Wearables for novel healthcare paradigms

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Chronic disease management
Chronic disease example: United states

117 million americans suffer from one or more chronic diseases.
33% of all adults
CHRONIC OBSTRUCTIVE PULMONARY DISORDER

3rd cause of death in Europe; 600 000 deaths related to pulmonary diseases

COPD is 10th cause of death in Japan; pneumonia (+ influenza) is 1st cause of death in Japan

TODAY THERE ARE VERY LIMITED TOOLS TO MONITOR THESE PATIENTS AT HOME
Sleep apnea

3-7 % of middle-aged men and 2-5 % of middle-aged women suffer from sleep apnea

9 % of Japanese men and 2.8 % of Japanese women suffer from sleep apnea

medically relevant sleep apnea – meaning at least five to ten breaths are missed per hour – does not only make you (permanently) tired, lacking in motivation and exhausted, but has serious consequences for your health
38% of all deaths in Europe are due to cardio (or cerebro) vascular disease

24% of all deaths in Japan are due to cardio (or cerebro) vascular disease
31% of all people in Japan have hypertension

9-20% of all adults and 40-60% of all elderly in Europe have hypertension

ONLY 12% OF ALL PATIENTS CHANGES HIS/HER LIFESTYLE
**Chronic Kidney Disease**

Frail CKD patient with typical comorbidities

- Diabetes
- Osteoporosis
- Muscle wasting
- Frailty
- Cardiovascular hypertrophy
- Vascular calcification

Role of Wearables for chronic disease management

Key to improving quality of life

- Early, affordable and reliable diagnosis
- Disease progression monitoring
- Personalized therapy and lifestyle change

→ Need for multi-modal, ultra-low-power signal acquisition platforms
→ Sensor fusion algorithms
→ Personalized and contextualized data analytics
Multi-modal wearables
Multi-modal wearables

• Heart rhythm and HRV
• Respiration patterns
• Body water composition
• Physical activity
• Core body temperature
• Blood pressure
• Blood oxygenation (SpO2)
• Breath analysis (CO2, NOx, ...)
• Body sounds

• Sensor fusion algorithms
• Artefact reduction
• Feature extraction and classification
• Personalized & learning algorithms
These wearables BUILD on circuit innovations
Next generation ASICs are key enablers

Vision & Ambition

multi-sensor interface
embedded signal processing
power management
radio
(data) security
Next generation ASICs are key enablers

Dedicated analog front-ends

Ultra-low power, high quality, robust, small analog front-end circuits

- Electrocardiogram (ECG)
- Bio-impedance (BioZ)
- Electroencephalogram (EEG)
- Galvanic skin response (GSR)
- Photoplethysmograph (PPG)
- ...

multi-sensor interface
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Next generation ASICs are key enablers

Ultra-low-power signal processing

- multi-sensor interface
- embedded signal processing
- power management
- radio
- (data) security

On the node ULP signal processing to minimize wireless power consumption

- Data synchronization
- Feature extraction and classification
- Motion artifact reduction
- Data compaction techniques
- Contextual awareness
- Personalized machine learning algorithms
Next generation ASICs are key enablers

Highly efficient power management

Highly power-efficient, low quiescent current power management

- Linear regulators for high accuracy analog blocks
- Switched regulators for digital with support for DVFS
- SIMO & capless topologies for a highly integrated solution and less external components
- Optimized efficiency for low average output power levels
- Support for novel battery technologies

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Next generation ASICs are key enablers

Wireless connectivity

- multi-sensor interface
- embedded signal processing
- power management
- radio
- (data) security

Wireless connectivity to leverage the power for the cloud

- Optimized ULP radio links with very low standby current
- Compatible with existing infrastructure for rapid user adoption and wide deployability
Next generation ASICs are key enablers

Security as early as possible in the signal acquisition chain

Medical data is sensitive! Medical devices are potentially life critical

- Guarantee data security through immediate on-the-node encryption
- Prevent tampering with the device by secure embedded software

multi-sensor interface
embedded signal processing
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DIVERSE applications enabled by IMEC’s uLP museic CHIPS

**MUSEIC V2** currently available for development projects

<table>
<thead>
<tr>
<th>Typical power (data-collection ECG + BIOZMF + PPG)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Digital (@0.6V)</strong></td>
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<tr>
<td>103μW</td>
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**Dedicated AFEs**
- ECG
- PPG
- BioZ
- GSR

**General purpose DSP**
- ARM Cortex M0+

**HW accelerators**
- MAU
  - Samplerate converter
  - Timestamp

**Embedded memory**
- 192Kbit SRAM

**LED drivers**
- Fully battery powered

**Integrated PMU**
- Fully battery powered
BEYOND WEARABLES: non-contact health sensing

RADAR SENSING (remote)

OPTICAL SENSING (remote & wearable)

CAPACITIVE SENSING (through textile)

Sensor fusion
BEYOND WEARABLES: non-contact health sensing

Multi-location capacitive ECG sensing

through bed linen
BEYOND WEARABLES: non-contact health sensing

Capacitive Bio-impedance based Respiration rate + depth sensing

*through shirt and sweater*
BEYOND WEARABLES: non-contact health sensing

Heart rate and respiration rate extracted from 2 meters distance using radar.
Example: driver monitoring
Towards disease prevention
Personal behavioral technology

WE PERFORM **DIGITAL PHENOTYPING** BASED ON CONTEXTUAL AND PHYSIOLOGICAL DATA FROM LARGE-SCALE TRIALS AND CREATE NEW TOOLS FOR PERSONALIZED BEHAVIOR CHANGE

Rich physiological information
(120 statistical parameters)

Learn behavior & habits & cravings
Find patterns & triggers
Give the right recommendation at the right time

Ongoing trials: stress & mental health, smoking cessation, eating disorders
DIGITAL PHENOTYPE

For increased PERSONALIZATION and BEHAVIOR change
Digital phenotyping: stress as a use case scenario

WEARABLE AND CONTEXTUAL INFORMATION FOR STRESS DETECTION

WEARABLES

- CHILLBAND
  - Skin conductance (SC)
  - Temperature
  - Acceleration (3 dim)

- CHEST PATCH
  - ECG
  - Acceleration (3 dim)

QUESTIONNAIRES

- Stress
- Activity
- Food/beverage intake
- Sleep
- Gastro-intestinal symptoms

LOCATION

- Continuous
- During questionnaires

VOICE

- PROXIMITY
- Acceleration
- Step count
- Screen on/off
- Ambient light
- Temperature
- Humidity
- ...
Sweet study – stress in the work environment
LARGE SCALE DATASET WITH CONTEXT AND PHYSIOLOGICAL DATA

945 SUBJECTS
11 COMPANIES
5 TB DATA
23,000 SELF-REPORTED STRESS RESPONSES
95,000 HOURS PHYSIOLOGICAL DATA
AND COUNTING ...
Stress physiology

THE FLIGHT OR FIGHT RESPONSE

Threat: an attack, harmful event, or threat to survival

Brain: processing + release of hormones (cortisol and adrenaline)

Physical effects:
- Heart rate increase
- Bladder relaxation
- Tunnel vision
- Shaking
- Pupil dilation
- Flushed face
- Dry mouth
- Slowed digestion
- Hearing loss

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A personalized stress model
a combination of physiological signals and contextual information

A unique personalized algorithm correlating your physiological signals (and context) to your stress
Age as identifier of physiological stress dynamics

- RIGID physiological stress response
- INTERMEDIATE physiological stress response
- DYNAMIC physiological stress response

NEGATIVE CORRELATION between AGE and the DYNAMICS of the PHYSIOLOGICAL stress response
Chronic depression levels as identifiers of physiological stress dynamics

NEGATIVE CORRELATION between DEPRESSION LEVEL and the DYNAMICS of the PHYSIOLOGICAL stress response
FUTURE

DIGITAL PHENOTYPING for PERSONALIZED BEHAVIOR CHANGE

PERSONALIZED MODELS to detect stress

Include CONTEXT information for modeling and feedback

Just-in-time FEEDBACK

Develop ‘types of users’ or ‘PERSONAS’ based on physiology
The role of wearables for chronic diseases may become key to improve the quality of life
- Not only as passive data loggers
- But more as an active contributor to wellbeing

Multi-modal, ultra-low-power signal acquisition ASICs with powerful integrated digital signal processing support is the trend in these wearables
- Digital filtering
- Machine learning
- Context aware / personalization

Wearables will become instrumental towards active disease prevention and behavioral change