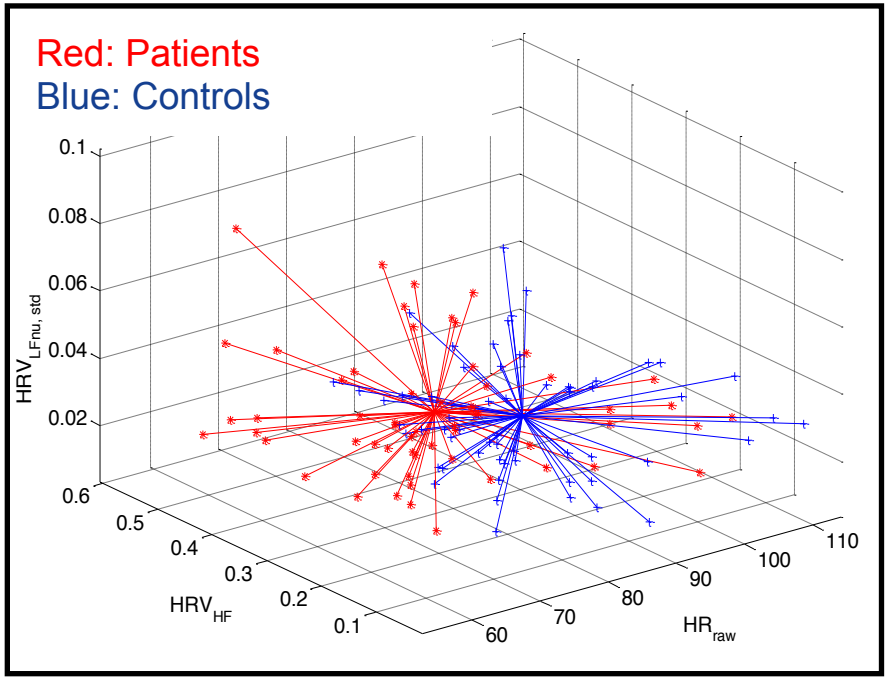
Koninklijke Nederlandse Schaakbond

FROM AROUSAL TO STRESS MONITORING
ANS as a predictor for stress?

Stress can be detected using ANS responses. Data shows that **heart rate solely** leads to an estimated **classification error of 10%**



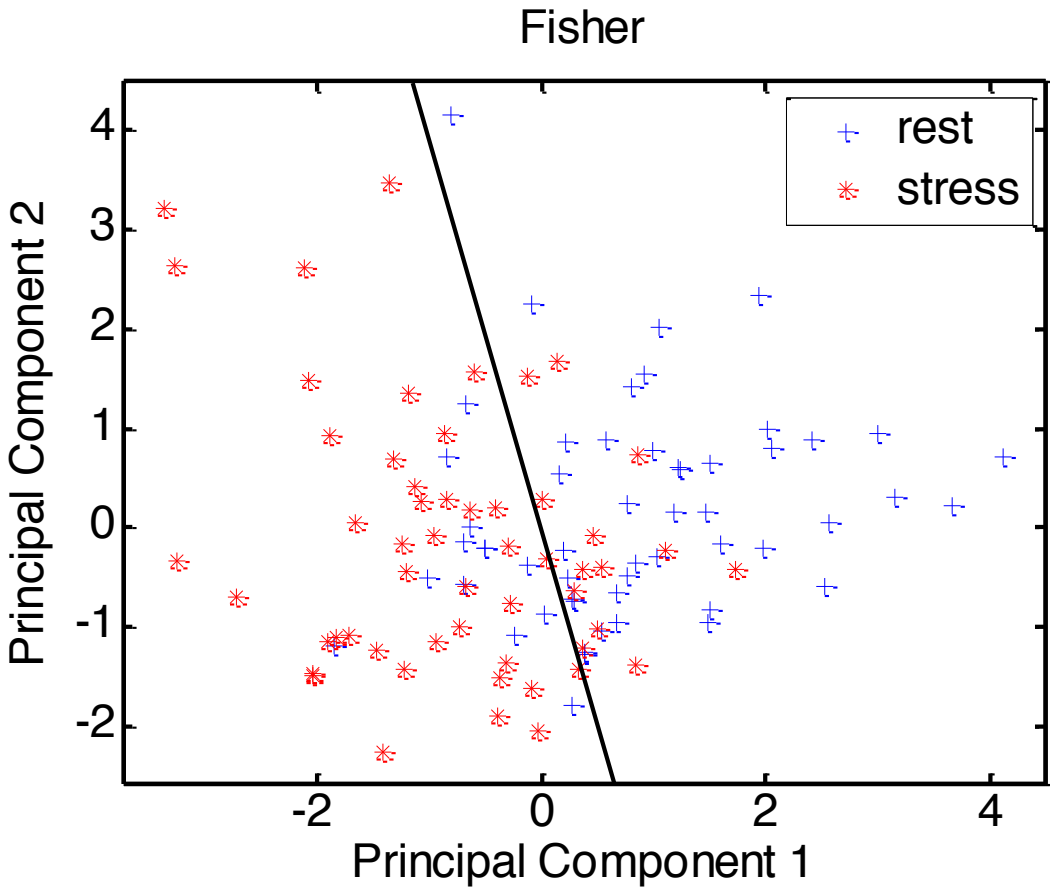


Comparing patients and healthy subjects may provide **new tools for assisting diagnosis** of stress disorders

Grundlehner et al, IEEE TITB (submitted)

MEASURING STRESS @ WORK?

- 9 features selected based on literature and physiological knowledge
- Results show near 80% accuracy in differentiating between stress and rest conditions



Classifier	Error rate (std)
Linear Bayes Normal	0.2167 (0.0250)
Quadratic Bayes Normal	0.2222 (0.0207)
K-Nearest Neighbor	0.2370 (0.0168)
Fisher's Least Square	0.2074 (0.0140)

Wijsman et al, EMBC 2011

IN THE *FUTURE:*
CORTISOL
SENSOR

Is managing stress of a few people the most important problem?

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Or is it about managing the HEALTH of BILLIONS of people

The patient of the future is a HEALTHY patient

And medicine will be about

MANAGING HEALTH

Stay FIT and LEAN

31%

Adults aged 15 and over are insufficiently active

1B

Overweight people

3.2M

Deaths each year linked to insufficient physical activity

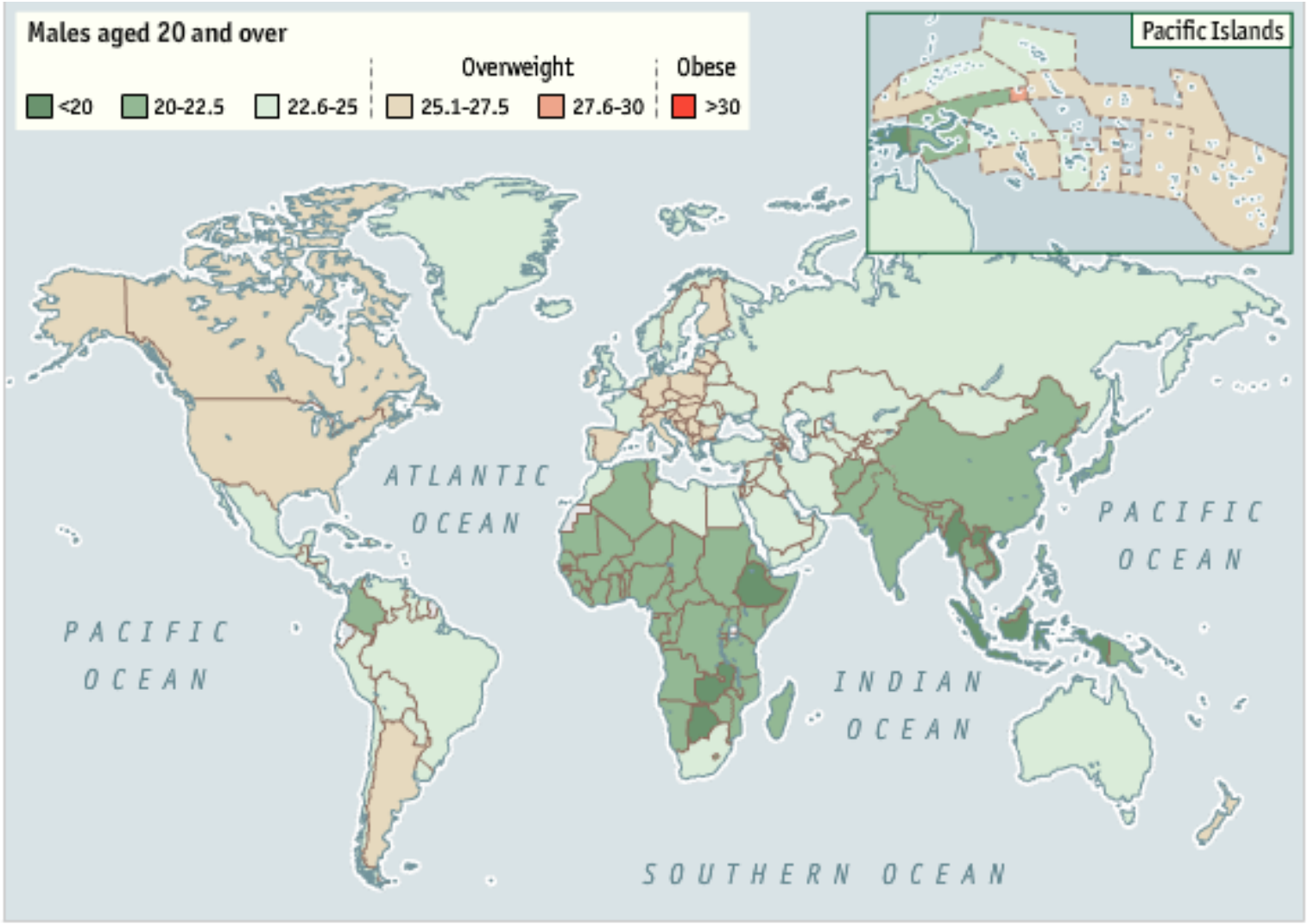
300M

Obese people worldwide

4th

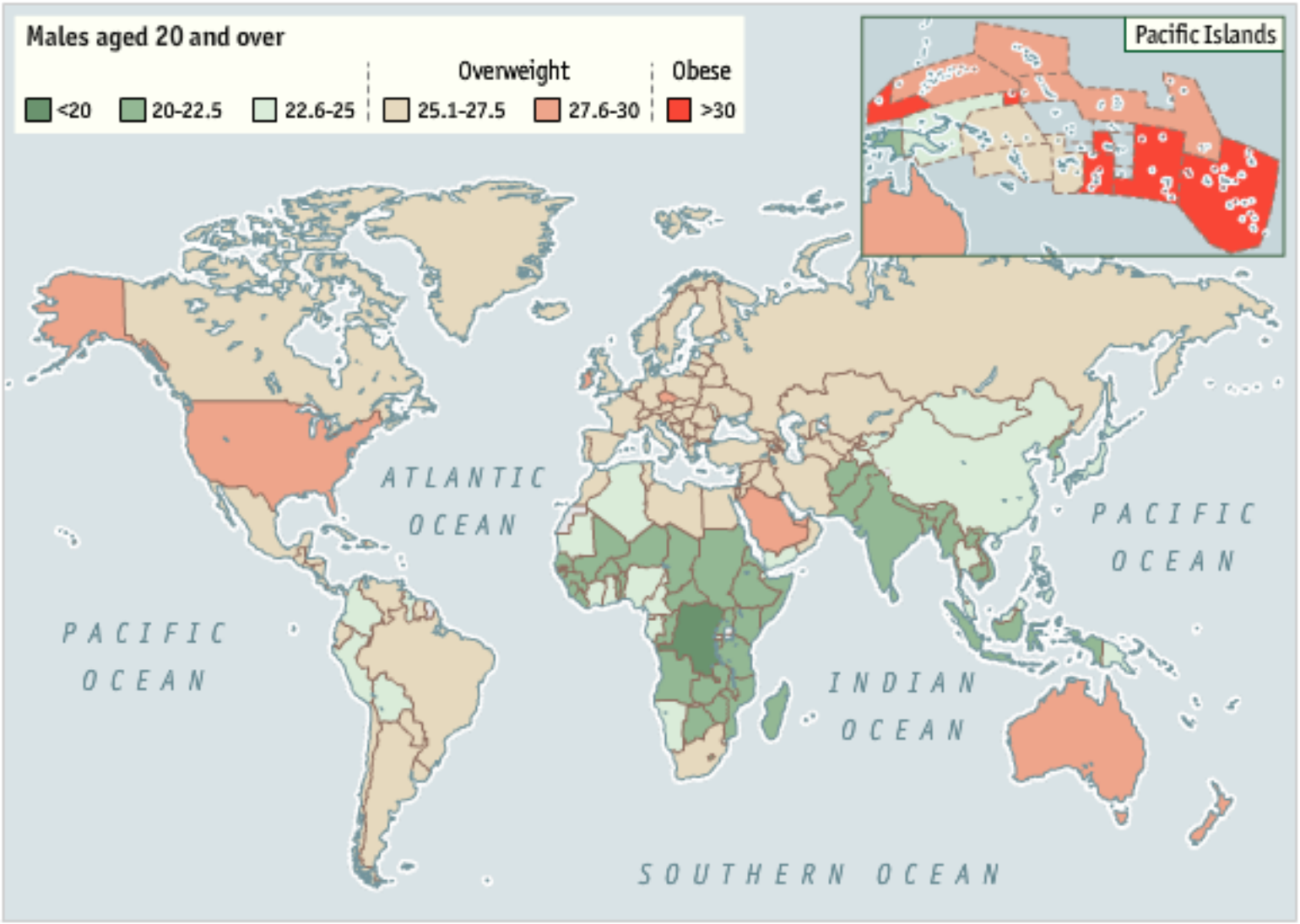
Leading risk factor for global mortality

A PROBLEM OF THE DEVELOPED WORLD



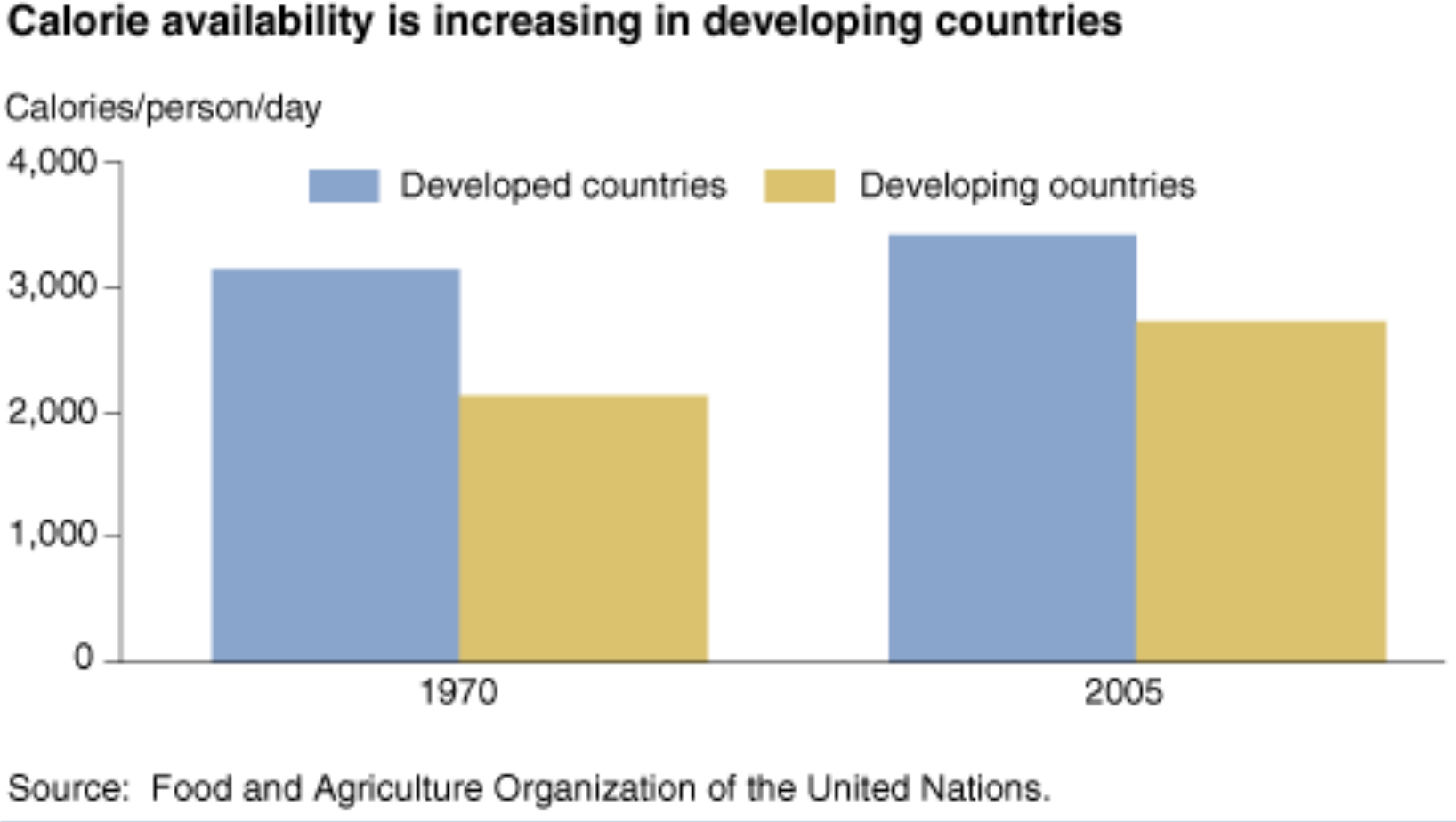
Body Mass Index in 1980 (source: The Economist)

REACHING THE DEVELOPING WORLD



Body Mass Index in 2008 (source: The Economist)

MORE CALORIES, AND LESS EXERCISE



It's about inducing **Behavior Change**

By providing feedback on **Energy Balance**

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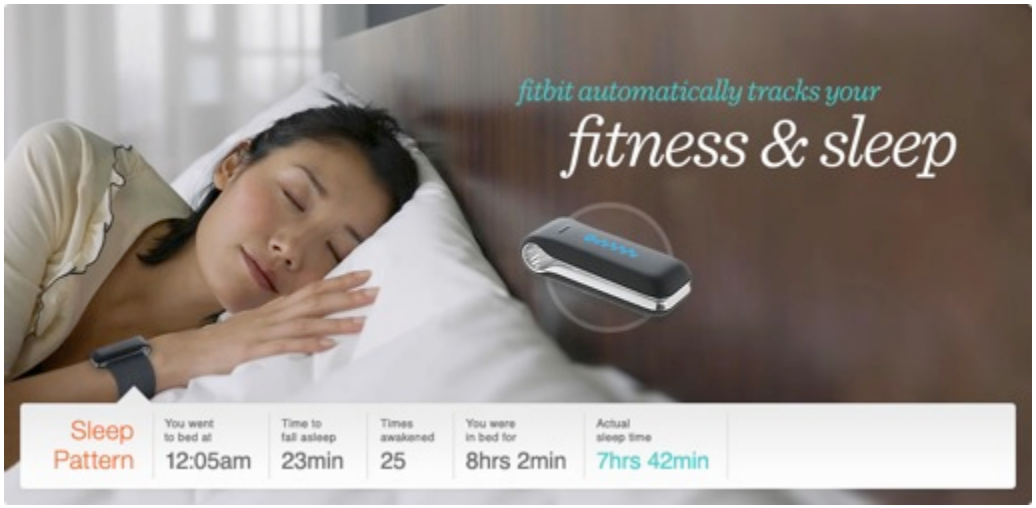
© IMEC 2012



Fitbit

Philips DirectLife

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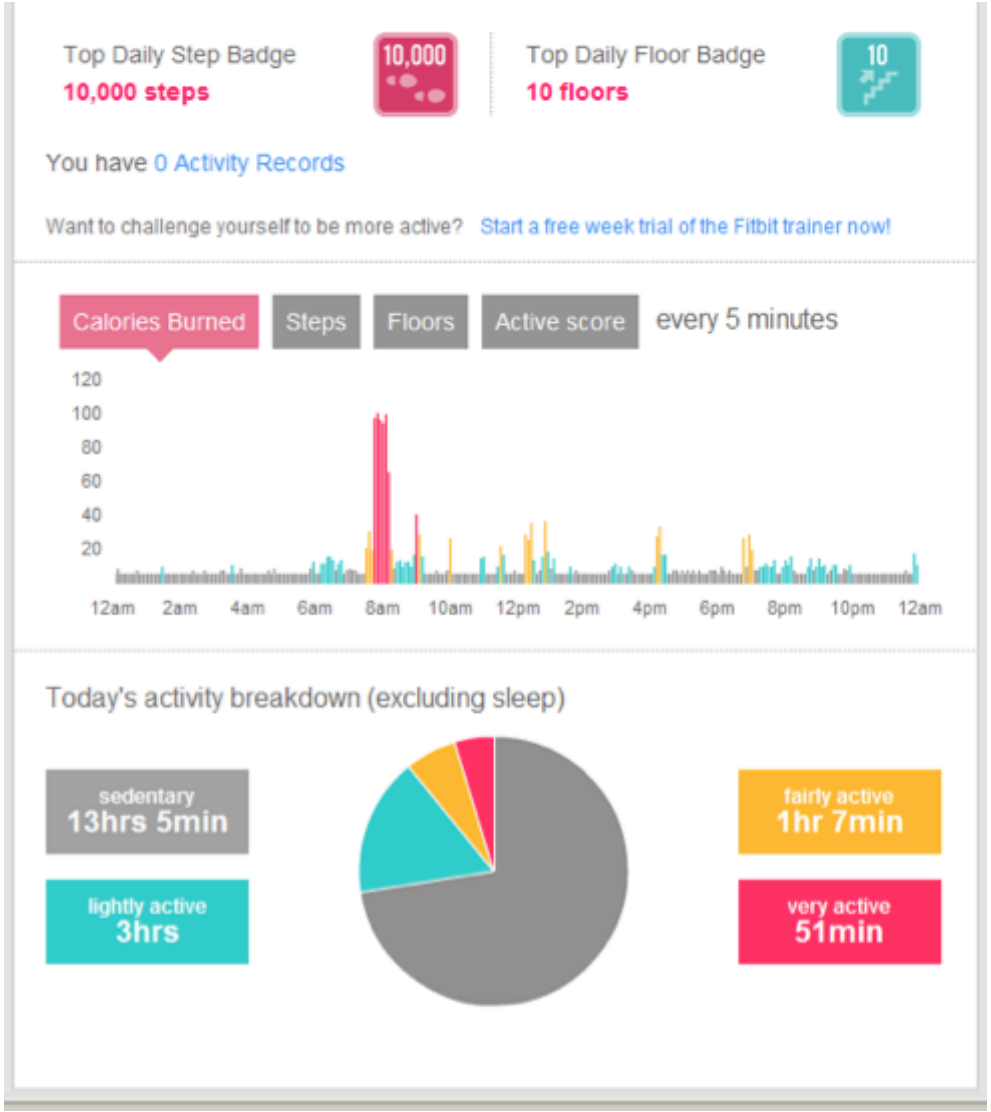
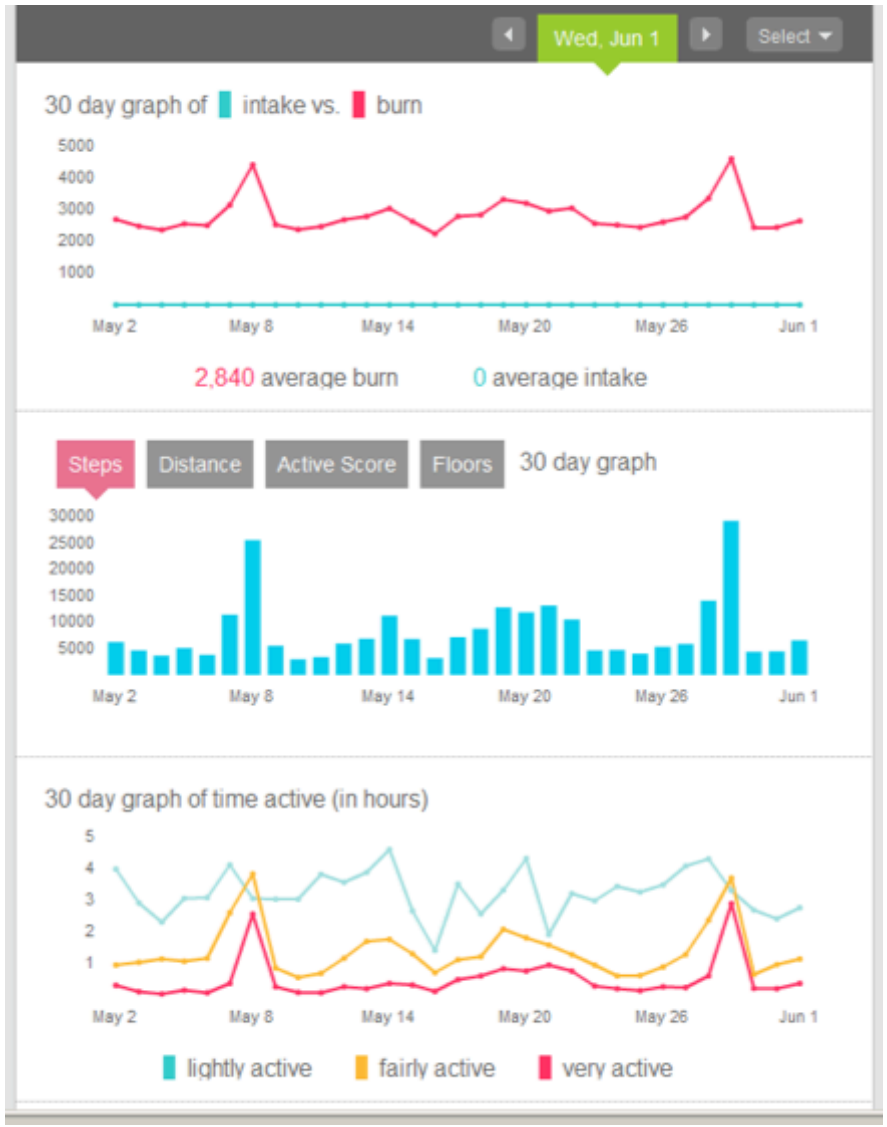
Daily profile



Monthly profile



November 14, 2009 Saturday
Today
Specific Days
Sync Armband
GOAL
ACTUAL
Report | Export |
Calories Burned
2060
2683
Calories Consumed
1810
1676
Calorie Balance
250
1007
You are on a weight loss trend
Physical Activity
0:45
1:32
Steps Taken
8000
8747
Sleep Duration
GoWear fit
BODYMEDIA
mode
light
1584
CALORIES
view
reset TRIP
BODYMEDIA

CARDIAC health management

The Economist

World politics | Business & finance | Economics | Science & technology | Culture | Blogs | Debate & discuss | Multimedia | Print edition

Chronic diseases in developing countries

Growing pains

Poor countries are developing the diseases of the rich, with lethal consequences

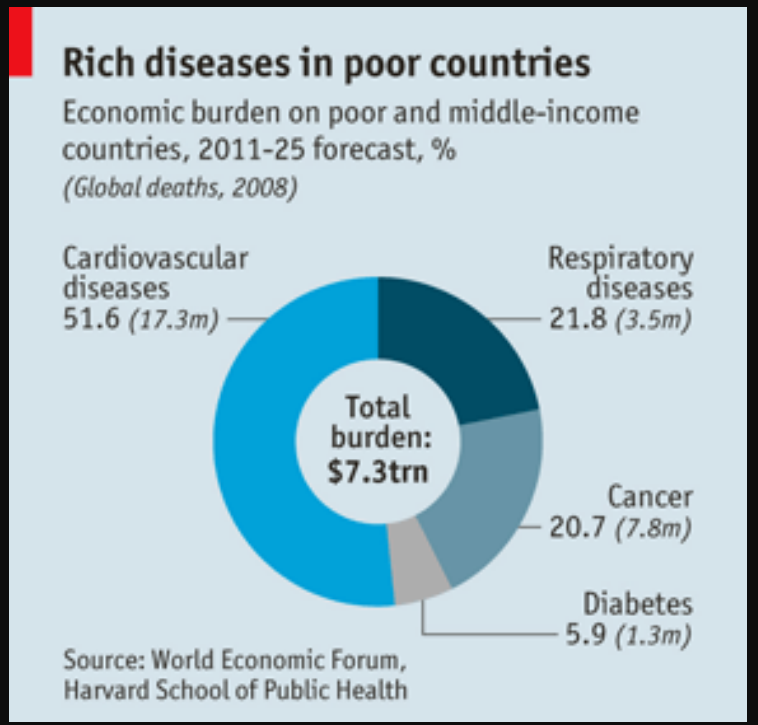
Sep 24th 2011 | KAMPALA AND NEW YORK | from the print edition

Like 92 Tweet 0

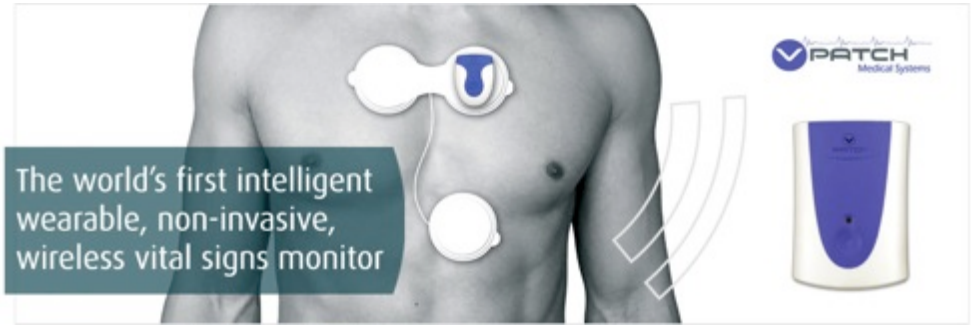
"Developing countries already bear more than 80% of the burden of chronic illnesses. Their share will grow—at a time when older diseases are still ravaging the poor."

"The World Health Organisation expects deaths from non-communicable diseases to rise by 15% between 2010 and 2020, with jumps of over 20% in Africa and South-East Asia."

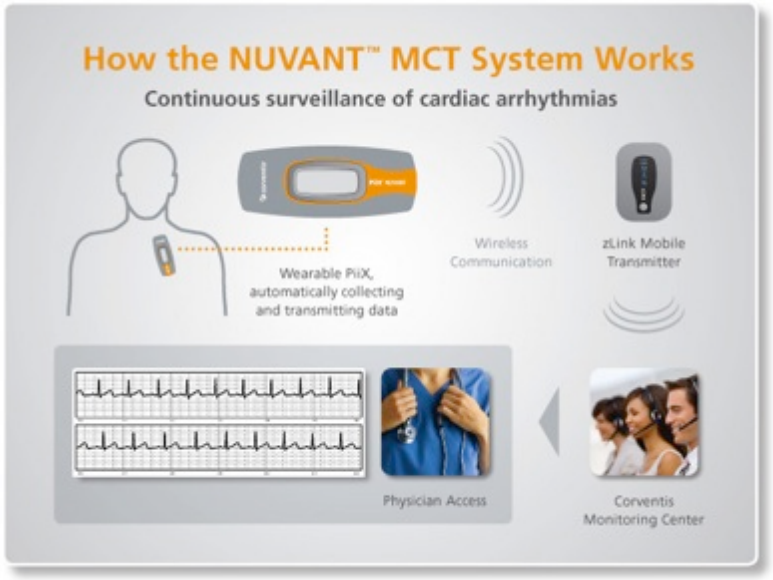
"Even in sub-Saharan Africa, chronic illnesses are likely to surpass maternal, child and infectious diseases as the biggest killer by 2030."



Zio by iRhythm



vPatch by Intelesens



Piix and Nuvant by Corventis

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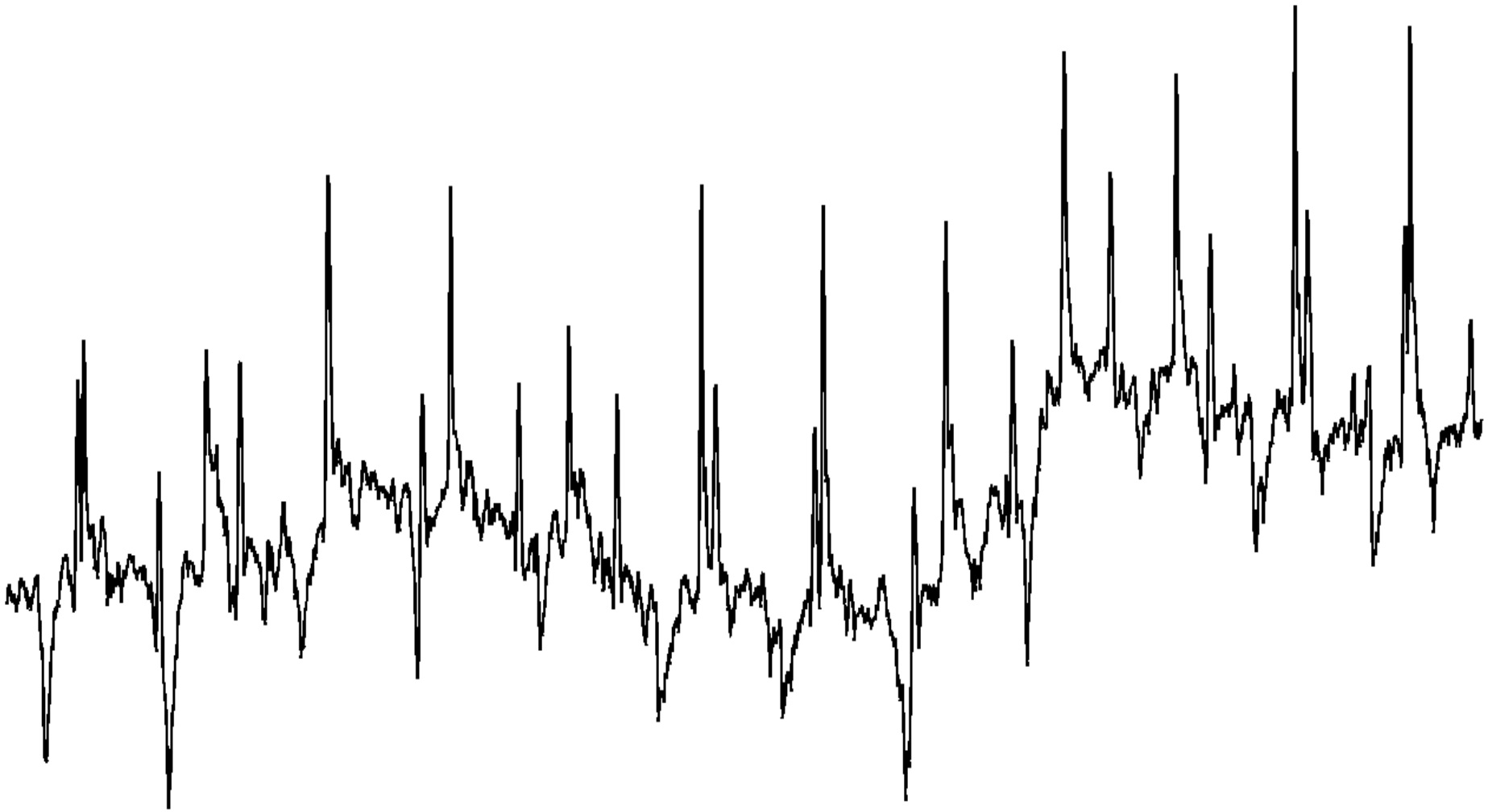
Grand challenge

Reliable in free-living conditions



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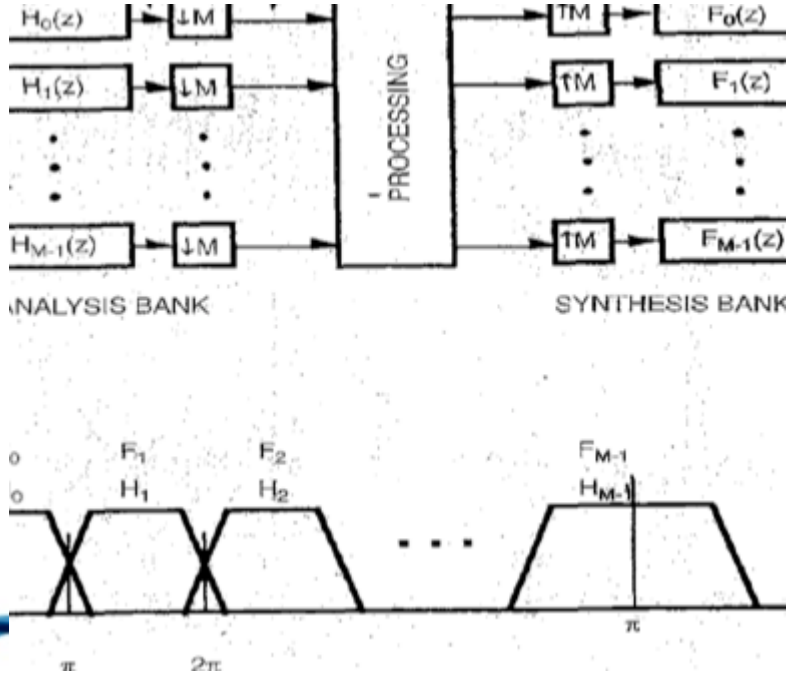
FILTER-BASED APPROACHES HAVE BEEN AROUND FOR 20 YEARS

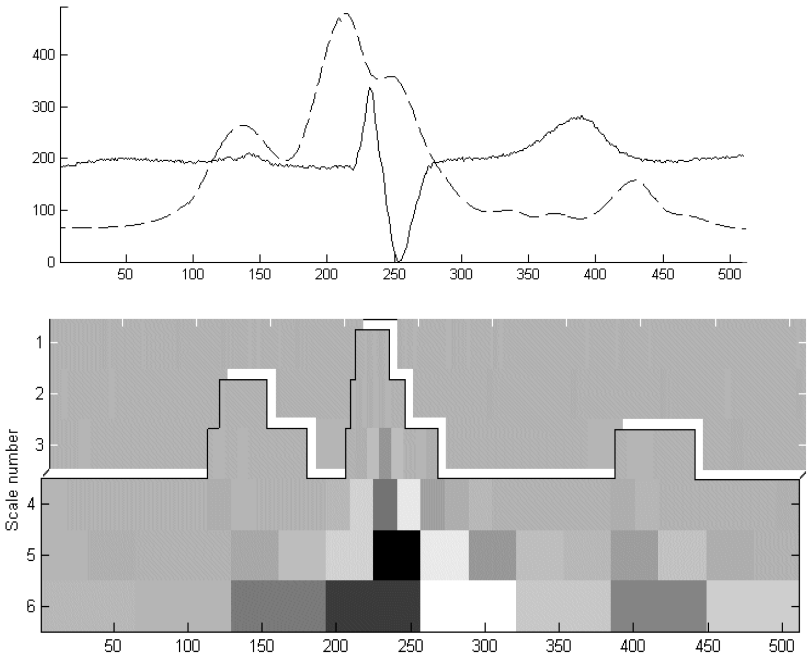
But have their limitations

- **Frequency domain:** Artifacts in the frequency band of interest
- **Time domain**: Require detection of a fiducial point

V. Afonso et al., IEEE Engineering in Medicine and Biology Magazine, vol. 15, pp. 37–44, 1996.

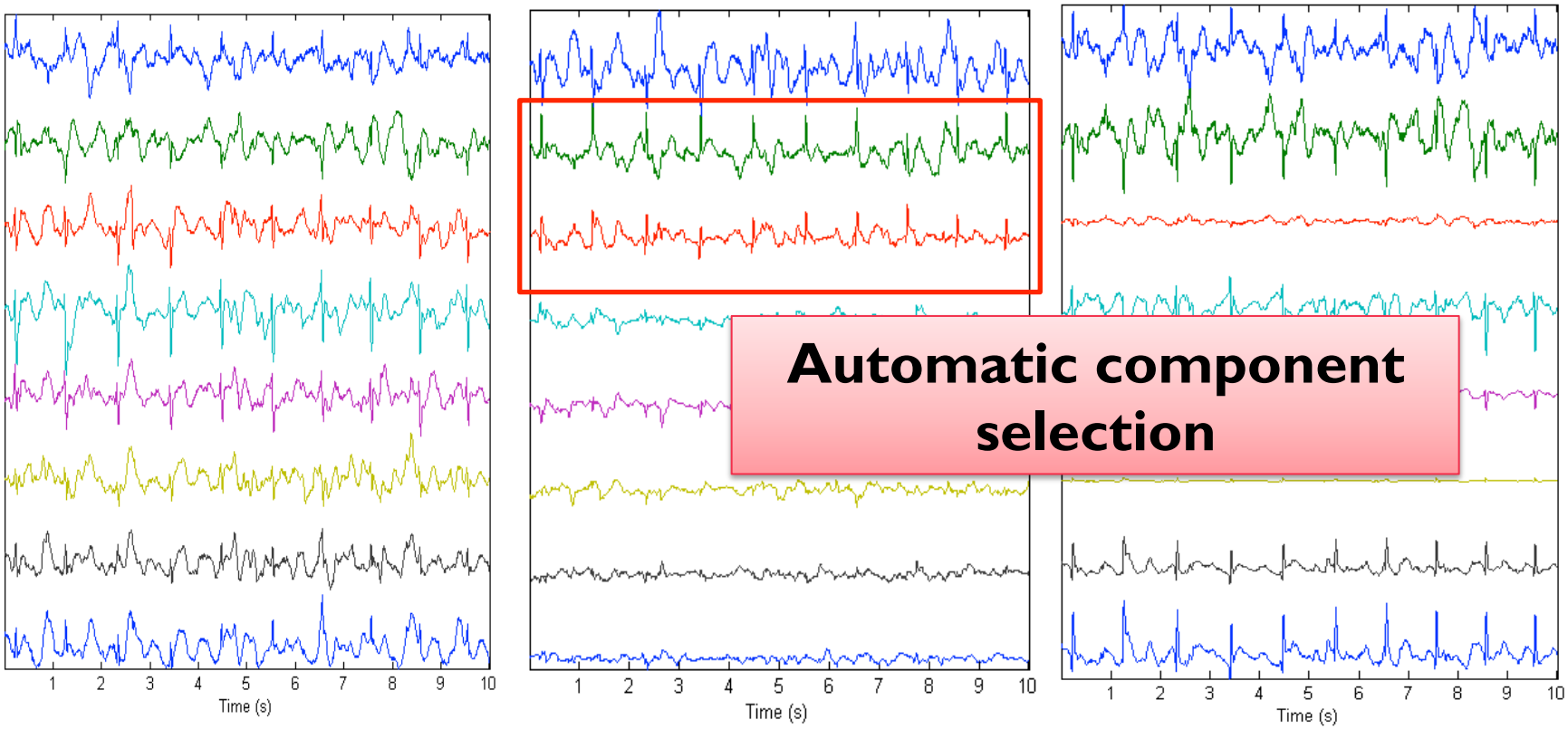


P. Augustyniak, in Proc. of the WACBE World Congress on Bioengineering, 2007.



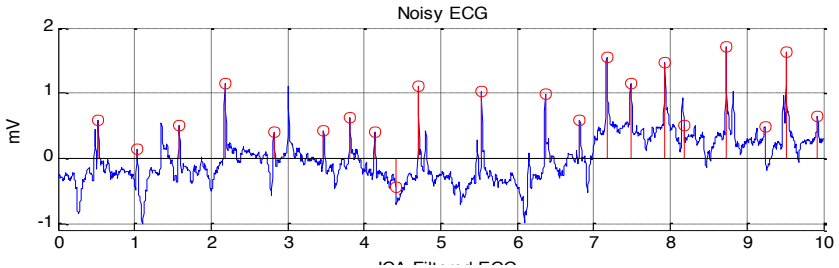
BLIND SOURCE SEPARATION METHODS HAVE PROVEN SUCCESSFUL

Romero et al., Computing in Cardiology, 2011;38: 613-616

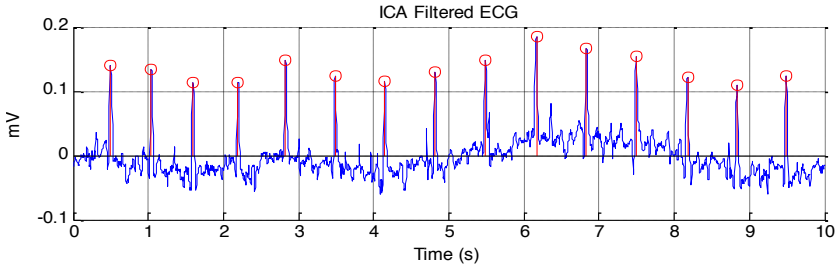


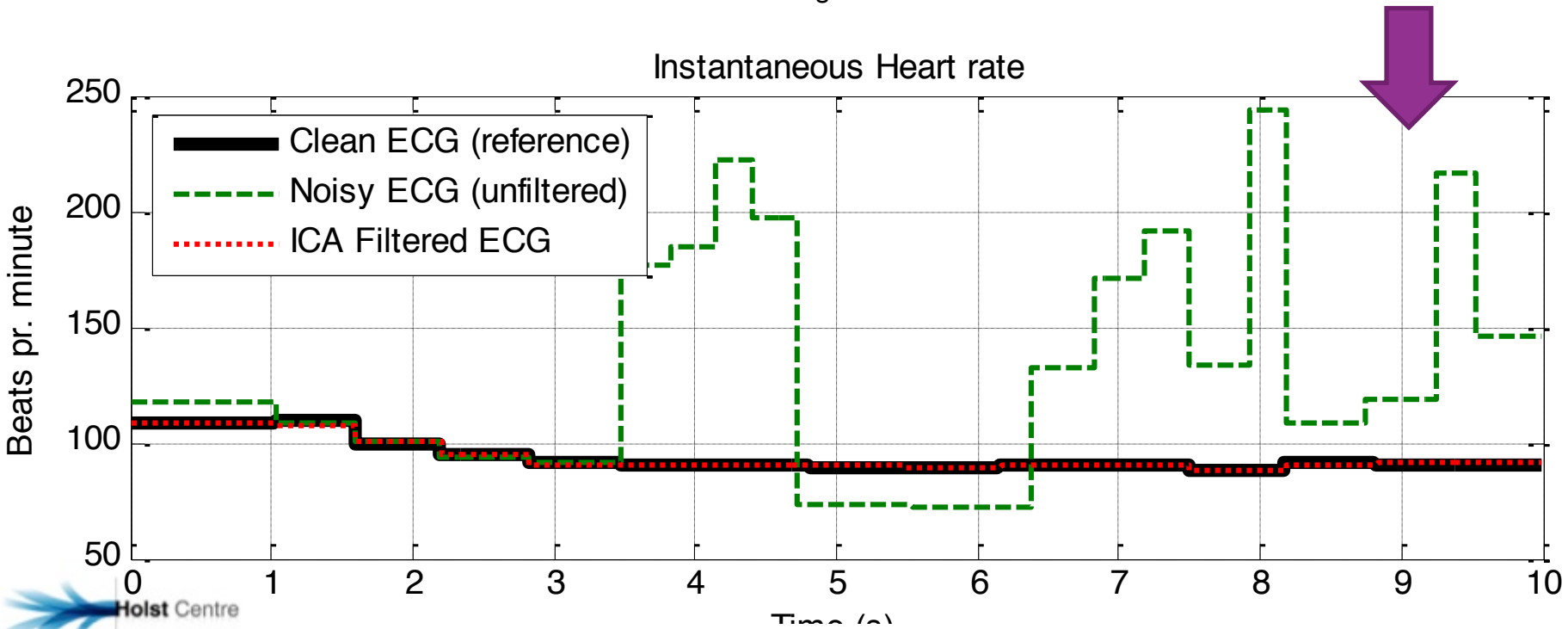
Multi-lead ECG ➡ **Components** ➡ **Filtered ECG**

BLIND SOURCE SEPARATION METHODS HAVE PROVEN SUCCESSFUL



Artifact filtering





Romero et al., Wireless Health 2011

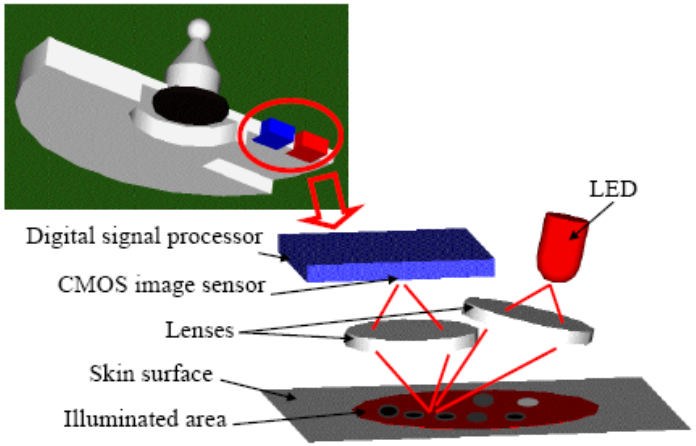
ADAPTIVE FILTERING TECHNIQUES REQUIRE AN ESTIMATION OF NOISE

The indirect approach: measure activity

- Accelerometers to reconstruct movement
- BUT overall body movement is not necessarily causing artifacts

A more direct way: measure skin stretch

- Optical or stress measurements
- Have shown good results in some cases



P. Hamilton et al, Biomedical Instrumentation & Technology, vol. 34, pp. 197–202, 2000.

P. Hamilton et al, Computers in Cardiology, vol. 27, 2000, pp. 383– 386.

D. Tong et al, Proc. Second Joint EMBS/BMES Conference, vol. 2, 2002, pp. 1403–1404.

M. Raya et al, in Proc. Second Joint EMBS/ BMES Conference, vol. 2, 2002, pp. 1756–1757

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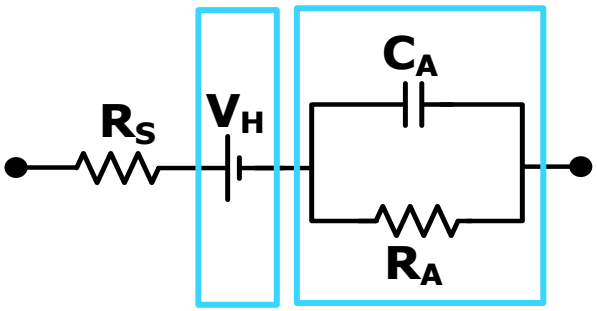
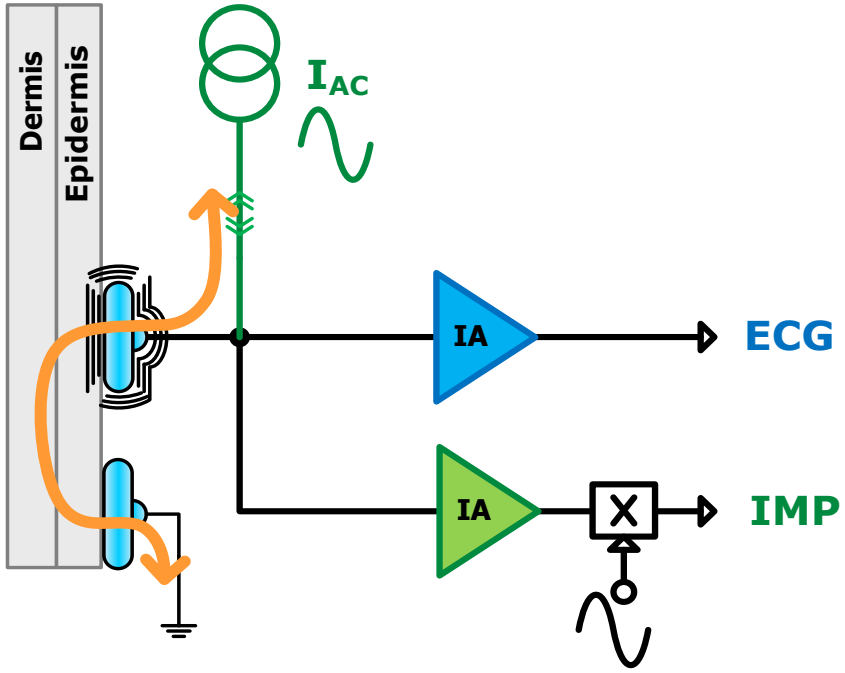
ADAPTIVE FILTERING TECHNIQUES REQUIRE AN ESTIMATION OF NOISE

The MOST direct approach: measure the cause of the artifact

- Electrode-tissue impedance changes due to motion
- Measure in real-time this impedance to detect artifacts





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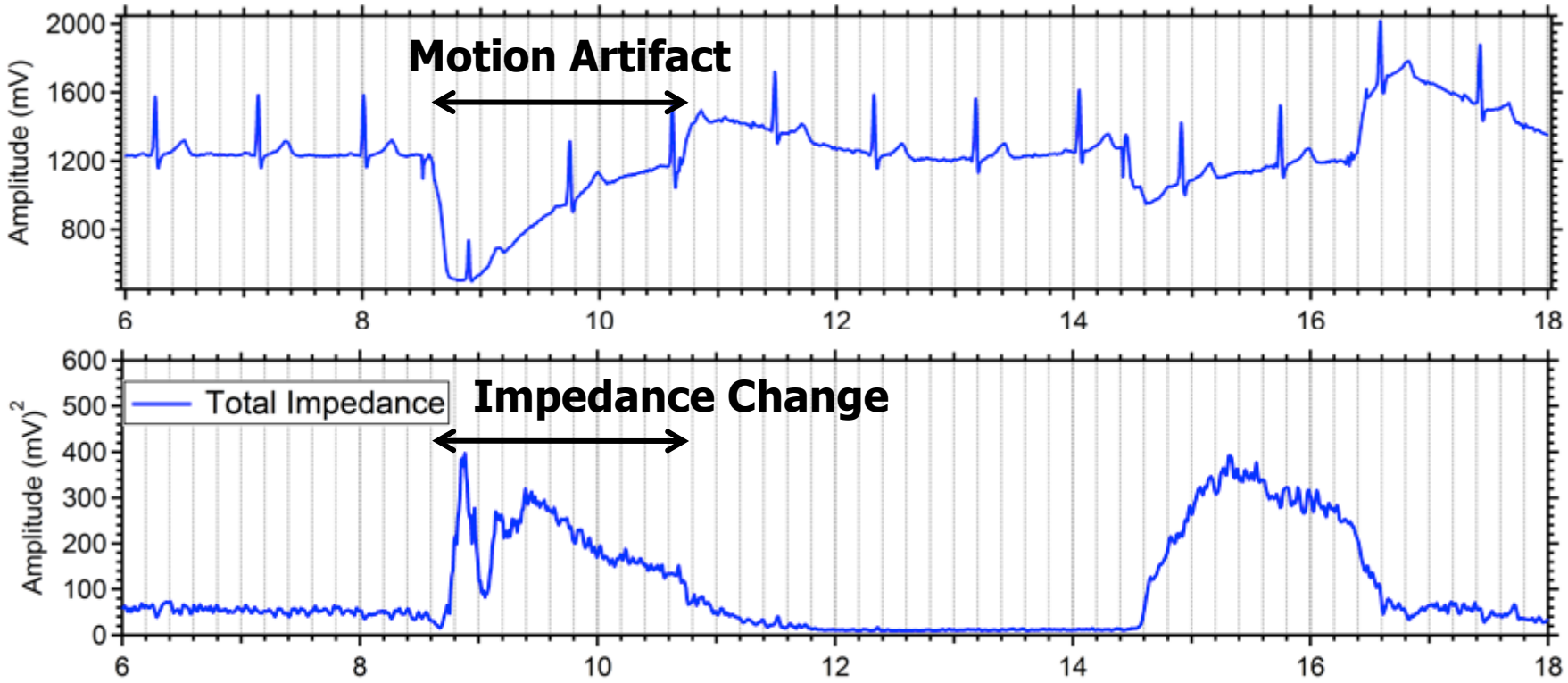
ELECTRODE-TISSUE IMPEDANCE

Measure the artifact…



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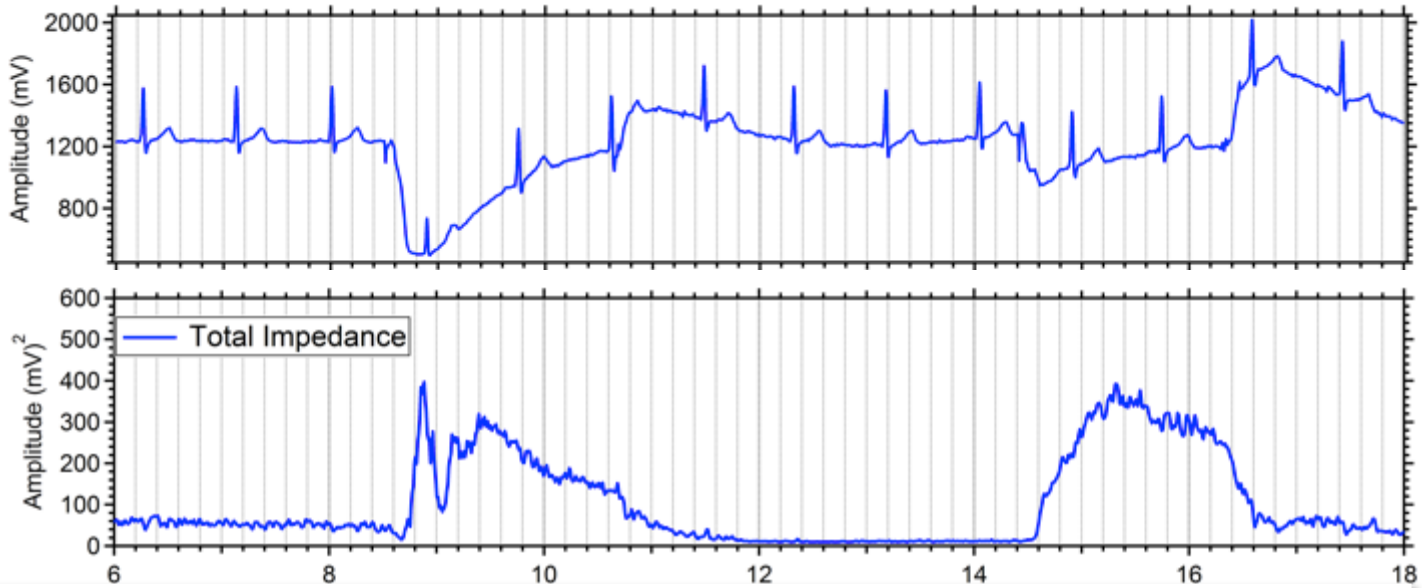
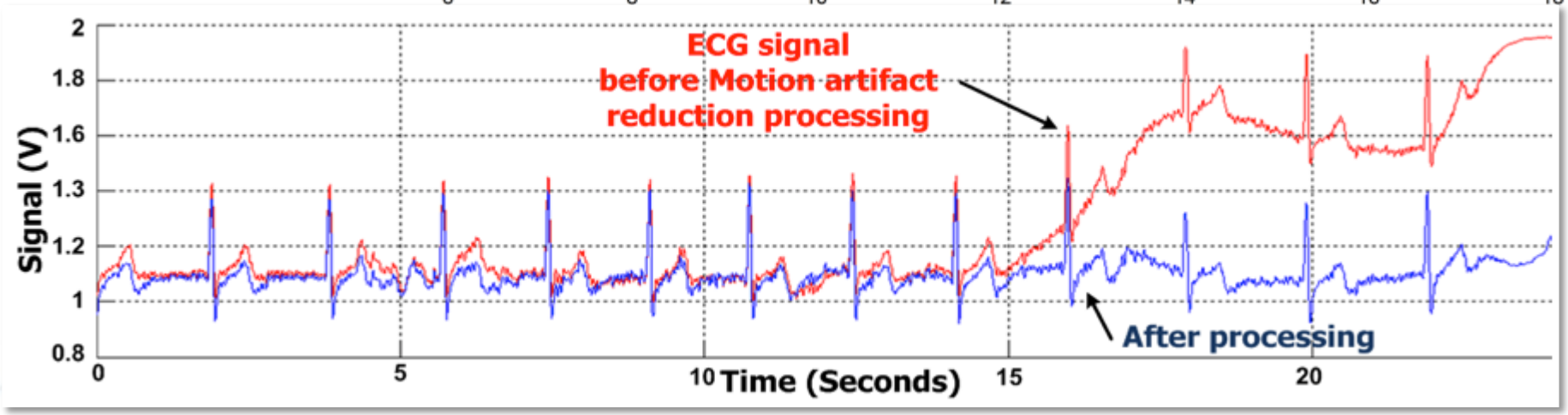
ELECTRODE-TISSUE IMPEDANCE
...And filter it out





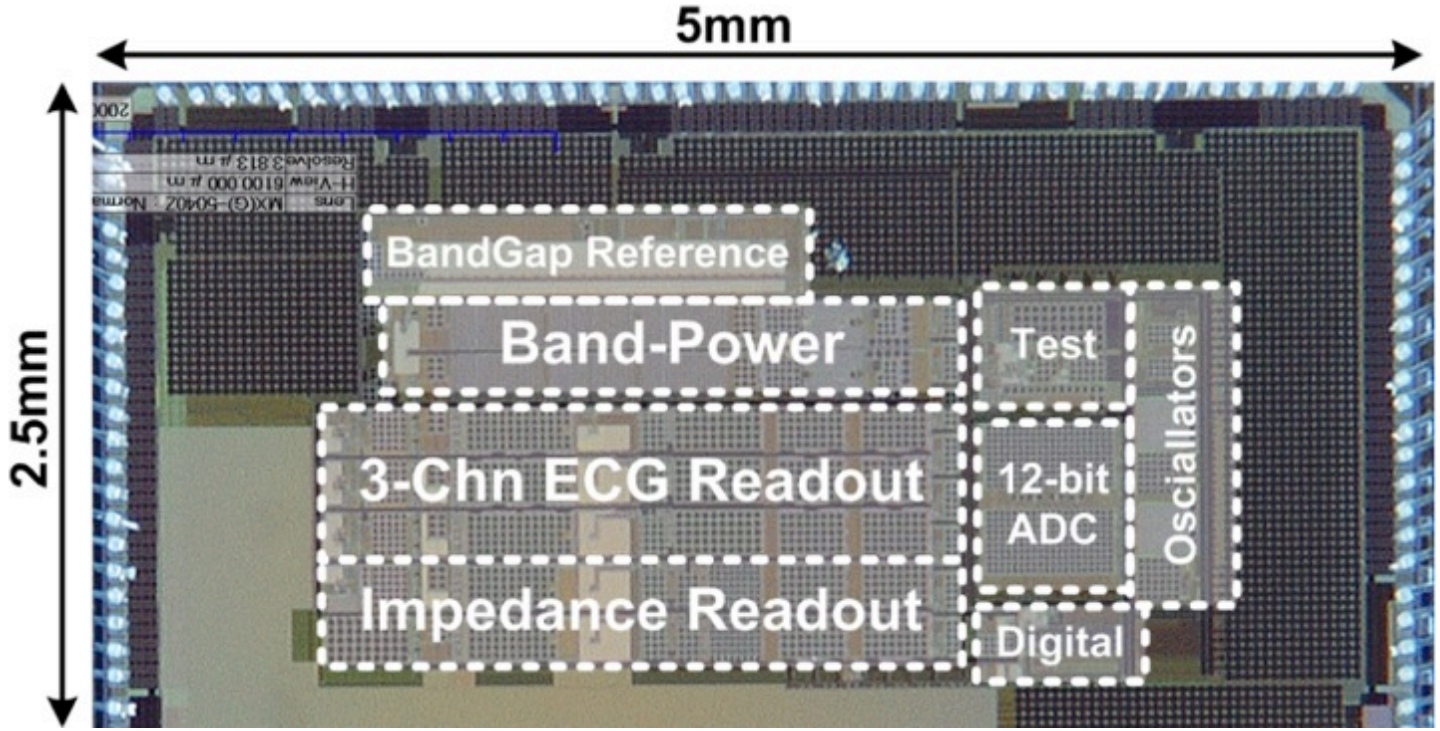
CUSTOM ULTRA-LOW-POWER ANALOG READ-OUT ENABLING ARTIFACT FILTERING

Key functional features

- **3-channel ECG** recording
- **1-channel impedance** measurement

At ultra-low-power

- Power consumption: 40uW
- Low-supply voltage: 1.2V



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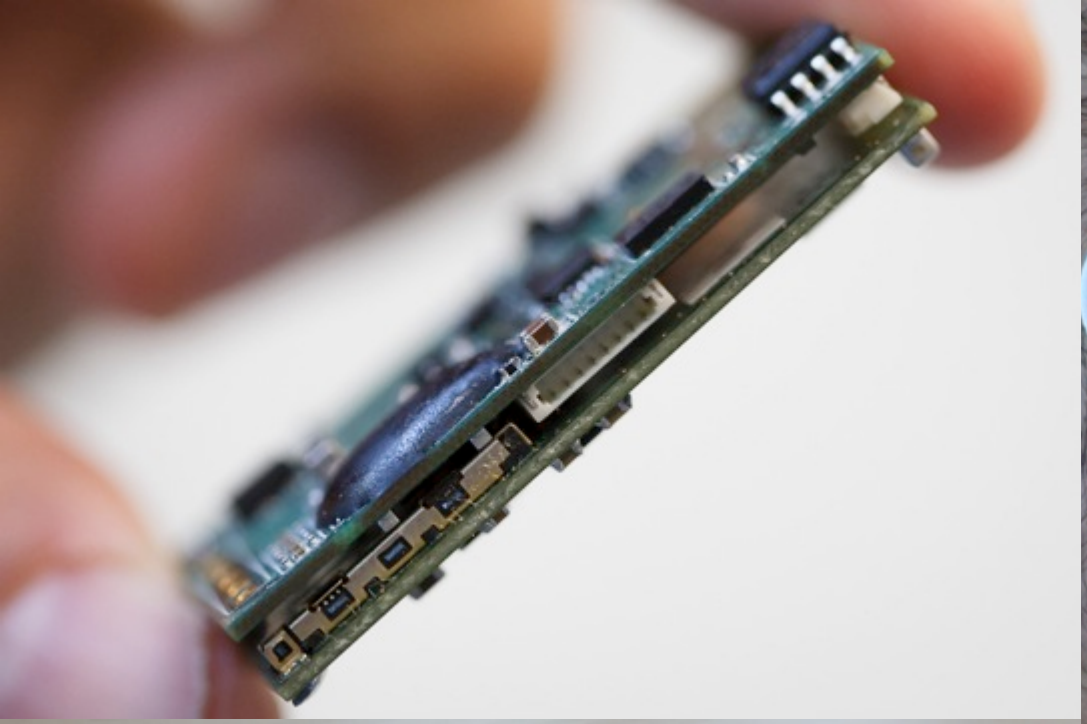
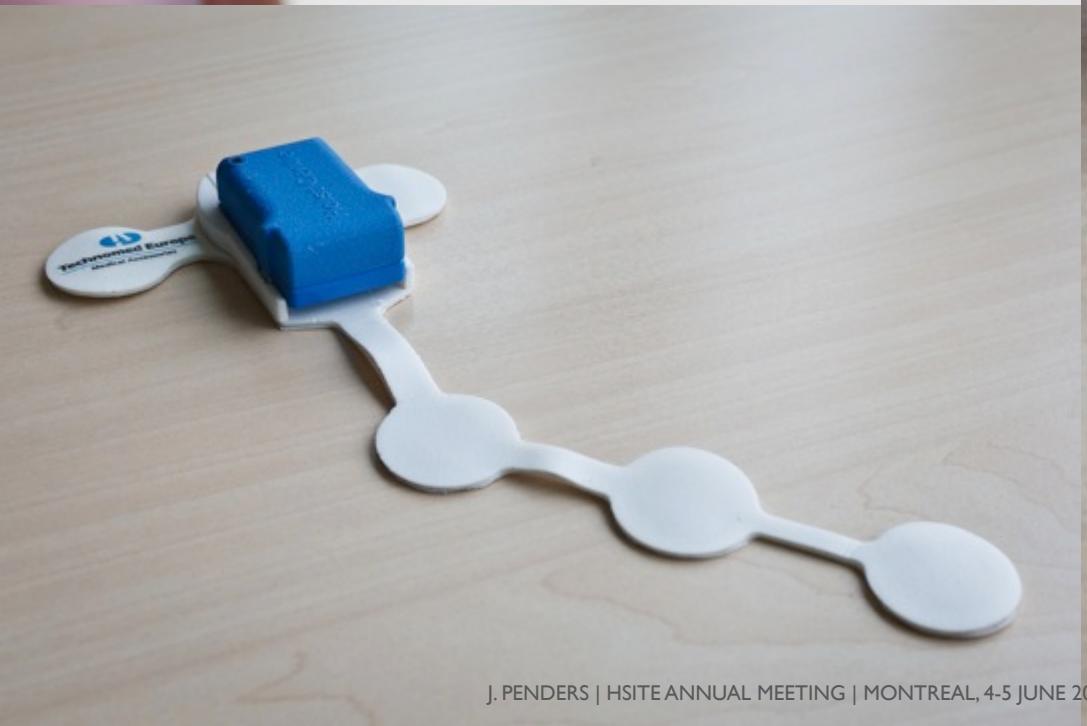
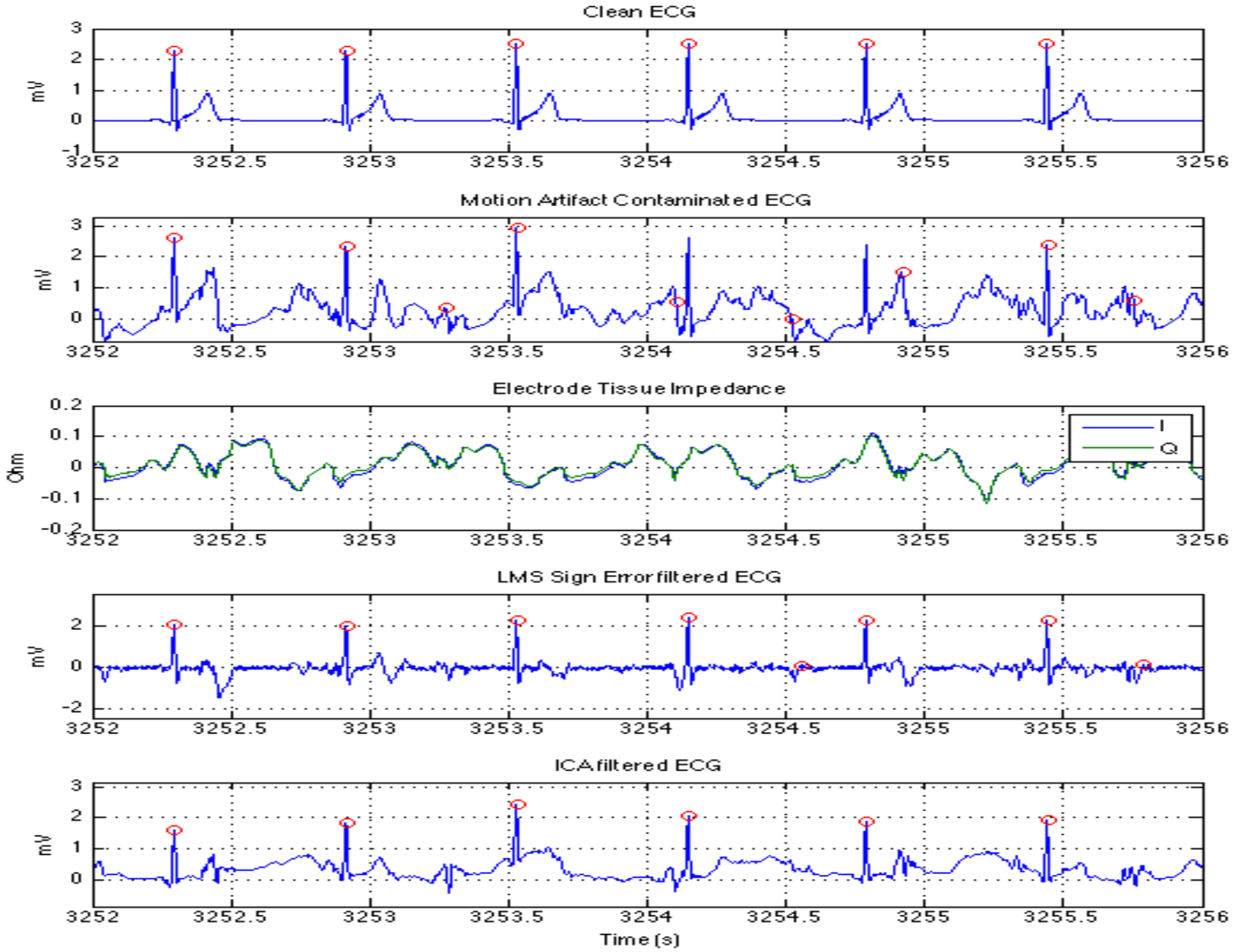




Integrated in a Patch


Clean ECG
mV
Motion Artifact Contaminated ECG
mV
Electrode Tissue Impedance
Ohm
I
Q
LMS Sign Errorfiltered ECG
mV
ICA filtered ECG
mV
3252
3252.5
3253
3253.5
3254
3254.5
3255
3255.5
3256
Time (s)

Grand Challenge

Smart & connected

ECG IS
AVAILABLE
ON YOUR PHONE
TODAY
SAMSUNG
Holst Centre

OR **BUILT IN** THE PHONE

BUT POWER CONSUMPTION REMAINS A PROBLEM (ANOTHER GRAND CHALLENGE)

BTLE ECG PATCH

For research use only

Bluetooth 4.0

COMBINING ULTRA-EFFICIENT ELECTRONICS WITH STANDARD RF INTERFACE

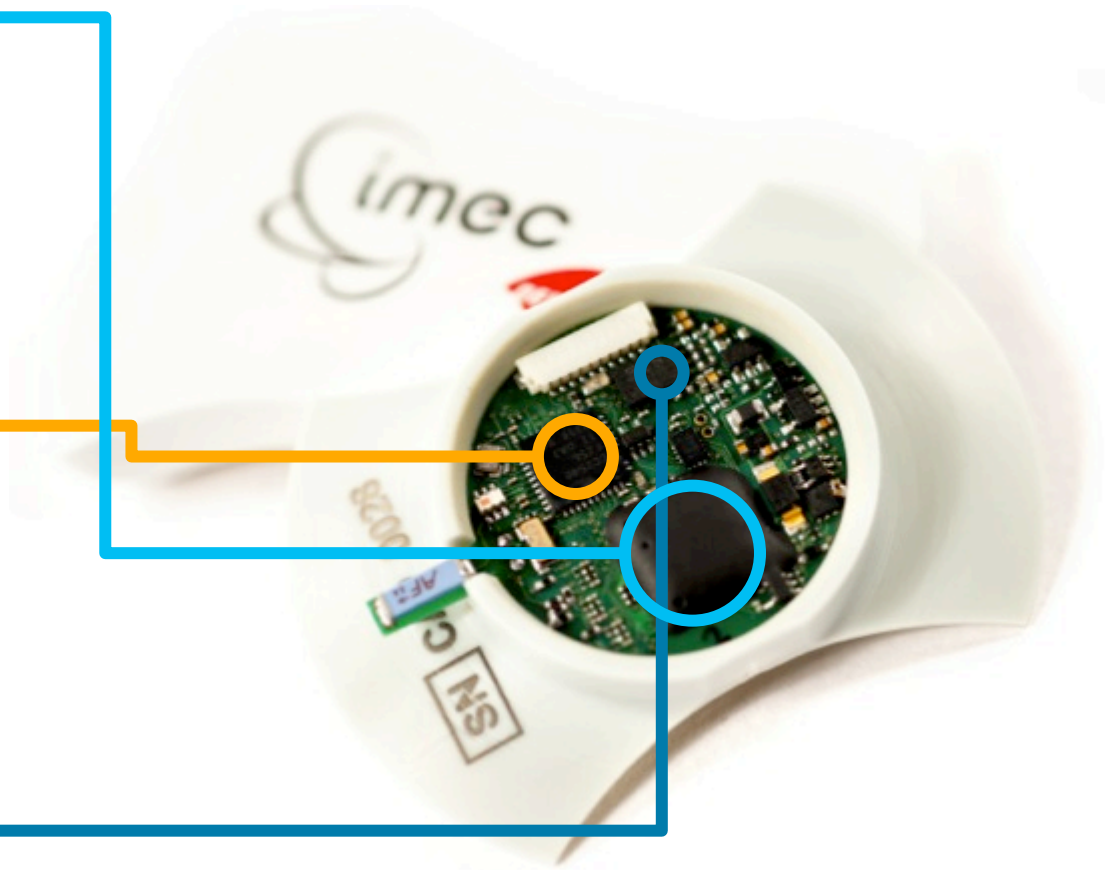
imec's ECG SoC

Ultra Low Power ~ 60 uW

TI's CC2540 Bluetooth Low Energy SoC

Standard radio interface

Accelerometer



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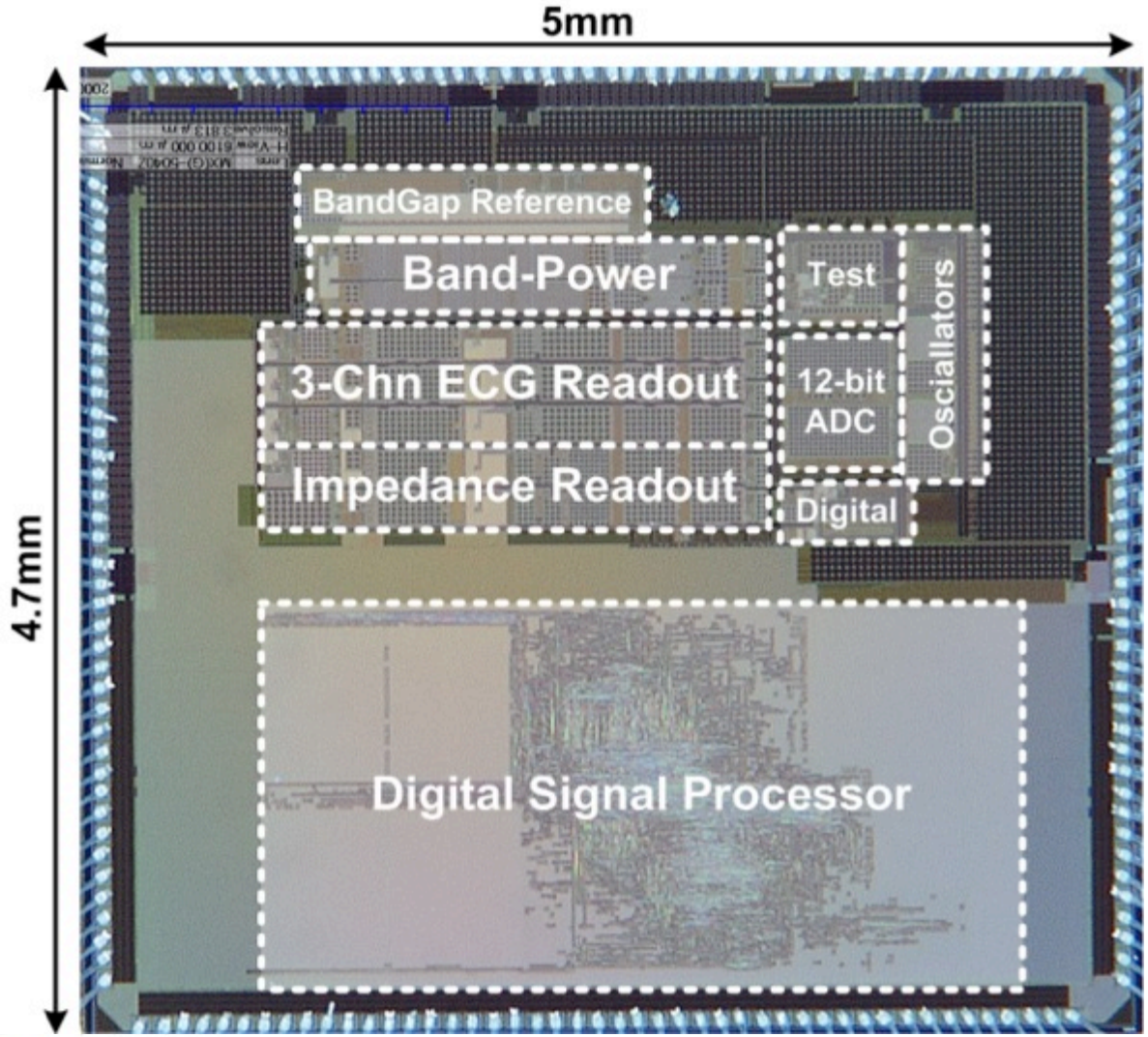
CUSTOM ULTRA-LOW-POWER ANALOG SYSTEM-ON-CHIP FOR LOCAL ANALYSIS

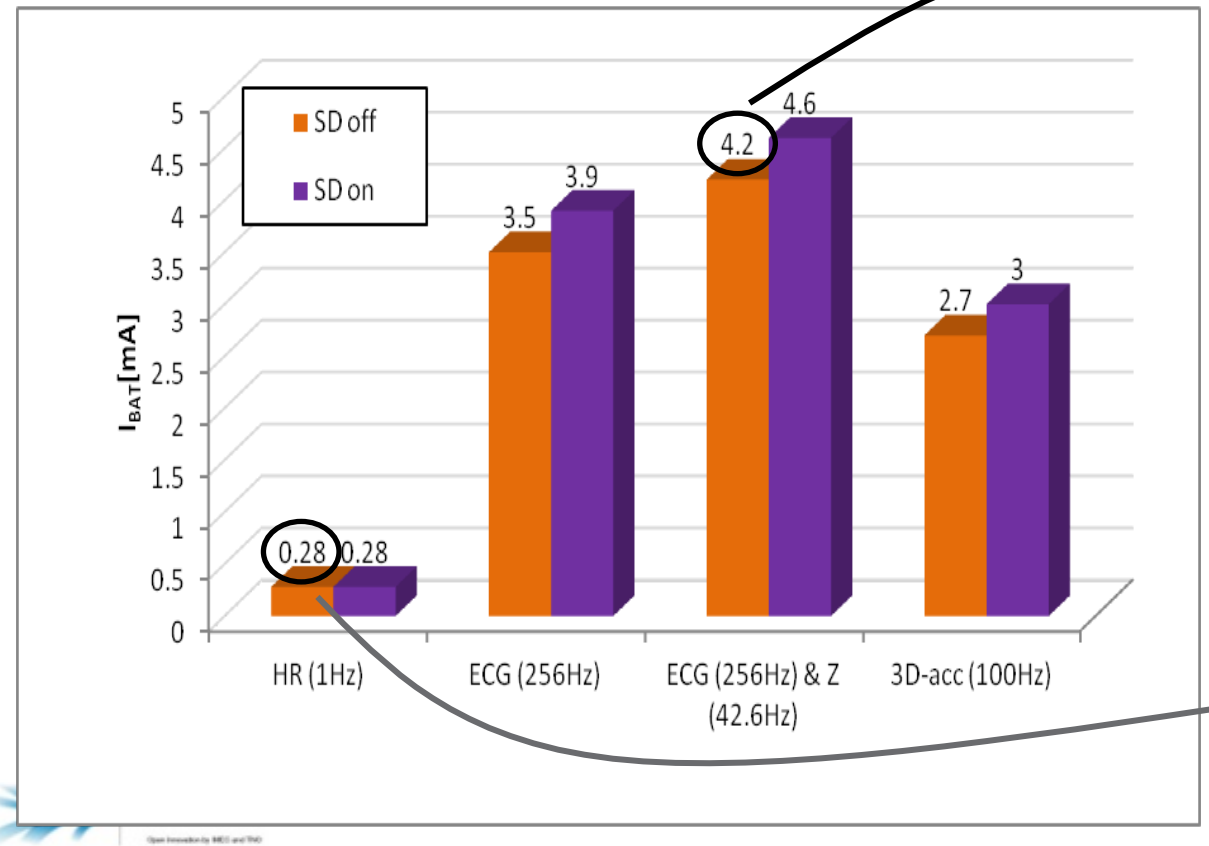


AFE & DSP

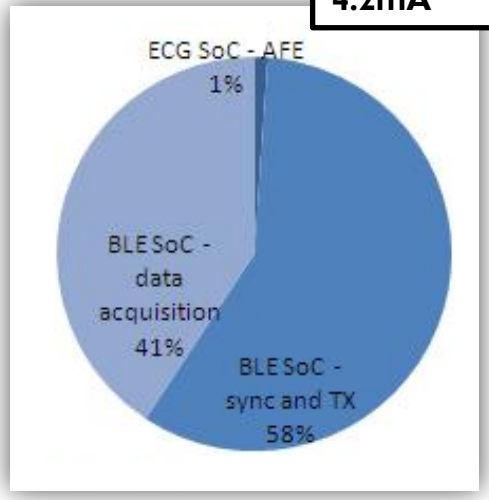
- **3-channel ECG** recording
- **1-channel impedance** measurement
- 32-bit 4-way SIMD processor
- 100uW at 1.2V

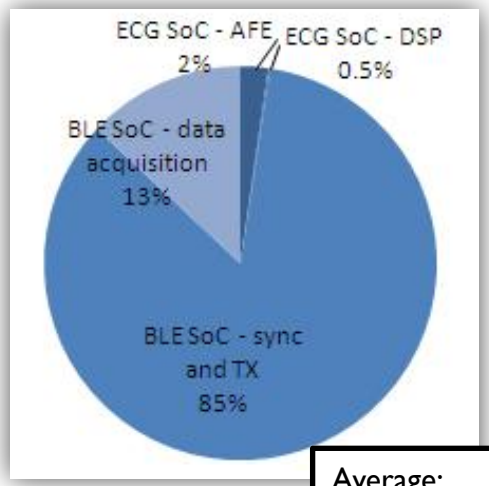
DRASTICALLY REDUCING SYSTEM POWER CONSUMPTION

1 month battery lifetime for HR streaming (280uA @ 2.1V)



Average: **4.2mA**





Average: **0.28mA**

Grand Challenge

Flexible & stretchable patches

imec

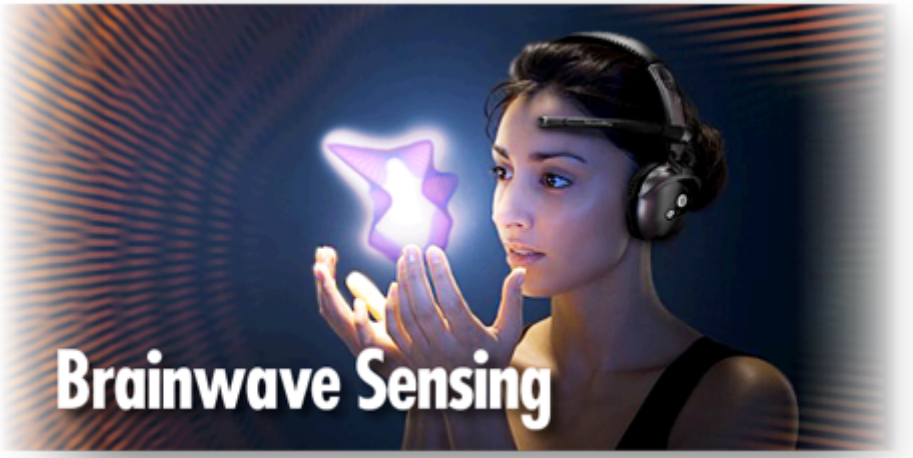
From re-usable Flexible patches

To disposable patches

Managing our BRAIN health

BCI FOR GAMING APPLICATIONS

Require comfort and ease of use



BCI FOR MEDICAL APPLICATIONS

Require high quality EEG recording

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Can we achieve

COMFORT & QUALITY

in EEG recording?

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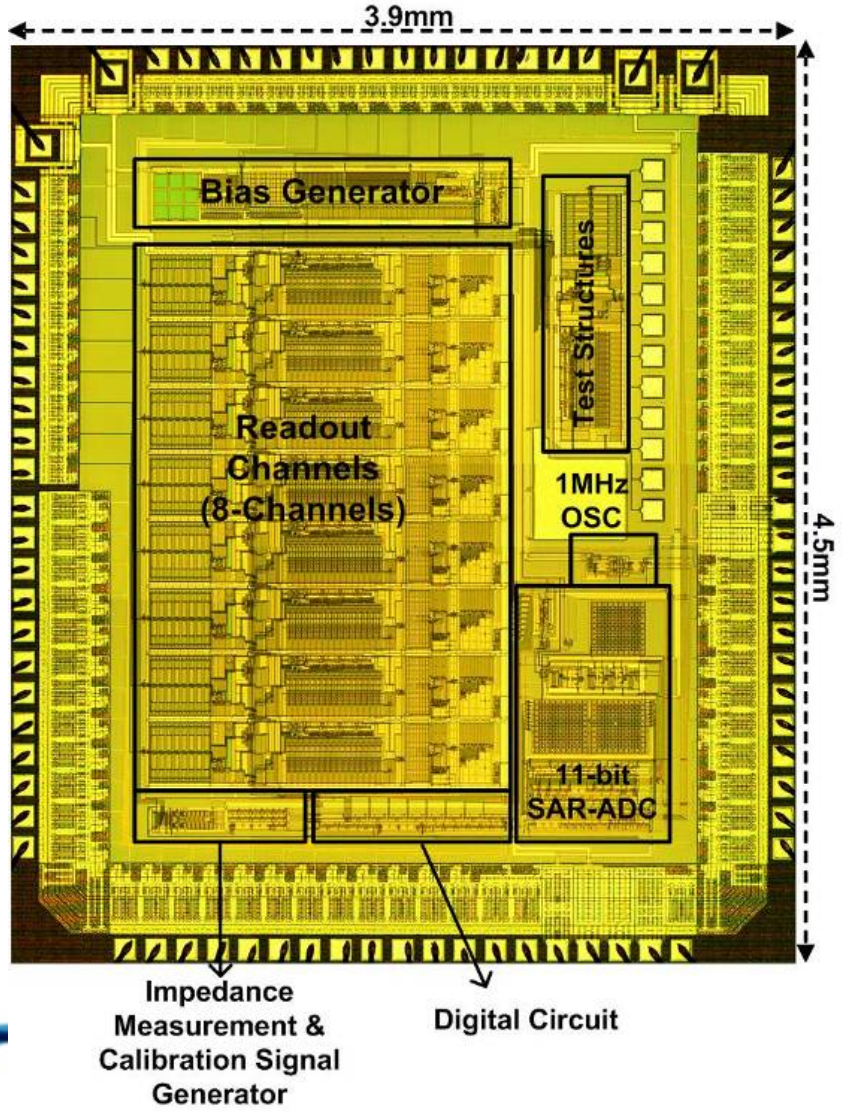
ULTRA-LOW-POWER READ-OUT FOR MINIATURIZED LOW-NOISE SYSTEM



Key Features

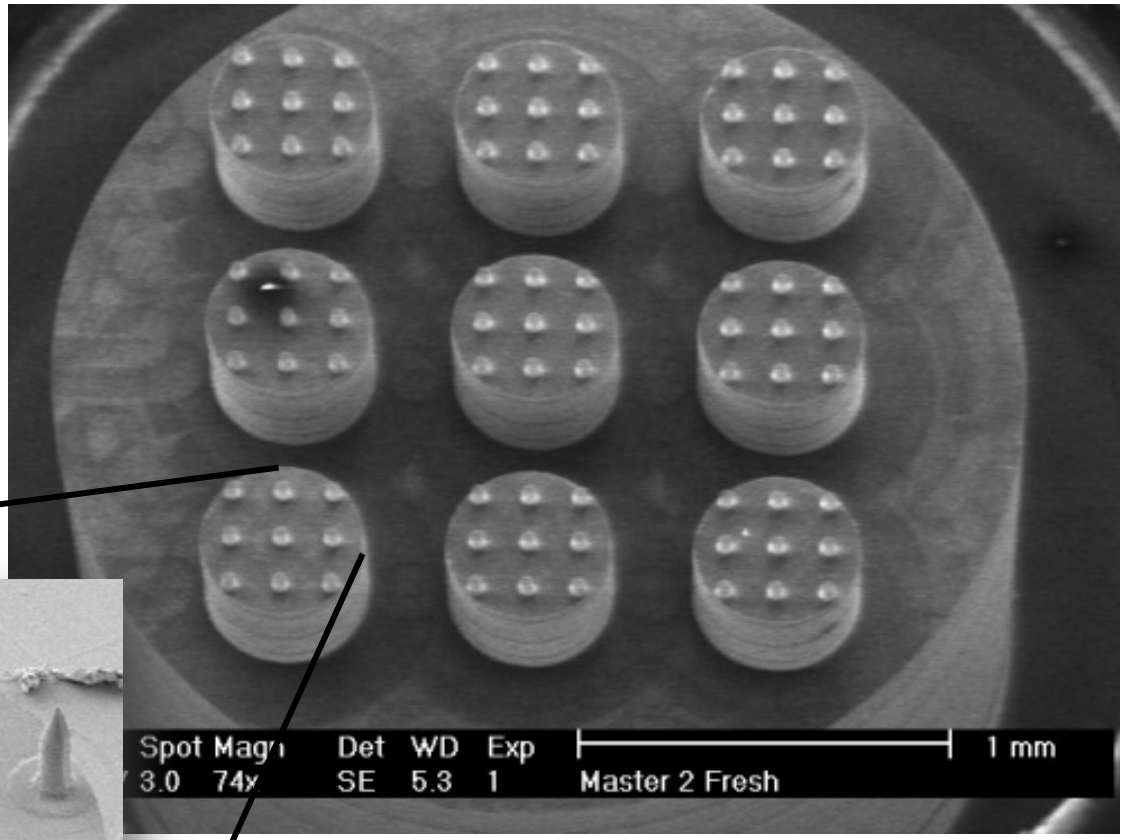
- 8 EEG Acquisition Channels
- Integrated 11-bit ADC
- Built-in impedance measurement mode

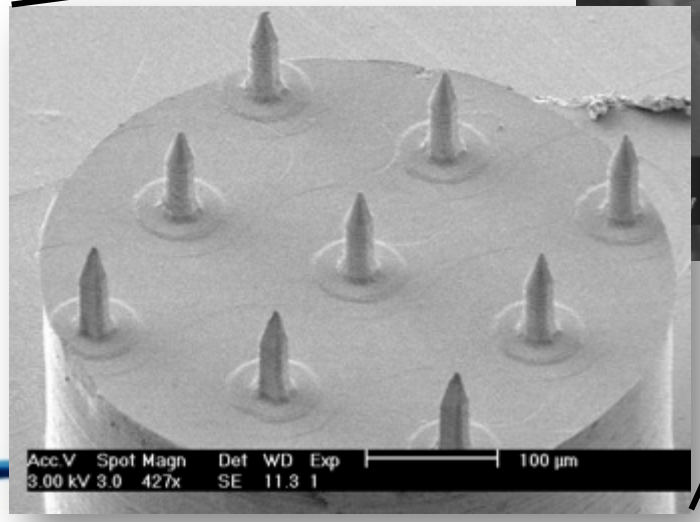
At ultra-low-power

- Total power dissipation: 200uW

DRY ELECTRODES ARE CRUCIAL

- Comfort & quality
- Easy (no skin prep)
- Clean (no gel)
- And Dirty cheap





BRAIN COMPUTER INTERFACES

are changing the life of paraplegic patients

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k
l
o
p
KATHOLIEKE UNIVERSITEIT
LEUVEN

And can tell whether you like or dislike things

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HYPOTHESIS: HEMISPHERIC ASYMMETRY

More left brain activity (reduction in left alpha)

More right brain activity (reduction in right alpha)

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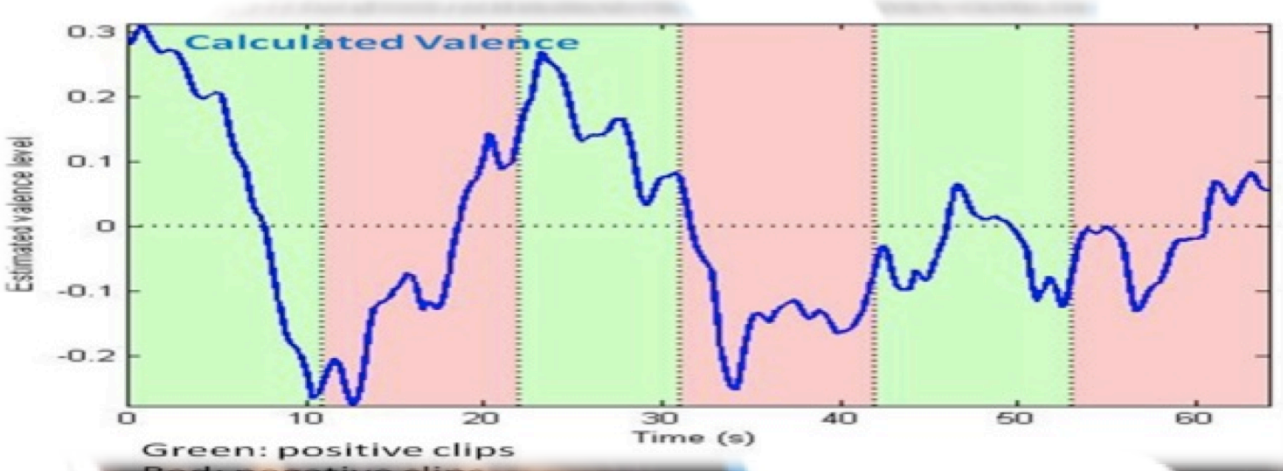
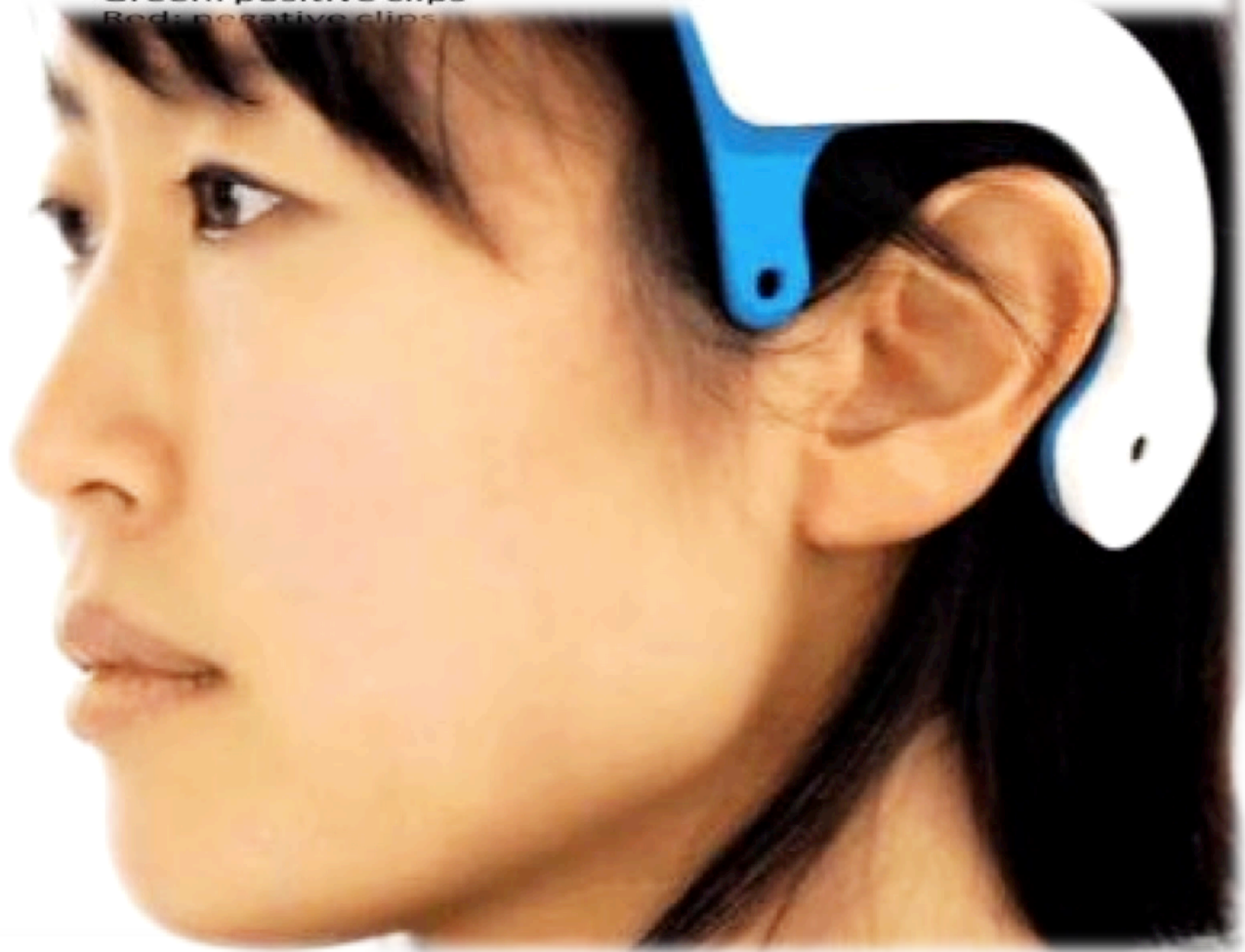
Built into the headset



Raw EEG data

Real-time alpha power

Real-time Valence



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Will you still need your doctor?

The doctor of the future will give no medicine

but will interest her or his patients in the care of the human frame, in a proper diet, and in the cause and prevention of disease

Thomas A. Edison, *US inventor (1847 - 1931)*

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CONCLUSIONS

Health(care) is changing

- The patient of the future is a **healthy patient**
- The doctor of the future is a **manager of health**, assisted by millions of virtual assistants: wearable sensors

Enabled by game-changing technologies

- Ultra-efficient electronics for long term monitoring
- Algorithms & circuits for monitoring in free-living conditions
- New sensor paradigms
- Miniaturization and extreme integration ('wear & forget')

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ASPIRE
INVENT
ACHIEVE

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