WEARABLE & PERSONAL DEVICES FOR HEALTHCARE and LIFESTYLE

CREATING A HEALTHY FUTURE. TOGETHER.

CHRIS VAN HOOF
WEARABLE HEALTH ADDRESSES 2 KEY MARKETS

MEDICAL: IMPROVED CHRONIC DISEASE MANAGEMENT

PERSONAL HEALTH: PREVENTION THROUGH HEALTHIER LIFESTYLE
75% of the health cost is ultimately due to our own behavior …

… yet only 3% of the health budget is spent on prevention … and wearable sensor data are going to be a key enabler
VISION:
MEDICAL QUALITY DATA in EVERYONE’S REACH
creating success stories in wearable health together with our partners:

customer-specific solutions building on generic technologies

KEYWORDS: Health wristband, ECG health patch, EEG headset
INTEGRATED APPROACH
FROM TECHNOLOGY BUILDING BLOCKS TO FULL APPLICATION VALIDATION

(100+ imec staff on wearable systems)
COLLABORATION AND CLINICAL VALIDATION ARE ABSOLUTELY ESSENTIAL
A WORLDWIDE NETWORK OF CLINICAL PARTNERS
Is this the new Holter? So small, compact, flexible!
Look at real-life problems … and their market potential!
JOEL: STRESS
30-40% stressful job

25% extended sickdays due to stress

4/10 leading causes of death due to stress

42B$ direct cost
48% insufficiently active

1B overweight

300M obese

3.2M deaths each year
LISA: CARDIAC RHYTHM DISORDER
Global Mortality Rate (56M lives)

- CVD: 30%
- Infectious Diseases: 18%
- Cancers: 14%
- Respiratory: 7%
- Injury: 6%
- Neurology: 23%
- Other: 23%

13.5M deaths from CVD
80% of CVD deaths in low- and middle-income countries
9.4M deaths due to high blood pressure
MICHAEL: EPILEPSY
50,000,000
People with epilepsy worldwide

30%
of epilepsy cannot be treated

30%
of diagnosed are children

15.5B$
cost associated with epilepsy in US alone
ANDRE: DEHYDRATION
500,000
Annual hospitalizations in the US alone

5B$
Direct hospitalization cost

10,000
Hospital deaths each year in the US

70,000
deaths in August 2003 European heat wave
JADE = just fine!
SENSING CHALLENGE
QUALITY OF DATA

USABILITY CHALLENGE
DESIRABLE FORMFACTOR

INTEGRATION CHALLENGE
LOW COST

POWER CHALLENGE
LONG BATTERY LIFE
WIRELESS HEALTH PLATFORMS

- brain monitoring
- smart contact lens
- smart wristband
- health patch
- smart textiles
- smart home/workplace/car
IMEC TECHNOLOGY PLATFORMS IN DEVELOPMENT FOR ENABLING WEARABLE HEALTH APPLICATIONS

Data Science Platform

1. Health Patch
2. Wristband
3. Headset
4. Smart Textiles
5. Smart Contact Lens
6. ULP Platform
HEALTH PATCH
ELS: CARDIAC RHYTHM DISORDER
THE HEALTH PATCH

Lowest power, smallest & robust

- Ultra-low power ECG & actimetry measurement
- BT4.0
- Embedded artifact reduction
- Accurate rhythm analysis
- Activity tracking & energy expenditure
- 30 days autonomy
CardioNet, Inc., IMEC and Delta Partner to Develop Next Generation Cardiac Monitoring Products

CONSHOHOCKEN, Pa.--(BUSINESS WIRE)--Feb. 21, 2013-- CardioNet, Inc. (NASDAQ:BEAT), the leading wireless medical technology and research services company with a current focus on the diagnosis and monitoring of cardiac arrhythmias, today announced a multi-year development agreement with the Belgium-based nanoelectronics research center IMEC and its Dutch affiliate Holst Centre. Over the next 18 months, the Companies will work to develop two revolutionary cardiac monitoring products.
imec ECG CIRCUITS – DESIGNED ACCORDING TO MEDICAL STANDARDS AND QUALIFIED

FEATURES:
- 3 channel ECG and ETI (concurrent)
- Supports motion artefact reduction
- All integrated clocking and biasing requiring only a single 32kHz external clock.
- SPI communication (1MHz)
- Low supply: 1.2V core and 2.5V I/O
- High-performance analog readout:
  - CMRR : > 81 dB
  - Differential input impedance: > 300MΩ
  - Noise: 1.3µVrms (0.5Hz – 100Hz)
- Programmable sample speed: 256 – 8K samples/sec
- Programmable gain: 75 - 300
- EMI Filter: 30dB suppression at 2.4Ghz
- Integrated ADCs:
  - 3 SAR-ADCs (ECG + ETI): 12bit
- Low Power Consumption:
  - Typical (3ch ECG + ETI): 65µW

DESCRIPTION:
The three-channel ECG readout ASIC is an ultra low-power (ULP) solution for small size, autonomous, battery-powered wearable ECG acquisition systems.

The ASIC features 3 identical, but independent readout channels each capable of measuring electrocardiogram (ECG) and electrode-tissue impedance (ETI) concurrently. The analog readout channels achieve a very high CMRR and common-mode input impedance, both of which can be calibrated after implementation to further increase these specs if so required.

The ASIC is a highly integrated solution offering all of the functionality of acquiring the biopotential signals requiring only a limited number of external components. All filter components are fully integrated. The biasing is generated completely internally requiring only a few external capacitors (<1µF each) for noise filtering. All the internal clocking can be derived from a single 32kHz input clock.

The ASIC is extremely suited for wearable solutions due to the support for motion artefact reduction in the analog domain. The ETI measurements can be used to estimate motion artefacts present in the ECG readout (using an algorithm running on an external microcontroller). The estimated artefacts can be subtracted from the ECG readout in the analog domain, reducing baseline drift and in some cases also preventing channel saturation due to severe motion artefacts.

The ASIC communicates through 2 SPI interfaces (programming the ASIC and data output SPI).

The ASIC is highly programmable and can be tailored to a wide range of applications. Each channel can be powered off independently. Gain and bandwidth are programmable. The ASIC features three 12b ADCs.

The ASIC allows low power systems to be implemented featuring a typical power consumption of 65µW (all channels active) drawn from a 1.2V supply. This can be reduced to less than 35µW for 1ch ECG only.
FEEDBACK FROM THE HEALTH PROVIDERS

Atrial fibrillation is relatively rare with young people, but 10 to 15% of people over 80 may be affected.
IMEC WEARABLE SENSOR VISION

24/7 MONITORING

LOW COST
(SINGLE USE)

ENVIRONMENTALLY
FRIENDLY
(DISPOSABLE)
TOWARDS A DISPOSABLE HEALTH PATCH
10 GRAM INCLUDING (FLEXIBLE) BATTERY

low weight, thin and flexible ECG patch
• multilayer printed circuit and electrodes on PET
• all complex / expensive electronics on a re-usable SiP
• meander technology used to reduce motion artifacts
TOWARDS A DISPOSABLE HEALTH PATCH
IMEC HEALTH PATCH – 10 gram including battery
TOWARDS A DISPOSABLE HEALTH PATCH: FLEXIBLE DISPLAY FUNCTIONALITY

Very thin

Very flexible

~30μm
TOWARDS DEHYDRATION MONITORING: IMEC ION SENSOR

Flexible

Multi parameter (pH, Cl⁻, Na⁺ ...)

μM Sensitivity

Miniaturized
SCREEN-PRINTED SWEAT SENSOR
TOWARDS DEHYDRATION MONITORING: IMEC BIO-IMPEDEANCE SENSOR
COMING IN 2015: PATCH FOR DEHYDRATION MONITORING
SMART TEXTILES
SMART TEXTILES: WELLNESS & SPORTS

Enabling new health & sports applications with smart textiles: *from compression to loose fit*

- Comfortable & unobtrusive
- Reliable in everyday situations
- Long autonomy & rechargeable
- Washable

Key technology development

- Sensing technology: *from biopotentials (compression) to capacitive/magnetic/RF/ optical (loose fit)–technology exploration & implementation*
- Interconnects & electrodes in garments
- Modules: miniaturized sensor systems & batteries
IMEC EXAMPLES OF SYSTEM-IN-FOIL & SMART TEXTILE INTEGRATION PLATFORM

into stretch

into textile
WRISTBAND
PROBABLY THE MOST HEALTH AND CONTEXT-AWARE SMART WRISTBAND FOR STRESS MONITORING
JOEL HAS STRESS
Signals are interpreted by the amygdala which sends a distress signal to the hypothalamus which commands the pituitary gland to release cortisol & adrenaline. These hormones trigger measurable physiological changes: increased heart rate, pupil dilation, blood vessel dilation, bronchial dilation, increased perspiration, ...
STRESS MANAGEMENT APPS

Your Stress Level: 6

Easy Stress Management
Healthcare & Fitness

Stress Management Complete Guide
Healthcare & Fitness

iStress
Medical

Cleveland Clinic Stress Meditations
Healthcare & Fitness

Stress Management - Simple Solutions to Lead a Stress-Free Life
Lifestyle

5 Steps to Counteract Stress
Healthcare & Fitness
STRESS AT WORK
80% accuracy in classifying stress from rest

STRESS PATIENTS
75% accuracy in classifying patients from controls
DEMONSTRATING RELEVANCE
MEASURING STRESS LEVEL DURING TRAINING OF EMERGENCY ROOM PERSONNEL

Stress level

Measured by imec wristband

Self-reported by nurse

Rest  Training  Rest

Rest  Training  Rest
EXISTING HARDWARE – THEY ALL HAVE CHALLENGES: POWER CONSUMPTION, SENSOR ACCURACY AND VALIDATION OF ALGORITHMS

**EMPATICA E3**
- Measures:
  - Heart rate (PPG)
  - Temperature + heat flux
  - Movement (3D acceleration)
  - EDA (electrodermal activity)
  - Positioning (BLE proximity)
- Algorithms:
  - None
- Connectivity:
  - BLE

**EXMOVERE EMPATH**
- Measures:
  - Heart rate (PPG)
  - Skin temperature + moisture
  - Movement (3D acceleration)
  - GPS tracking
  - SOS button
- Algorithms:
  - Pedometer
  - Calorie counter
  - Hand writing recognition
- Connectivity:
  - GSM

**HEARTMATH**
- Measures:
  - Pulse (ear lobe)
- Algorithms:
  - Biofeedback (brain fitness, inner balance, meditation)
  - Based on heart rate variability spectral analysis

**NEUMITRA NEUMA**
- Measures:
  - EDA (electrodermal activity)
  - Skin temperature
  - Acceleration
- Algorithms:
  - Stress monitoring
MULTI-APPLICATION PLATFORMS
INTEGRATION OF IMEC SENSING TECHNOLOGY IN SAMSUNG SIMBAND

Powered by IMEC’s Sensing Technology

Source: Samsung Strategy and Innovation Center
http://www.samsung.com/us/globalinnovation/innovation_areas/
INTEGRATING INDUSTRY’S MOST ADVANCED SENSING TECHNOLOGIES FROM IMEC

Source: Samsung Strategy and Innovation Center
http://www.samsung.com/us/globalinnovation/innovation_areas/
INCREASED COMFORT

Stretchable patch design and System-in-Foil integration for a thinner and lighter wristband
## A MULTITUDE OF DEVICES …

<table>
<thead>
<tr>
<th>Site</th>
<th>Name</th>
<th>Price</th>
<th>Features</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>© IMEC 2014</td>
<td>[Sheet1]</td>
<td>[Sheet2]</td>
</tr>
</tbody>
</table>

### Application Appearance

- | | © IMEC 2014 | [Sheet1] | [Sheet2] |
BUT MEASURING **ACTUAL** ACTIVITY HAS NEVER BEEN SO COMPLICATED...
SAME ACCURACY
RELIABLE IN EVERYDAY SITUATIONS
1 MONTH AUTONOMY

the imec solution
the perfect solution
Online Feature extraction and activity classification on the phone

Online personalized energy expenditure estimation on the phone

Filter activity allocation and energy expenditure by location

Daily summaries
HEADSET
TREND: INCREASED QUALITY & COMFORT

Clinical EEG today

EEG for lifestyle today

Quality

Comfort
BRAIN MONITORING: EEG HEADGEAR

Easy, fast, comfortable and reliable EEG monitoring on-the-go

- Low noise & scalability
- Reliable & good quality
- Comfort & ease of use

Key technology development

- Low-power (digital) active electrodes using off-the-shelf rigid electrodes and custom-made rubber electrodes
- Reduced set-up time (fast settling of EEG signals)
- Continuous run-time impedance check
New medical-grade active electrode
EEG
Embedded processing power
Smartphone connectivity

imec generic EEG development platform
EXAMPLE FROM PLATFORM TO PRODUCT FOR CLINICAL RESEARCH - “WITH IMEC R&D INNOVATIONS INSIDE”

Validated and embedded algorithms for signal enhancement and pre-processing

- Motion artefact reduction
- Feature extraction

**KEY APPLICATIONS: from extracted DATA:**

- Mental wellness, cognition, relaxation
- Neurofeedback
- Brain trauma
- Mental / neurological conditions: detection and treatment of AD(H)D, PTSD, Anxiety, dementia, schizophrenia, autism
Example application of EEG concentration game

Based on mental engagement estimated from EEG power spectra model parameters (alpha peak frequency amplitude)
TOWARDS A HIGHLY COMFORTABLE EEG HEADSET IN DESIGN USING SMART TEXTILES
SMART CONTACT LENS
CURRENT PASSIVE PRESBYOPIA SOLUTIONS

- Multifocal glasses or multifocal contact lenses

- **Drawbacks:**
  - Limited field-of-view
  - Reduced contrast
  - Reduced depth perception
SMART CONTACT LENS for vision correction (Presbyopia)
SMART CONTACT LENS NEEDS ULTRA-LOW POWER CIRCUIT PLATFORM

- For smart contact lenses both *ultra-low-power* chips as well as *ultra-small area* chips are crucial.
ULTRA-LOW-POWER PLATFORM

For wearable applications
Listen to your sensor symphony orchestra …
Andre may need sensors in a PATCH

Joel may need sensors in a WRISTBAND

Jade may need sensors in GLASSES

Michael may need sensors in SHOES
MANY APPLICATIONS SHARE THE SAME CHALLENGES

- Long Term Battery Autonomy
- Desirable form factor
- Low Cost
- High Quality and Reliable Data
- 99.999%
- Personalized
A VERSATILE PLATFORM FOR CONNECTED & PERSONALIZED WEARABLE SENSING

- Interfacing with Various Sensors
- Flexible to integrate Different Algorithms at Extreme Low Power
- Managing Batteries
- Connected to Different Platforms
- Smart
- Battery Management
- Low-Power & Miniature Area
- Embedded Signal Processing
- Multi-Parameter Sensor Interfacing

imec
PLATFORM APPROACH: USING THE SAME IC for Different and Diverse Applications

Activity Monitoring Device
- Motion Sensor
- Pressure Sensor
- Display
- Battery
- MUSEIC
- BTLE
- FLASH Storage

Portable EEG (up to 16 leads)
- Motion Sensor
- Battery
- MUSEIC
- BTLE
- FLASH Storage
- Analog Extension
- EEG electrodes

Sleep Monitoring (EEG, EOG, EMG)
- Motion Sensor
- Battery
- MUSEIC
- BTLE
- FLASH Storage
- Analog Extension
- EEG electrodes
- EOG Electrode
- EMG Electrode
OUR MULTI-LEVEL NANOELECTRONIC INNOVATIONS

- Multi-Parameter Sensor Interfacing
- Embedded Signal Processing
- Battery Management

Reduce External Components and Battery Size
Utilize Power More Efficiently
Reduce Size
Adaptive to the User
Reduce Noise & Interference & Artefacts
MUSEIC GEN1

HIGHEST INTEGRATION LEVEL:
- MULTI PARAMETER ANALOG INTERFACES
  - ARM CORTEX M0
  - 128kB SRAM
  - DIGITAL HW ACCELERATORS

LOWEST POWER DISSIPATION
- LESS THAN 1mW Total Power

MEDICAL GRADE ACCURACY
- 18-bit ADC
- Low-Noise (50nV/rtHz)

Temperature
ECG
Bio impedance
Accelerometer
GSR
Sensors

Host
Flash Memory
Radio

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A VERSATILE PLATFORM WITH ULTRA-LOW POWER WIRELESS CONNECTIVITY
A VERSATILE PLATFORM WITH ULTRA-LOW POWER WIRELESS CONNECTIVITY

3.5mW Bluetooth Low Energy SoC

- Interoperable in 2.4GHz ISM band, incl. BT-SMART and Zigbee
- One-die 40nm SoC radio including AFE, BB, ARM Cortex M0
- 3-5x lower power consumption than market solutions
- Operating from tiny ZnAir battery
DATA SCIENCE PLATFORM

PERSONALIZED ALGORITHMS FOR SENSOR AND CONTEXTUAL DATA ANALYTICS
KEY PLATFORM DEVELOPMENT: DATA ANALYTICS

Personalized and adaptive, relying on machine learning algorithms

Data fusion from physiological, contextual, and other information sources

Identification of biomarkers, prediction, coaching & advice
DATA DRIVEN HEALTH SOLUTIONS: OUR SYSTEMS PROVIDE HEALTHCARE AND LIFESTYLE DATA

Personal Data & Goals

Sensor 1
Sensor 2
Sensor 3
Sensor 4

Apps

Coaching
Prediction
Data analytics
Sensor fusion
Database infrastructure
PERSONALIZED ALGORITHMS INCREASE ACCURACY SIGNIFICANTLY

Different parameters:
- Heart rate (ECG) (-6%)
- ECG combined with accelerometer (-51%)
- Personalized algorithms for energy expenditure (-27%)

3x error reduction!
WIRELESS HEALTH PLATFORMS

- brain monitoring
- smart contact lens
- smart wristband
- health patch
- smart textiles
- smart home/workplace/car
imec brings MEDICAL QUALITY DATA in EVERYONE’S REACH
FUTURE VISION IN WEARABLES

It is about **truly personalized health and lifestyle solutions**, and making health management mobile, ubiquitous and convenient.

It is about **advanced wearable platforms** on new body locations and **advanced smart peripherals** around us.

Expand beyond **monitoring** – opportunities for feedback, for coaching, for stimulation, for treatment, for prevention.

Go beyond **generic** needs - additional target groups: children (teenagers), specific professionals, late adults (elderly), gender-specific, …
CREATING A HEALTHY FUTURE. TOGETHER.