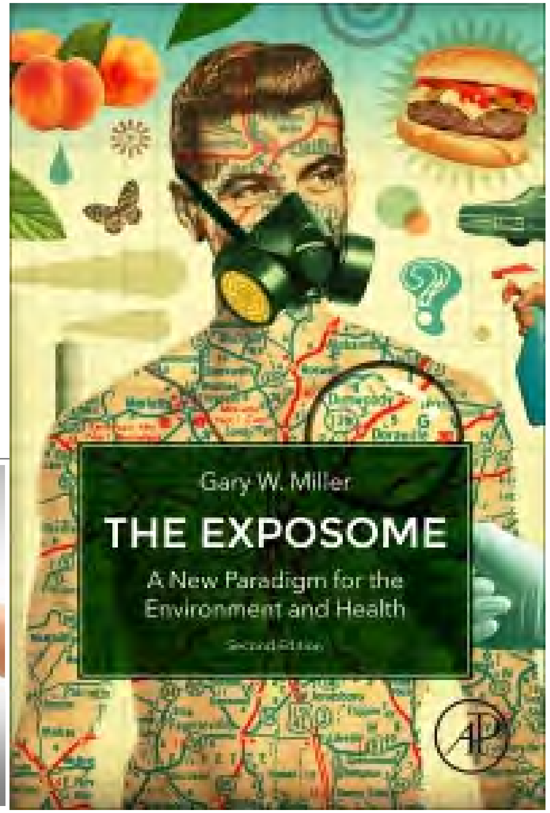
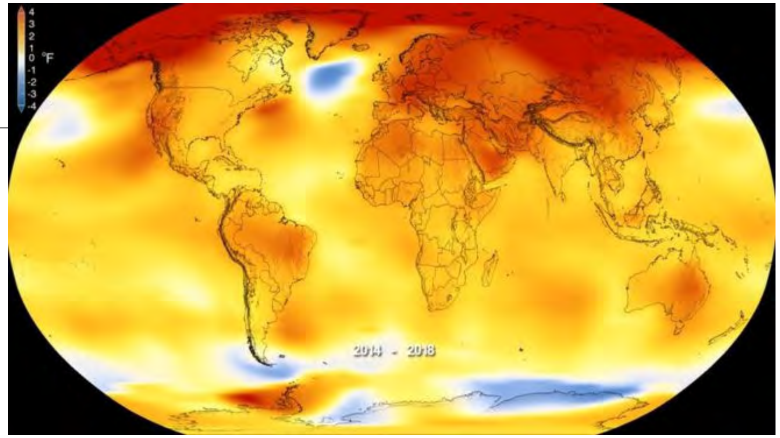
FRICTIONLESS ENERGY EFFICIENT CONVERGENT WEARABLES FOR HEALTHCARE AND LIFESTYLE APPLICATIONS

- Overview -



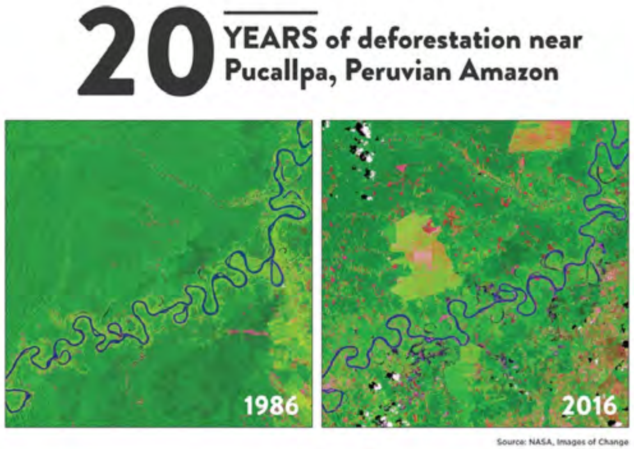
ADRIAN IONESCU, EPF LAUSANNE

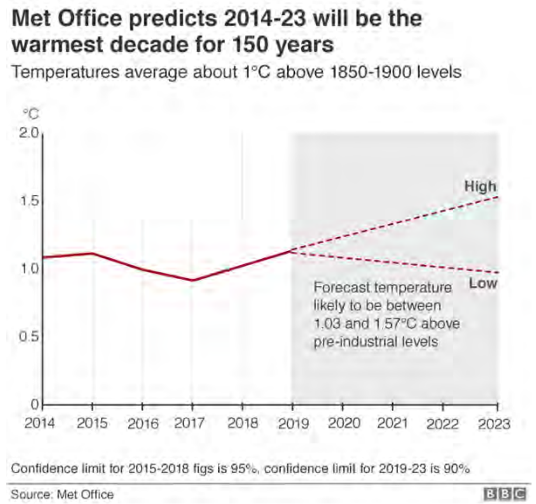
Global Challenges for Humanity in 21st Century



1. Climate Change

Greenhouse gas emissions must be drastically reduced within the next decade to stay within 1.5°C of warming above pre-industrial levels to avert the worst impact of climate change.

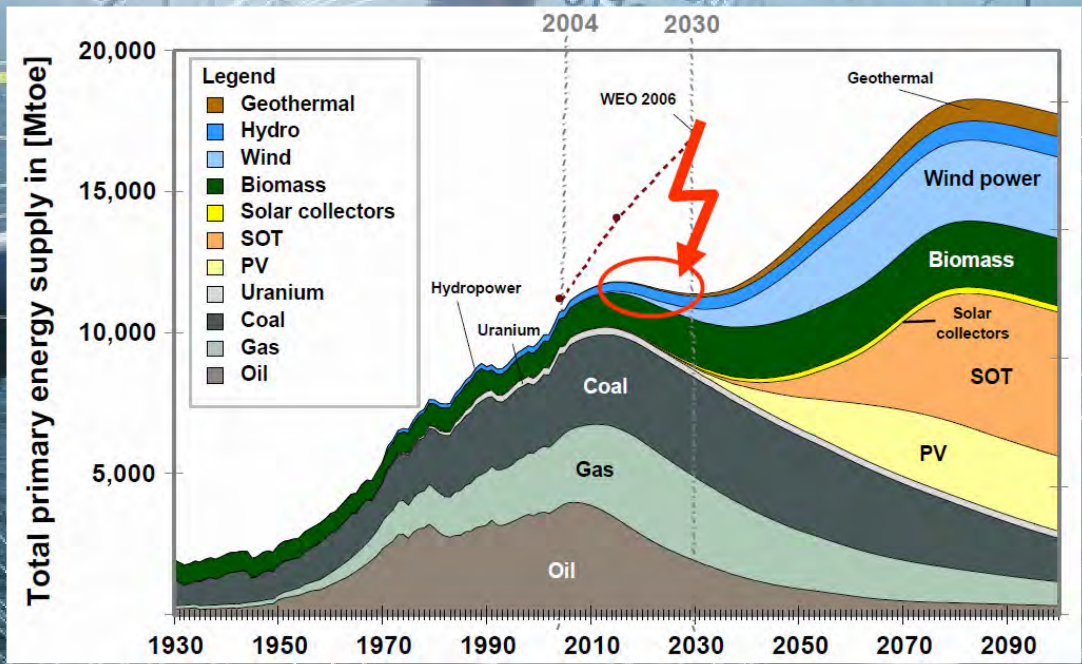




Global Challenges for Humanity in 21st Century

2. Energy

We are at a crucial point on how we make and use sustainable energy.

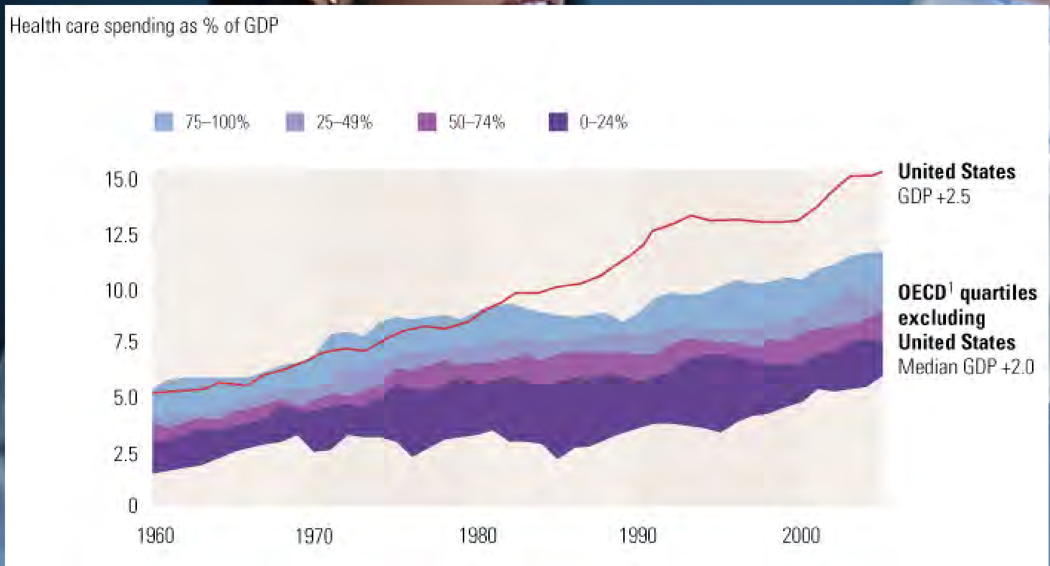


Technology to play a big role!

Global Challenges for Humanity in 21st Century

3. Health

The 20th Century reactive healthcare model is unsustainable!



The median increase in health care spending has been 2% points above GDP for nearly 50 years in all OECD countries, with only minor fluctuations.

Expectations:

- **30% of GDP in the United States by 2040** (up to 97% in 2100)
- **30% of the median OECD GDP by 2070**

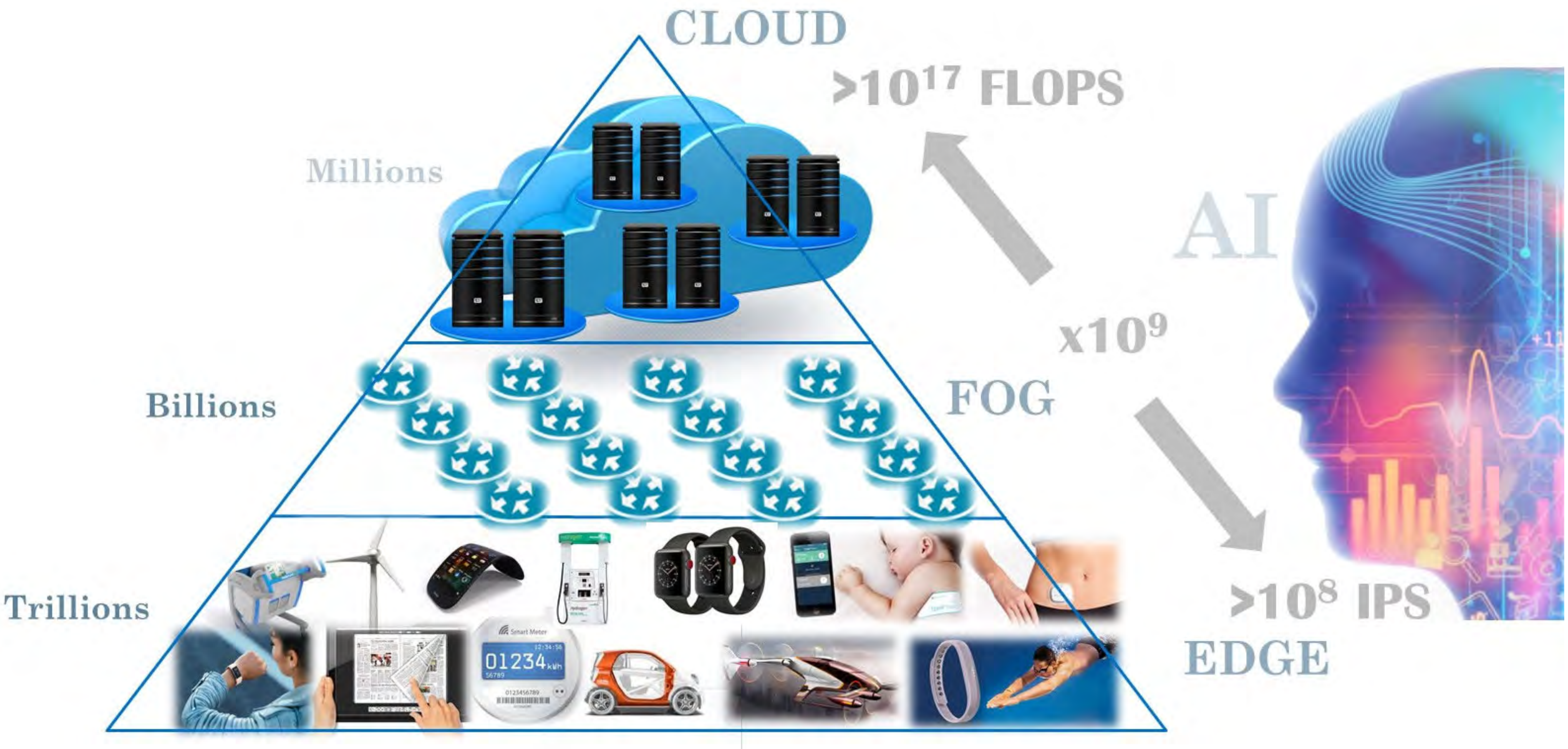
We need a paradigm change: a P3 Digital Healthcare revolution.

Technology to play a big role!

How technology can help for global challenges?

- Every day **new evidence of our unsustainable impact** on the environment is emerging.
- We have **a critical window of opportunity** to put in place commitments and actions to reverse the trend of nature loss.
- **Digital Technology** should play a crucial role in **decoupling development and environmental degradation**.

Edge-to-Cloud Technologies and AI



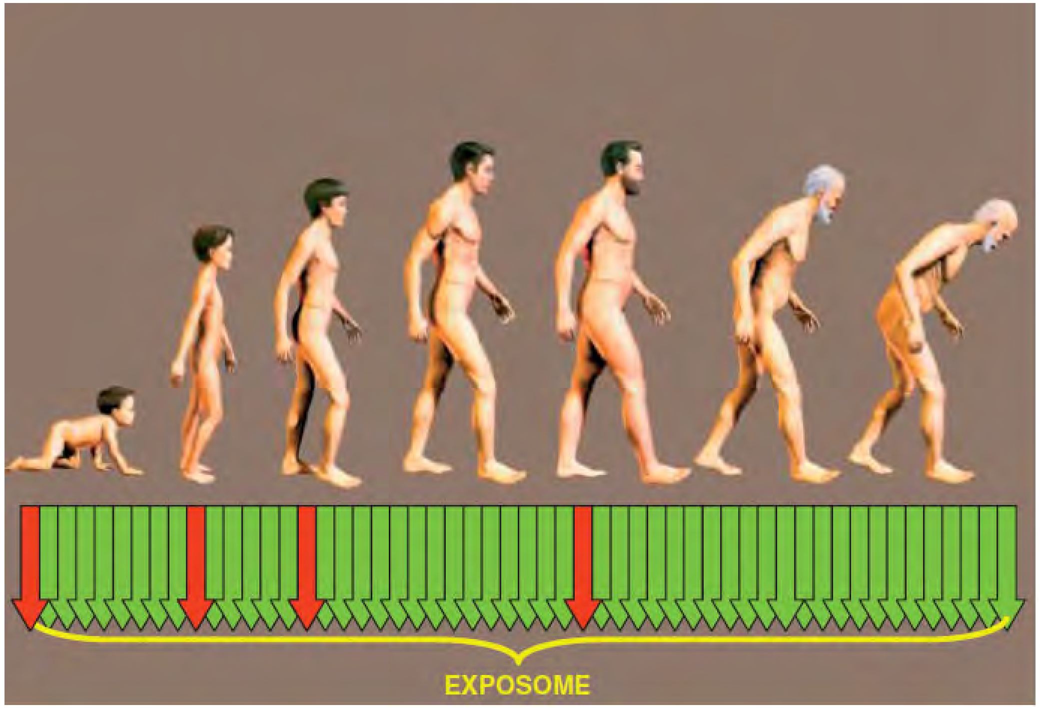
The exposome: from concept to utility

The exposome would require Edge AI enabling technology to measure and interpret exposures over the life course of an individual.

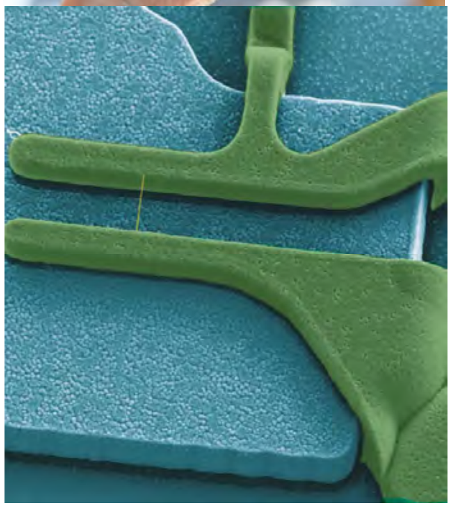
Human exposome: totality of environmental exposures encountered from birth to death; includes a diverse mix of dietary nutrients, pharmaceutical drugs, infectious agents, and pollutants.

Table 1 Some examples of approaches and tools to measure the exposome

Approach	Tools
Biomarkers (omics)	
General	Genomics, transcriptomics, proteomics, metabolomics, epigenomics
Targeted	Adductomics, lipidomics, immunomics
Sensor technologies (including mobile phones)	Environmental pollutants, physical activity, stress, circadian rhythms, location [global positioning systems (GPS)]
Imaging (including mobile phones, video cameras)	Diet, environment, social interactions
Portable computerized devices (including palmtop computers)	Behaviour and experiences (ecological momentary assessment), stress, diet, physical activity
Improved conventional measurements (combined with environmental measures)	Job-exposure matrices; dietary recall (e.g. EPIC-Soft)



My Exposome: understanding personalized environment-health interactions enabled by CONVERGENCE



Environmental related diseases:

- CARDIOVACULAR DISEASES: 2.5 million people die every year from cardiovascular disease attributable to pollution.
- RESPIRATORY INFECTIONS: more than 1.5 million deaths annually from respiratory infections due to environment.
- CANCER: environmental accounts for an estimated 31% of global lung cancer burden.
- DIARRHOEA: about 1.5 million deaths per year from diarrhoeal diseases; 88% of all cases of diarrhoea attributable to water and hygiene.
- MALARIA, INTESTINAL NEMATODE INFECTIONS, HEPATITIS B and C, TUBERCULOSIS, etc.

Human Exposome data is key part of personalized prevention and early detection with Digital Twin technology.

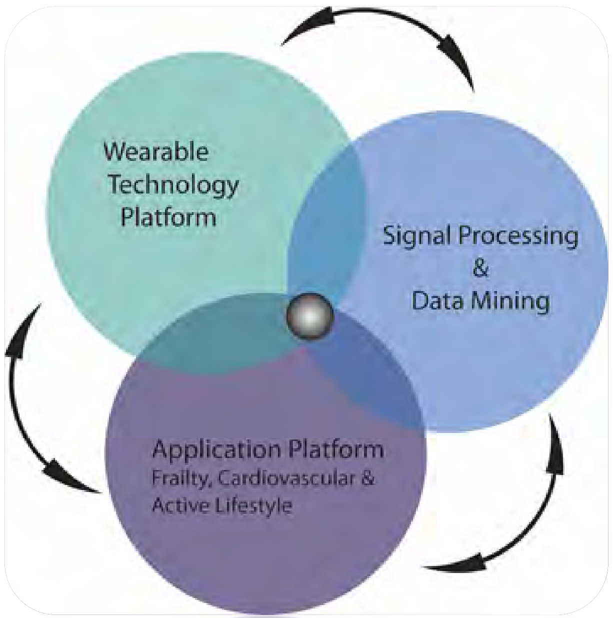
CONVERGENCE: CONCEPT & GOALS (1)

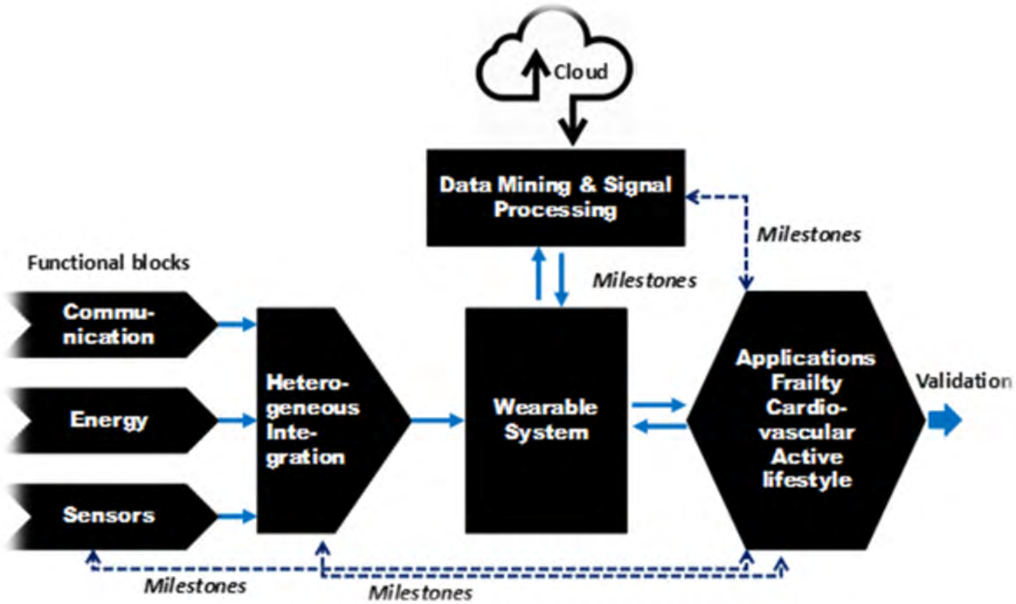
Energy efficient wearable platform:

- low power bio- and environmental sensors
- energy management
- wireless communication
- heterogeneous integration
- data transfer and analytics
- preventive life-style and healthcare applications

CONCEPT & GOALS (2)

Convergence of technologies into smart sensing systems driven by life-style and health care applications: enable access to MyExposome and its impact of healthcare.



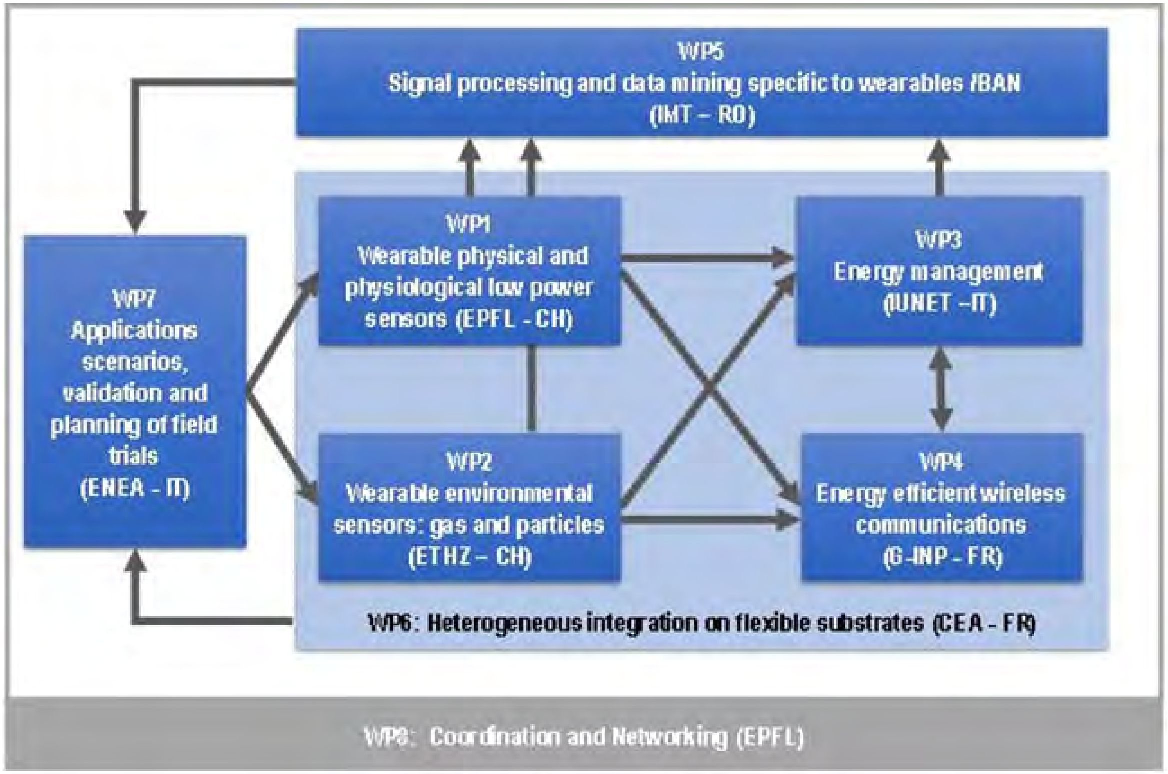


CONSORTIUM

https://www.convergence-era.org/

1. EPFL – Ecole Polytechnique Fédérale Lausanne
2. IUNET – Consorzio Nazionale Interuniversitario Per La Nanoelettronica
3. UCBM – Università Campus Bio-Medico di Roma
4. TAGLIAFERRI Srl
5. CEA – Commissariat à l’Energie Atomique
6. UCL – Université catholique de Louvain
7. IMT – National Institute for R&D Microtechnologies
8. HCC – Hirslanden Clinic Cecil
9. METU – Middle East Technical University
10. ETHZ – Eidgenössische Technische Hochschule Zürich
11. ENEA – Italian National Agency for New Technologies, Energy and Sustainable Economic
12. UNICA – Università degli Studi di Cagliari
13. G-INP – Institut Polytechnique de Grenoble
14. ST – STMicroelectronics
15. EDI – Elektronikas un datorzinatnu instituts
16. UTBV – Universitatea Transilvania din Braşov
17. UTT – Tallinn University of Technology

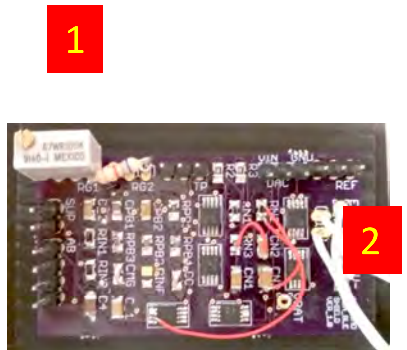
Workplan & Major milestones

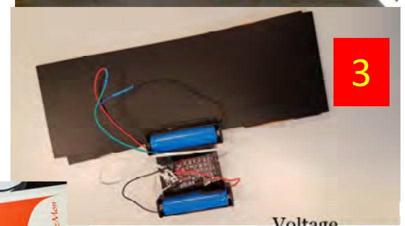


MM1	M15	WP1	**Done - First generation of multi-parameter functionalized biosensors for frictionless sweat analysis in combination with activity tracking and core body temperature**
MM2	M18	WP2	**Done - First generation of gas sensors developed, field-validated and ready for integration**
MM3	M18	WP3	**Done - Choice of the energy-management architecture compatible with the systems defined in WP6.**
MM4	M24	WP4	**Done - First implementation of a low cost and interoperable protocol on a specific hardware dedicated to radio communication.**
MM5	M24 (delayed to M26)	WP5	**Done - First set of algorithms for sensor data fusion ready for testing**
MM6.1	M6	WP6	**Done - Test platform for sensors and Energy harvesters available**
MM6.2	M32	WP6	**Done - Simplified test platform on flexible substrate available**
MM7	M6	WP7	**Done - Issuing of Wearable requirements**
MM8	M12 -> M17 M24 -> M20 M36	WP8	**2 Done + 1 scheduled in 2020 - Convergence Workshops: Workshop #1 was organized in M17, Workshop #2 in M20 and Workshop #3 is planned as special session @ Eurosensors 2020, Italy.**

WP1: Wearable physical and physiological sensors

- **1st prototype ECG contactless sensor**: Supply Voltage = 6V, Dimensions: 65 cm2, Separated electrodes
- **2nd prototype ECG sensor:** Supply Voltage = 3.6V, Dimensions: 50x28 mm, Separated electrodes
- **3rd prototype ECG sensor:** Electronics & electrodes cointegrated





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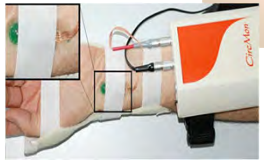
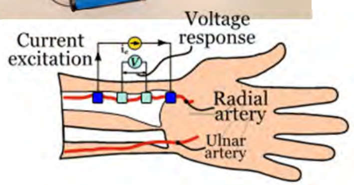
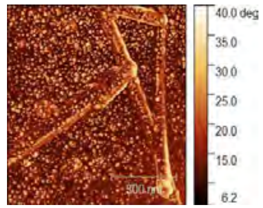
Measurement of radial bioimpedance radial form and new electrodes

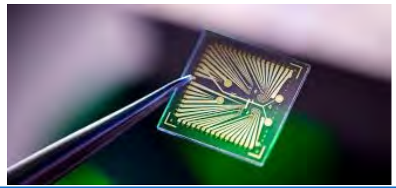




Development of silicon nanonet aptasensors based on electrical field effect detection



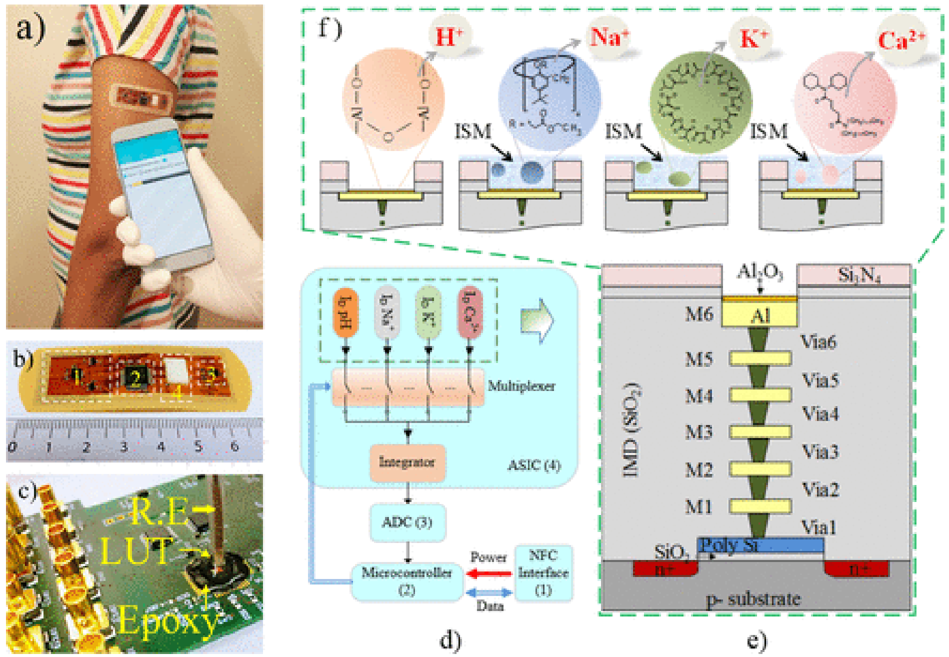
- **Extended-gate ISFET for wearable sensors based on Lab-On-Skin**
- **1st wearable troponin ISFET sensor**



WP1 – ISFET sensors for the detection of pH and electrolytes in human sweat: Lab-On-Skin^{TM} wearable platform (1)

Main achievements:

- a **multianalyte sensing platform** that incorporates high performance, high yield, high robustness, three-dimensional-extended-metal-gate ISFETs (3D-EMG-ISFETs) realized by the post processing of 0.18 µm CMOS.
- the detection of four analytes (pH, Na+, K+, and Ca2+) was reported with excellent sensitivities (58 mV/pH, −57 mV/dec(Na+), −48 mV/dec(K+), and −26 mV/dec(Ca2+)) close to the Nernstian limit, and high selectivity, achieved by the use of highly selective ion selective membranes based on post-processing and integration on CMOS chips.



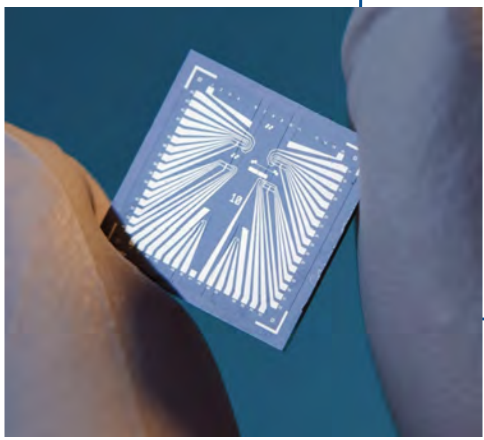
J. Zhang et al, ACS Sens. 2019, 4, 8, 2039-2047, July 8, 2019.

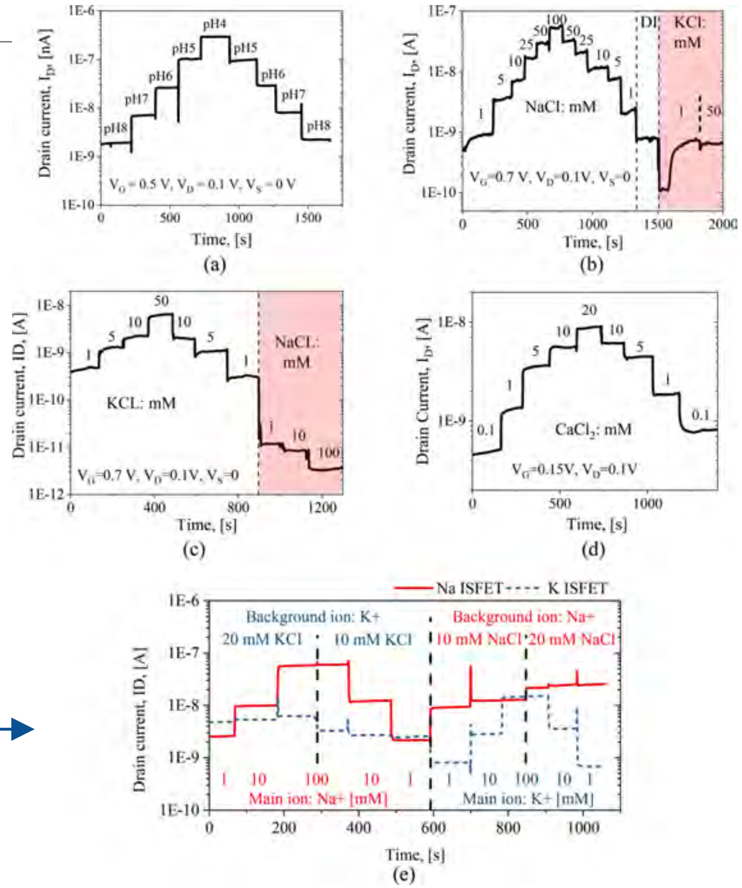
WP1 – ISFET sensors for the detection of pH and electrolytes in human sweat: Lab-On-Skin^{TM} wearable platform (2)

- sub-nanoWatt, selective 3D-EMG-ISFETs as enablers of arrayed Multi-Ion Sensingsensing
- Fully reversible measurements
- Time response < 5s
- Selective simultaneous sensing of #different analytes demonstrated (Na+ and K+)

EPFL's ISFET chips:

- **transferred to CEA-LETI for integration on the flexible CONVERGENCE platform**
- **new coooperation with IUNET for modeling of noise & understanding limit of detection (LoD).**





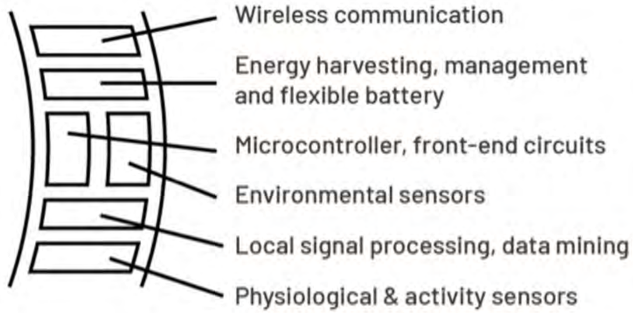
WP2: **Environmental sensors** generations in CONVERGENCE (ETHZ)

- gases (O_3, $NO_{2/x}$, SO_2, CO, CO_2, VOCs), particles (PM2.5, PM10) and relative humidity (R.H.).
- Resolution: according to EC Standards
- Power consumption: ~10µW (incl. ROIC).
- Form factor (size): 0.1-1cm.
- Reporting rate: 1-10 Hz.
- Extensive benchmarking of CONVERGENCE and outsourced gas sensors

(M15)
1st generation of gas sensors for system integration and **early data collection**

(M24)
2nd generation of gas sensors optimized for energy-efficiency **ready for on-foil integration**

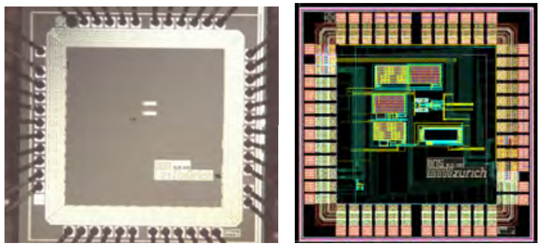
alphasense CO-B4 alphasense NO_2-B4 aeroqual SM-50 (O_3)



WP2: Environmental sensors - Major Achievements

- 4 Portable Sensor Modules Developed (NO_x, NH_3, CO, CO_2) which can communicate with a cell phone via BLE (thanks to on-board nRF51 chips)

ETH zürich UCL ENEA IMT-Bucharest UNIVERSITÀ CAMPUS BIO-MEDICO DI ROMA



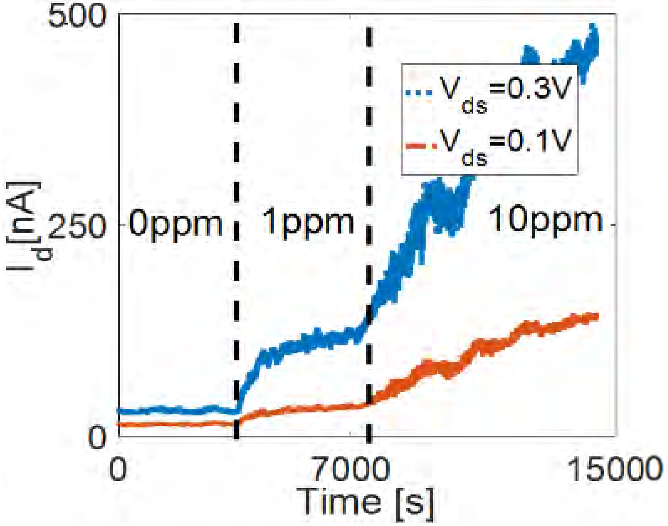
- 1 Sensor Readout IC in 180nm CMOS ETH zürich

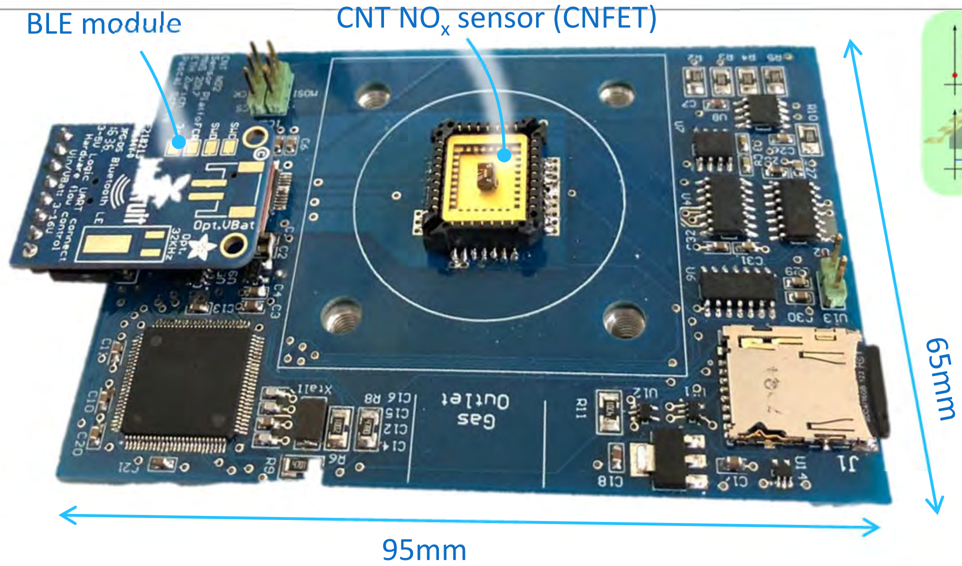
- 1 Integrated Functionalized Multi-Sensor Chip (NO_x, NH_3, CO) for on-foil integration UCL ENEA IMT-Bucharest

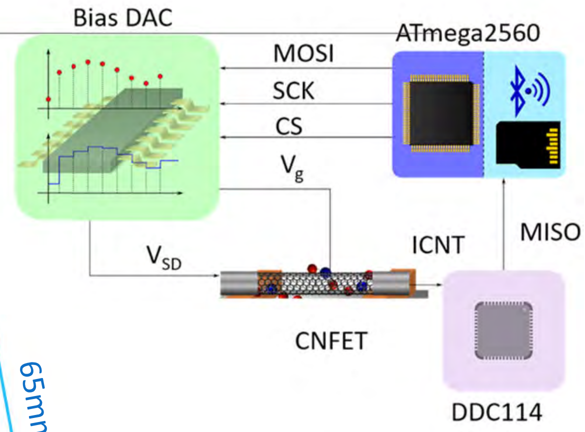
ETH zürich

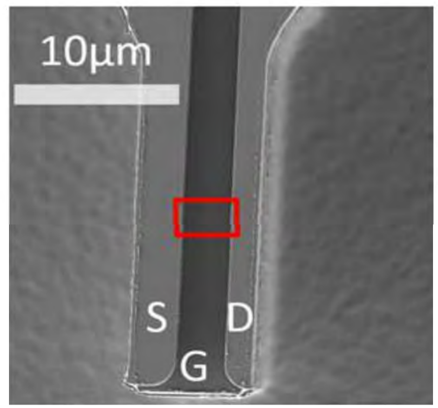
- 1 Comprehensive Survey on Air Monitoring Sensors [Maag *et al.*, IEEE IoT J, 5 (2018) 4857, 10.1109/JIOT.2018.2853660]

WP2: Example of great achievement (ETHZ)







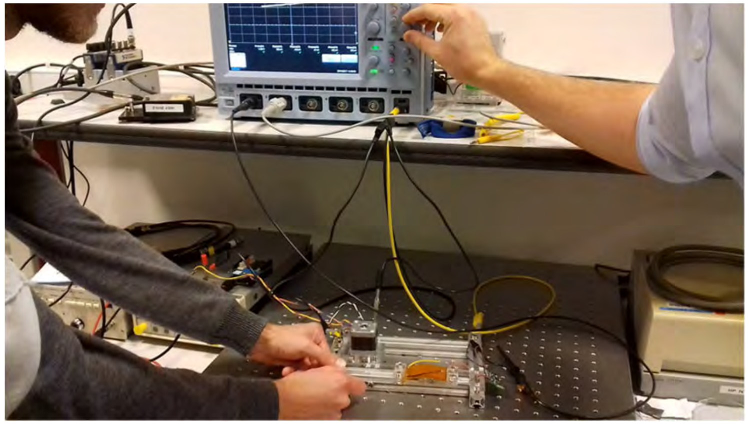


- Portable Carbon Nanotube NOx Sensor, nA to µA range, 20bits resolution, 3.12 kSPS, 5.2 ppm FSR noise factor, 76 mW average power (incl. BLE), 50 ppb NO_2 LoD.
- **Accepted at nanoFIS 2020. Extended paper invited to mdpi Sensors (June 2020)**

WP6: Test platforms and **heterogeneous integration** on flexible substrates (CEA-LETI)

T6.1 IoT platform on a rigid substrate

Generic demonstration platform on a rigid substrate
with Bluetooth Low Energy communication compatible
with different kind of sensors and energy harvesting sources



Rigid **energy harvesters platform**

- Design and fabrication
- Laboratory tests
- Compatible with different energy harvesting sources (light, vibrations, flows,…)

Rigid **sensors platform**

- Design and fabrication
- Laboratory tests
- Data emission in BLE (**bluetooth low energy**) at 10 Hz
- Compatible with different kind of sensors in order to interface with the sensors provided by the partners

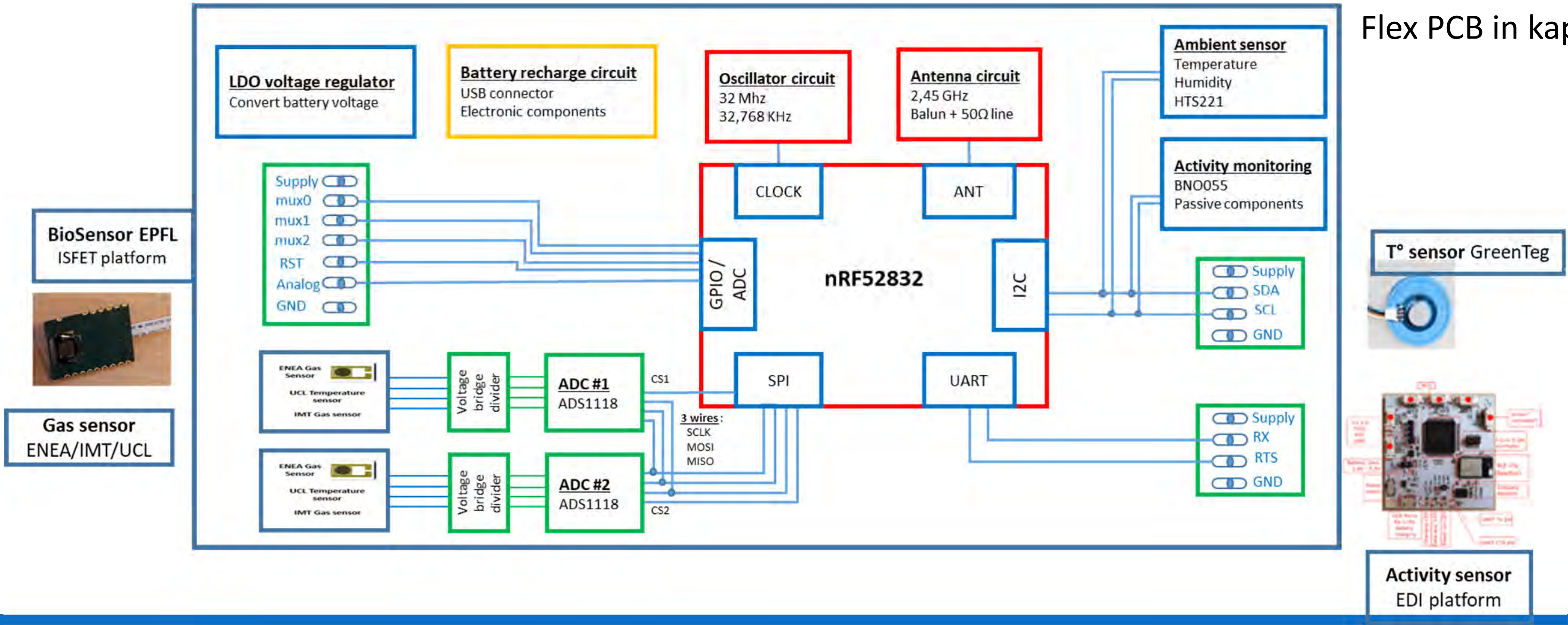
Strong cooperation with partners for the tests

- EPFL; UCL; IMT; ENEA; G-INP; IUNET

WP6: Test platforms and **heterogeneous integration on flexible substrates** (CEA-LETI)

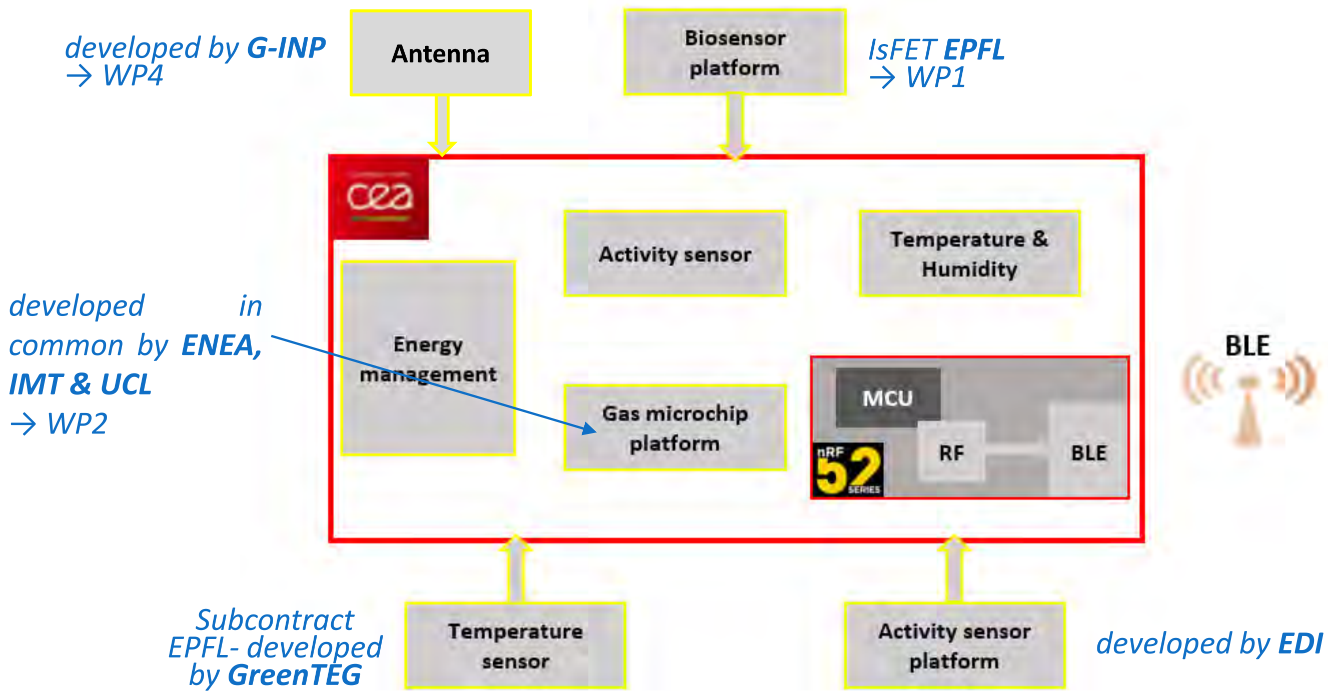
T6.2 IoT platform on a flexible substrate: architecture & design

Flex PCB in kapton



WP6: Test platforms and **heterogeneous integration** on flexible substrates (CEA-LETI)

T6.2 IoT platform on a flexible substrate



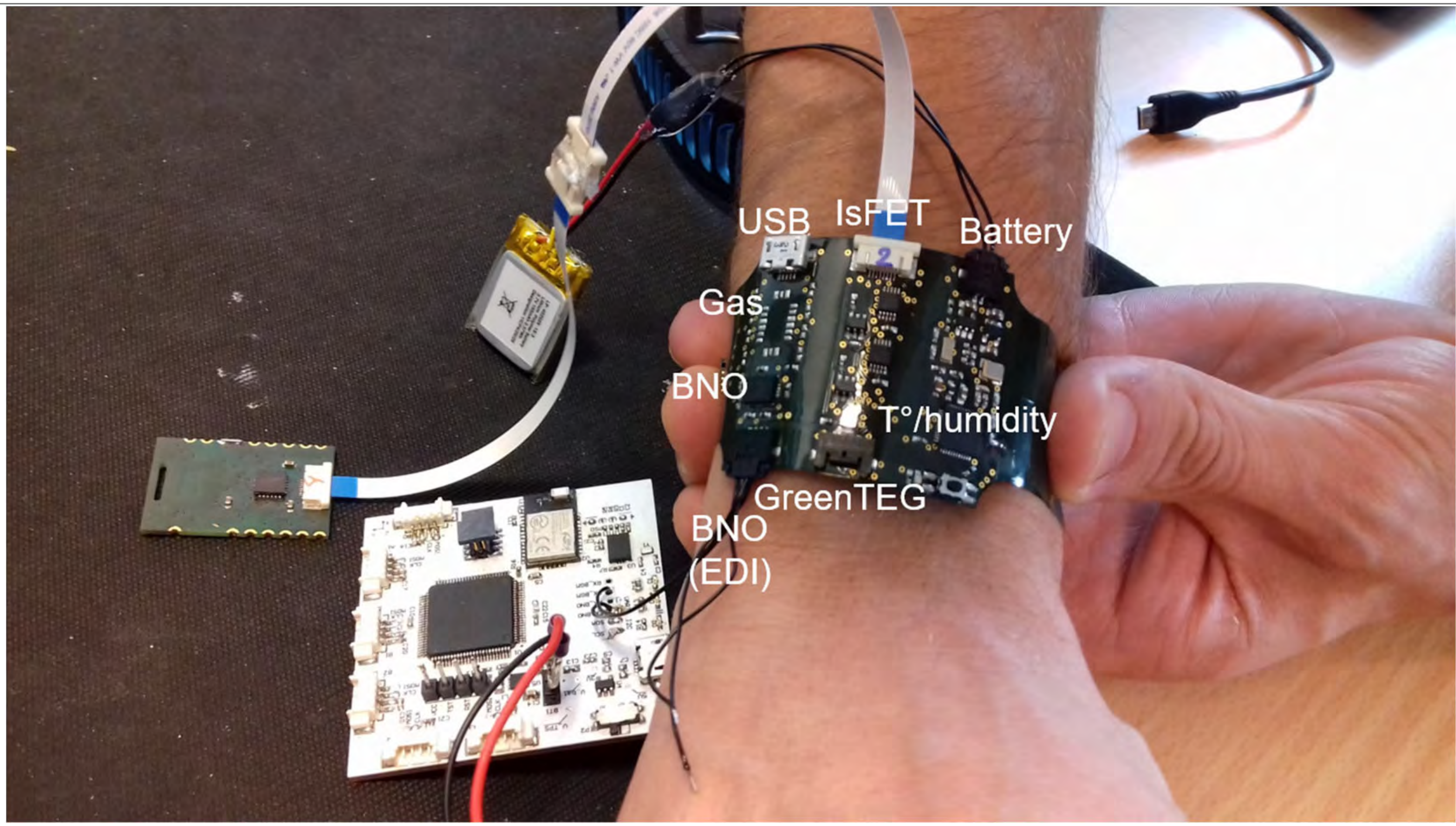
Design and fabrication Flex PCB in kapton

- Bluetooth Low Energy 2.4 GHz
- Antenna circuit designed by GINP.
- Datas visualization in real-time with specific App

Laboratory tests with:

- Embedded activity, T° and humidity sensor
- EDI activity platform
- IsFET from EPFL
- T° sensor from GreenTEG

Ongoing: experiments and validation tests with the flexible substrate platform @ CEA-LETI



WP6: deliverables and major milestones

Deliverables

D6.1 Communicating Testing platform for energy harvesters and sensors available –*[M6]* ***Done:* object + report**

D6.2 Test reports on first test platform with energy harvesters and sensors – *[M12]* ***Done:* report**

D6.3: system definition for a IoT platform on flexible support for wearable applications [M14]→ ***Done:* report**

D6.4: Proof of concept of highly flexible sensor node available [M36] → ***Done:* report**

D6.5: Generic ioT platform on flexible substrate available [M24] → ***Draft objects (+ report)***

Major Milestones

MM6.1 WP6 Test platform for sensors and Energy harvesters available *[M6]* → ***Achieved:* objects**

MM6.2 WP6 Test platform for sensors and Energy harvesters available *[M24]* → ***In progress (platform achieved, tests with partners sensors in progress)***

Extension work objectives (+6 months) in WP6

- 02/20: EDI platform test at CEA-Leti
- 03/20: Bonding test of gas sensors dies at CEA-Leti
- 04/20: Platform delivery to EDI and EPFL for tests by partners
- 05/20: Final integration on the flexible demonstrator at CEA-Leti (wire bonding)
- 06/20: Gas sensor tests & conclusion
- 09/20: Final report with validations

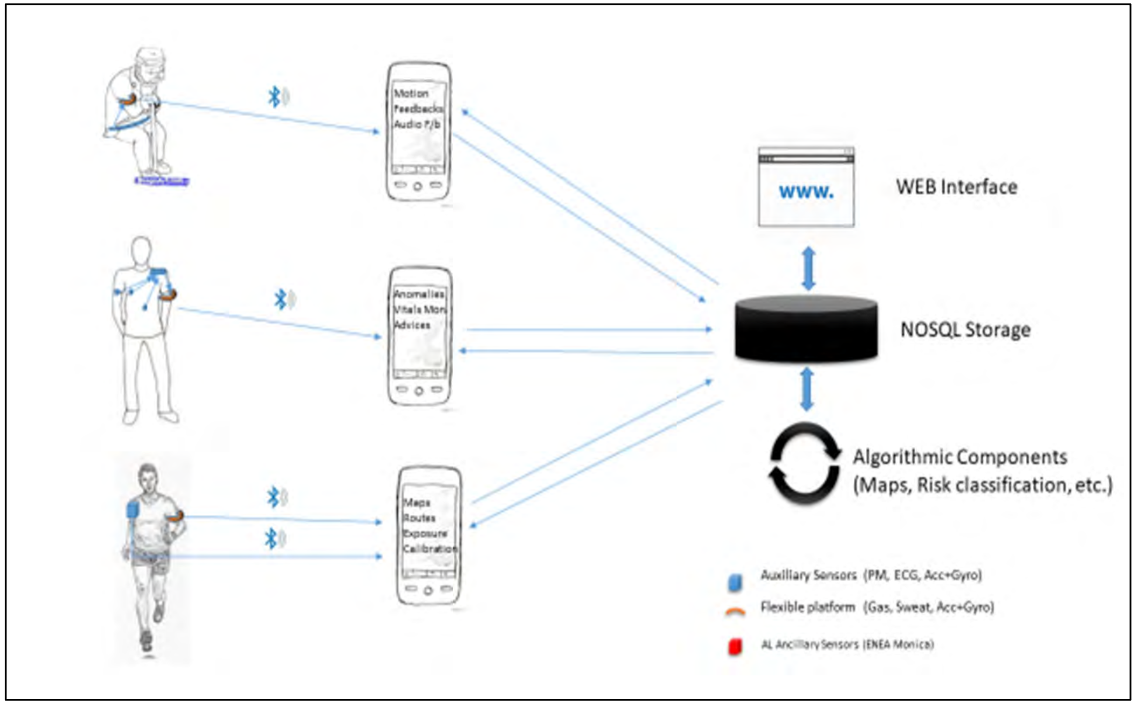
Wp7: Application scenarios and validations (ENEA)

3 Different scenarios and unified framework: development using baseline sensor technology

Frailty: Monitoring frail people gait for assisted living and rehabilitation purposes based on IMU sensors.

Coronary Artery Disease:
Monitoring CAD patients with non-contact wearable ECG for extended follow up

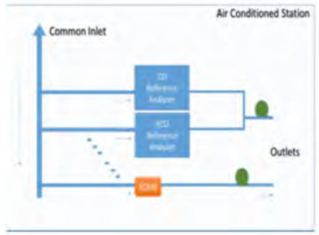
Active Life: Promoting & Improving Active life for asthma patients, elderlies and active population removing air pollution barriers

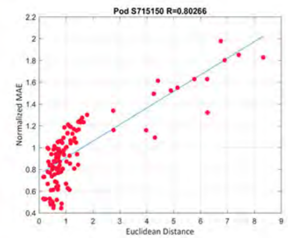


WP7: Progress and major achievements

- **ENEA team:** *S. De Vito, T. Polichetti, E. Esposito, E. Massera, S. Ferlito, F. Formisano, B. Alfano, M. Miglietta*
- **Strong cooperation** with project partners for
  - sensors testing by making available chemical sensors controlled atmosphere laboratory and hosting research visits form partners: EPFL; UCL; IMT; ENEA; G-INP
  - validation set ups and components with EDI, UCBM, UNICA, IUNET, Tagliaferri

- **NO2 Graphene based sensor**
  - Design and fabrication
  - Laboratory tests
- **Electrochemical sensors based mobile AQ monitor**
  - Laboratory tests
  - Integration & Long term colocation field tests
  - IoT Backend development
- **Demonstration of feasibility of long term operation of low cost sensor based mobile platforms**
  - Advanced calibration strategy design implementation and testing
  - Network calibration strategy implementation and testing





Active Life: Example of validation

Functional/proof-of-concept Validation tests with first version ancillary devices

45 Users

30 cities/towns in 9 Italian Regions

1 month test usage x User

WP7: Deliverables

Deliverables

- D7.1 Requirements Definition Document for Wearable systems –[M6] Done, report
- D7.2 Validation Planning for Active Life Scenario– [M24] Done, report
- D7.3: Validation Planning for CAD Scenario– [M24] Done, report
- D7.4: Validation Planning for Frailty Scenario [M24] Done, report
- D7.5 Validations Report on wearable systems [M32] → In progress [6 month extension -> M42]

Rationale for 6 month project extension (September 30th, 2020)

- **Finalization/completion of 4 key deliverables in WP1, WP2, WP6 and WP7** (particularly concerning the validations of wearable sensor applications in healthcare scenarios and of the heterogeneous integration flexible demonstrations) with high quality content
- **Use at best of all remaining resources for the work mentioned at point I** as well as to better prepare the future
- Organization of **two final dissemination events in September 2020**; a special session at Eurosensors 2020 in Italy, and, a CONVERGENCE summer school by ENEA
- Preparation and submission of **a Consortium wide review paper with our major achievements** in the Journal Sensors of MDPI Sensors (www.mdpi.com/journal/sensors), in a Special Issue of Sensors (Guest Editor, Fernanda Irrera, Uni Roma Sapienza) on Wearable/Wireless Body Sensor Networks for Healthcare Applications.
- Italian partners have faced multiple challenges in starting and carrying activities without a distributed budget and a very late confirmed (signed) project.

CONVERGENCE contribution to CSA FET Flagship Health EU

- **12 partners of CONVERGENCE active in building Health EU**

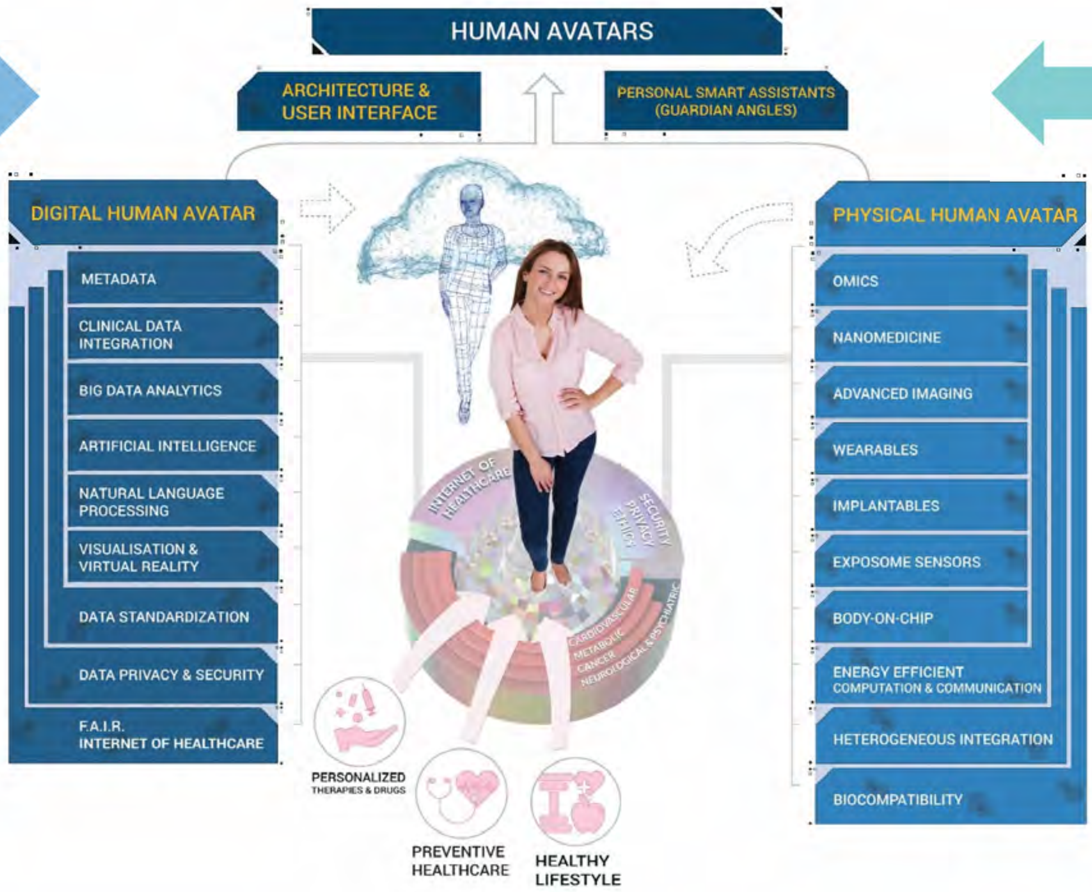
The missing link of the 21st century for breaking barriers between Medical Knowledge Creation and Medical Knowledge Application

Creates a P3 Citizen – Human Avatar – Clinical Professional triangle

© Health EU

Human Avatar Integrative Technology Platform

Big Data Analytics



Data Generator Technologies

Conclusions: scientific dissemination and project valorization

Publications (> 40)

- International peer reviewed journals
- International peer reviewed conferences
- National conferences
- Planned in extension: 1 invited review paper of CONVERGENCE in MDPI Speciall Issue Journal

Patents

- 2 patents (UTT - Tallin): impedance analysis by digital excitation; quantization of response signal differences
- 1 patent pending (EPFL + Xsensio): Troponin wearable sensors

Sessions and outreach

- Special session at NEWCAS 2018 (Joint)
- CONVERGENCE strong involvement in www.health-eu.eu proposal
- Special Session @ Eurosensors 2020
- Convergence Summer School (organized by ENEA), 6-9 September, Lecce, 2020.

Conclusions

- CONVERGENCE made great scientific and technical progress in both wearable (bio and gas) sensor developments, their integration on heterogeneous flexible platform and validations in defined scenarious
- All milestones are achieved
- 4 final deliverables needs extra-work (~6 months) for completion with existing resources
- Convergence parnters contributed to Health EU CSA FET Flagship (was on waiting list of funding, all thresholds passed): possible follow-up in Horizon Europe
- Two final dissemination events planned in Septmeber 2020: special session @ Eurosensors 2020 and Convergence Summer school.

CONVERGENCE WP1 – WP4 activities

Luca Selmi – IUNET Consortium

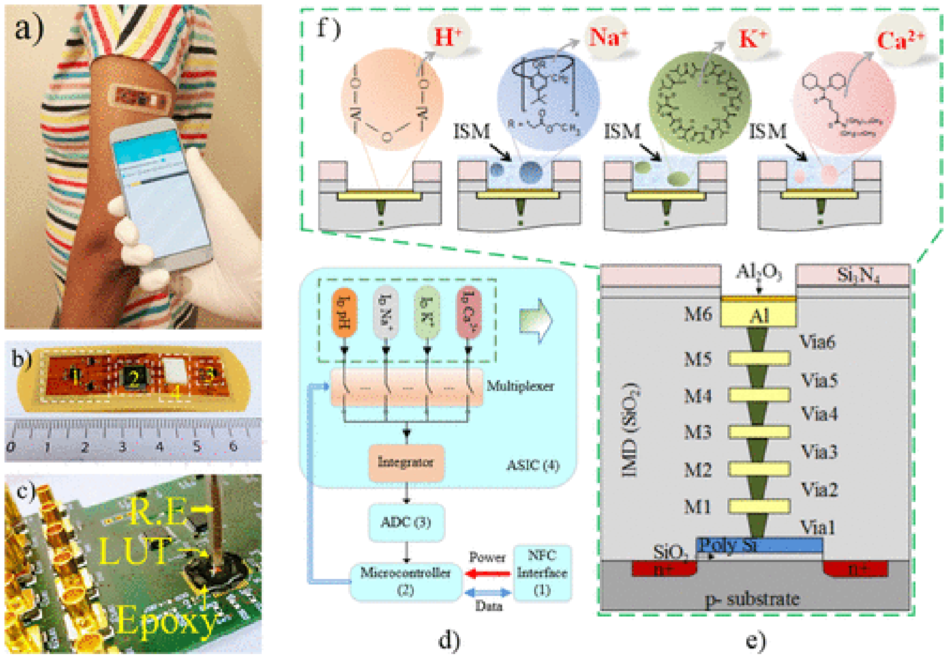
WP1: Physico-physiological sensors (lead: EPFL)

- **Device level:**
  - EPFL: Multisensor platfom (pH, Na+, Cl-, K+, Ca2+ and troponin)
  - UniUD+UniMoRe: Sensor modeling and simulation at device and SPICE level (DC, AC, transient, noise)
- **Circuit level**
  - EPFL: Integrated readout for Multisensor platform
  - UniBO: Enery efficient ultra low power multi-parameter event-driven readout
- **System level**
  - EPFL: Sweat Biomarker Sensor Incorporating Picowatt Ion Sensitive Field Effect Transistors
  - UCBM: Wearable ECG with electronics and electrodes integrated in one device

WP1 – ISFET sensors for the detection of pH and electrolytes in human sweat: Lab-On-Skin^{TM} wearable platform (1)

Main achievements:

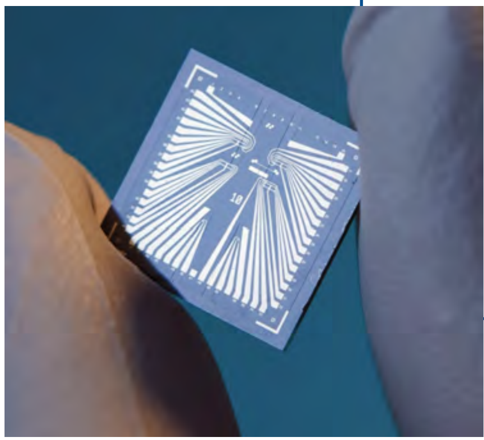
- **A multianalyte sensing platform** that incorporates high performance, high yield, high robustness, three-dimensional-extended-metal-gate ISFETs (3D-EMG-ISFETs) realized by the post processing of 0.18 µm CMOS.
- **Detection of four analytes (pH, Na+, K+, and Ca2+)**
- **Excellent sensitivities,** close to the Nernstian limit
- **High selectivity with highly selective membranes**

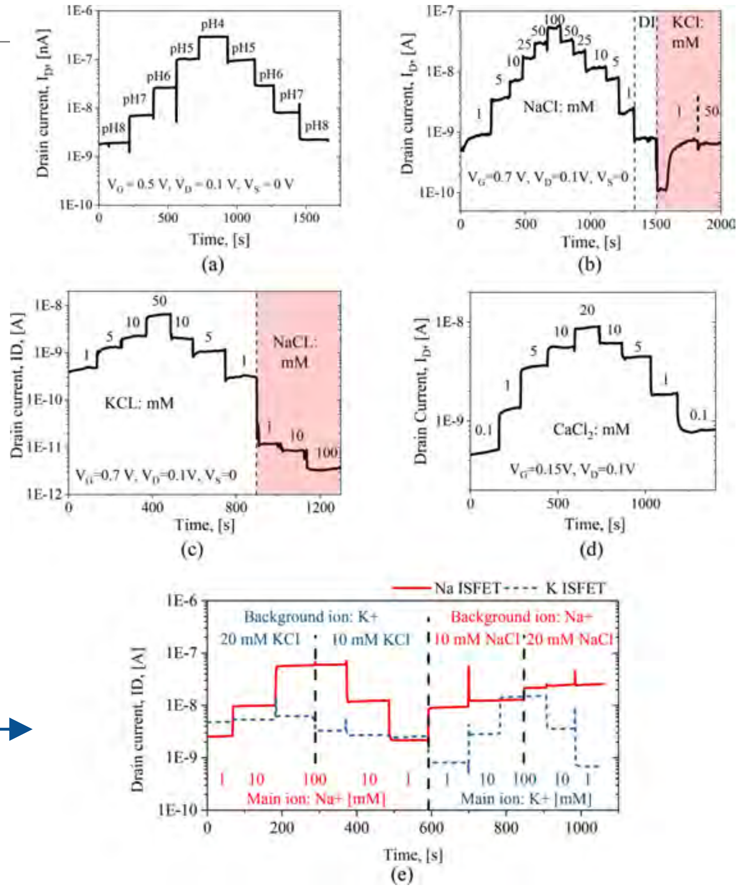


J. Zhang et al, ACS Sens. 2019, 4, 8, 2039-2047, July 8, 2019.

WP1 – ISFET sensors for the detection of pH and electrolytes in human sweat: Lab-On-Skin^{TM} wearable platform (2)

- sub-nanoWatt, selective 3D-EMG-ISFETs as enablers of arrayed Multi-Ion Sensing
- Fully reversible measurements
- Time response < 5s
- Selective simultaneous sensing of #different analytes demonstrated (Na+ and K+)



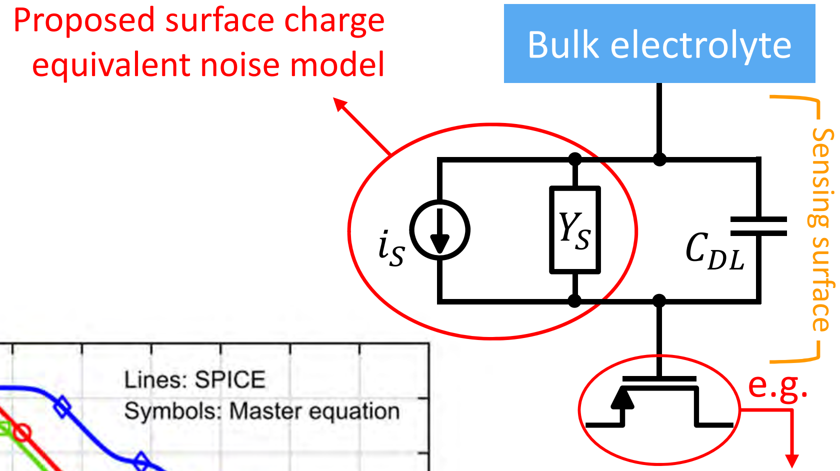


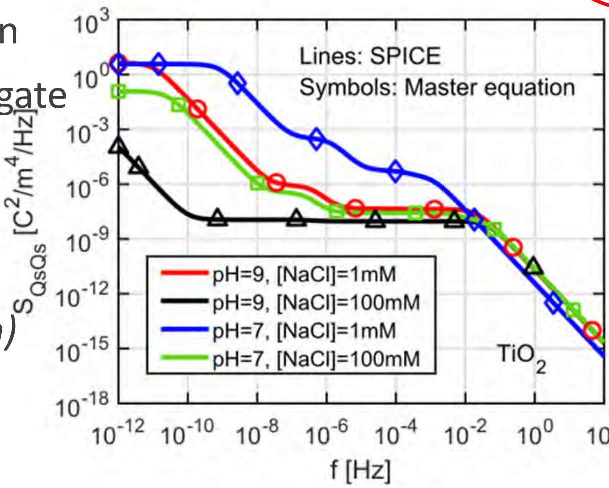
EPFL's ISFET chips:

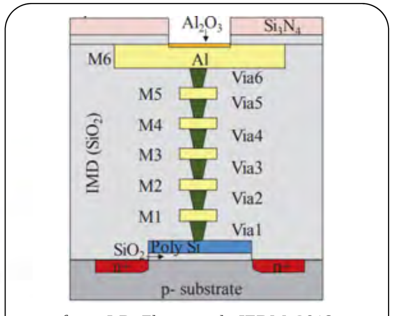
- **transferred to CEA-LETI for integration on the flexible CONVERGENCE platform**
- **new coooperation with IUNET for modeling of noise & understanding limit of detection (LoD).**

WP1: Modeling of potentiometric ion sensors (IUNET UD+MoRe): last year

- **<u>Past activity:</u> DC, AC and transient Verilog-A model of ISFETs**
- **<u>New:</u> Physical model for the surface charge** induced by binding of ions/analytes
  - Arbitrary number of chemical reactions (binding/unbinding) can be included
  - **Computes the chemical noise** (full spectrum) via master equation
  - **Provides the threshold-voltage** shift of MOSFETs with extended gate
- **<u>New:</u> Physical model for ion-selective membranes**
  - DC model with fixed charge, free ions and ionophores
- **<u>New:</u> Circuit model of** the surface impedance and noise *(see sketch)*
  - **Add-on to any MOSFET compact model**
  - Computes threshold voltage shift / AC impedance /noise PSD







from J-R. Zhang et al., IEDM, 2018

WP1: Impedance sensing (IUNET-UNIBO)

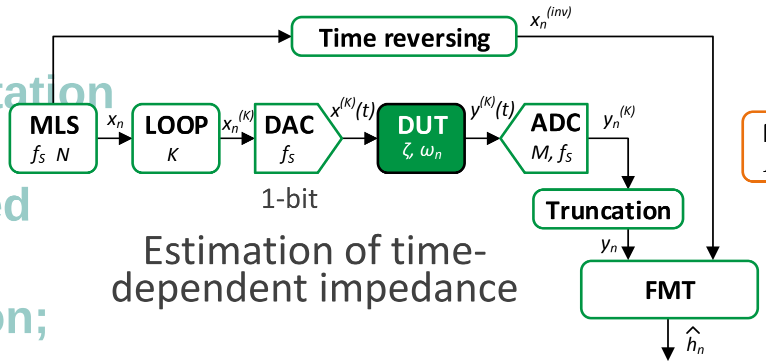
Energy efficient event driven read-out front-end

Ultra-low power ADC and specific circuits** for **activity, multi-parameter sweat sensors** and **body temperature

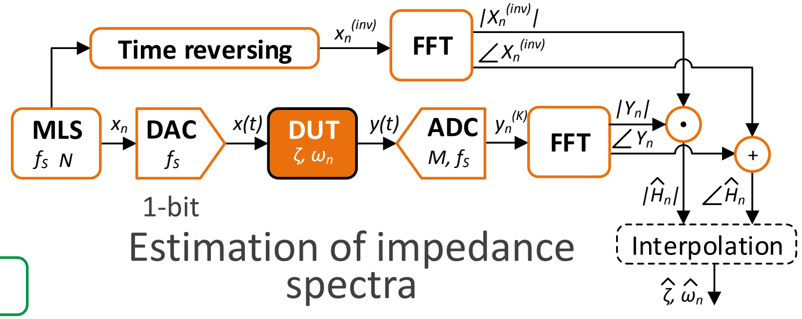
The targets:

- Based on digital noise excitation
- Ultra low power;
- Implementable on embedded platform;
- Fast and real-time estimation;
- Enabling phase sensing.

- Enabling reduced cost for complex wearable devices



Estimation of time-dependent impedance



Estimation of impedance spectra

Energy-efficient implementation of two algorithms for the real-time estimation of time-dependent impedance and impedance spectrum.

Energy efficient event driven read-out front-end & ultra-low power ADC and specific circuits for activity, multi-parameter sweat sensors and core body temperature

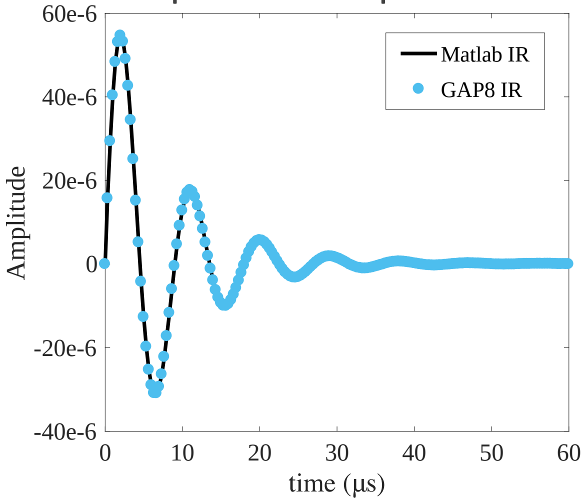
Last year results (IUNET-UNIBO)

Implementation on the energy-optimized digital processing GAP8 platform

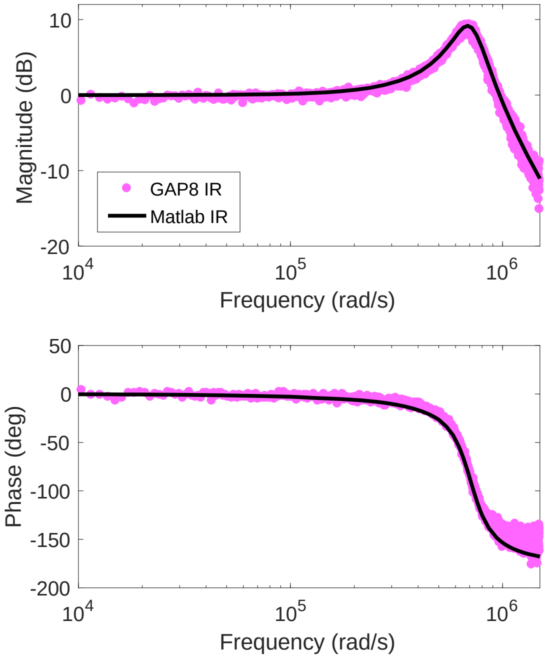
First characterization in lab.

GAP8 platform

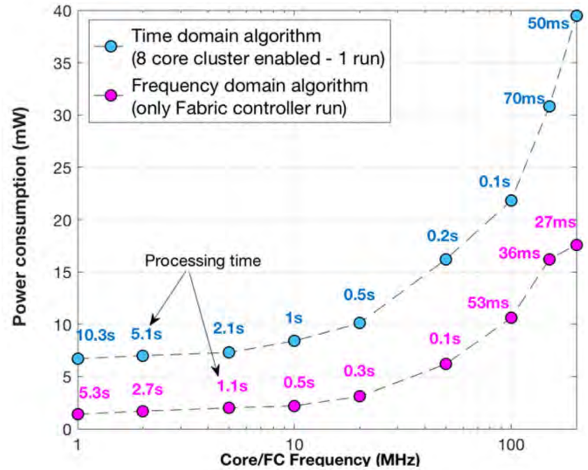
Estimation of time-dependent impedance



Estimation of impedance spectra



Power consumption and processing time



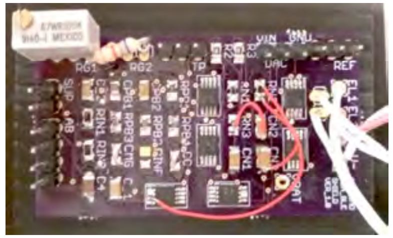
WP1: UCBM overall scientific results

Date	Results
April 2017	**First** prototype of the **ECG contactless sensor** Supply Voltage: 6V Dimensions: 65 cm^2 Separated electrodes 1
September 2018	**Second** release of the **ECG sensor** Supply Voltage: 3,6V Dimensions: 50x28 mm Separated electrodes 2
March 2019	Starting of the **clinical experiment** in CAD scenario
January 2020	**Final device of the ECG sensor** **Electronics and electrodes integrated in the same device** 3

Measurements in the UCBM hospital (Unit of Cardiosurgery)

1

2



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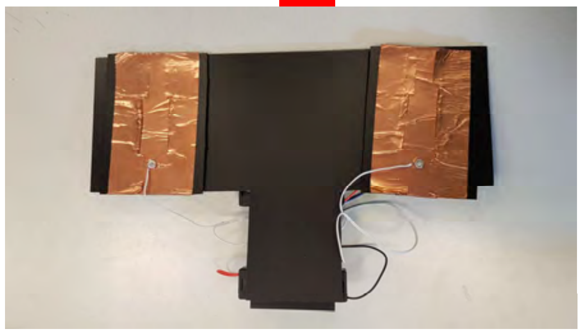


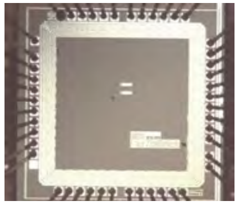
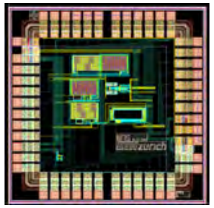
WP2: Environmental gas sensors (lead: ETHZ)

- Device level:
  - ETHZ: CNT-based Nox sensor
  - UniBO: Sensor modeling and simulation at device level (DC, AC, transient, noise)
  - UCL:
- Circuit design level
  - ETHZ: Integrated readout for 4 channels Nox sensor
- System design level
  - ETHZ, ENEA, UCL, IMT: 4 Portable Sensor Modules Developed (NO_x, NH_3, CO, CO_2)
  - UCL, ENEA, IMT: 1 Integrated Functionalized Multi-Sensor Chip (NO_x, NH_3, CO) for on-foil integration
  - ALL: One comprehensive Survey on Air Monitoring Sensors

WP2: Major Achievements

- 4 Portable Sensor Modules Developed (NO_x, NH_3, CO, CO_2) which can communicate with a cell phone via BLE (thanks to on-board nRF51 chips)

ETH zürich UCL ENEA IMT-Bucharest UNIVERSITÀ CAMPUS BIO-MEDICO DI ROMA

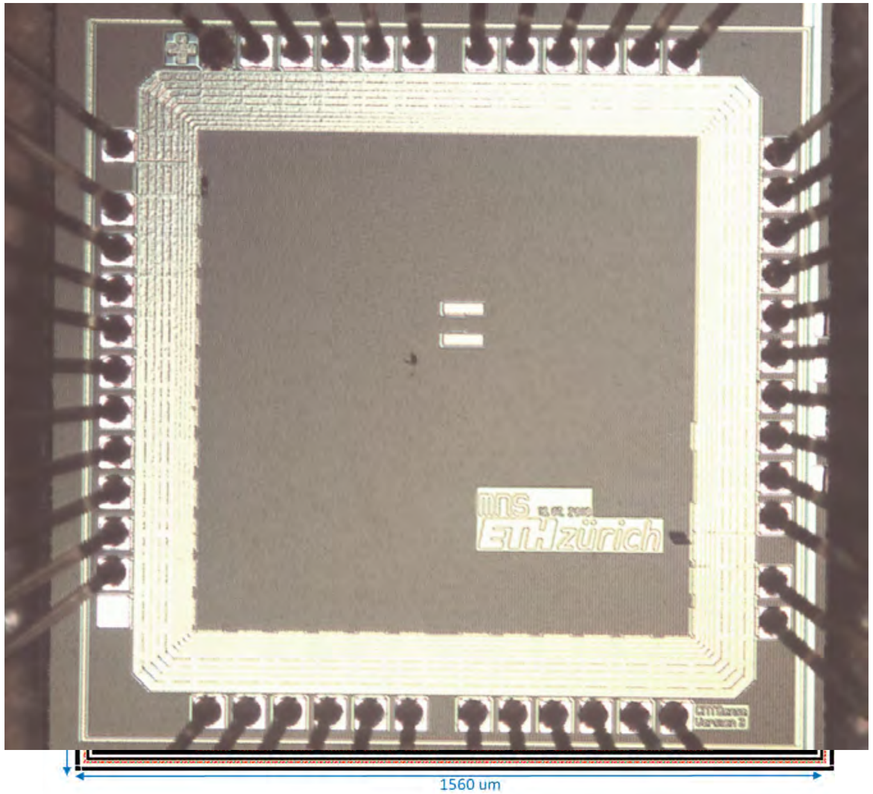
- 1 Sensor Readout IC in 180nm CMOS ETH zürich

- 1 Integrated Functionalized Multi-Sensor Chip (NO_x, NH_3, CO) for on-foil integration UCL ENEA IMT-Bucharest

ETH zürich

- 1 Comprehensive Survey on Air Monitoring Sensors [Maag *et al.*, IEEE IoT J, 5 (2018) 4857, 10.1109/JIOT.2018.2853660]

ETHZ-MNS: Scientific highlights 2019



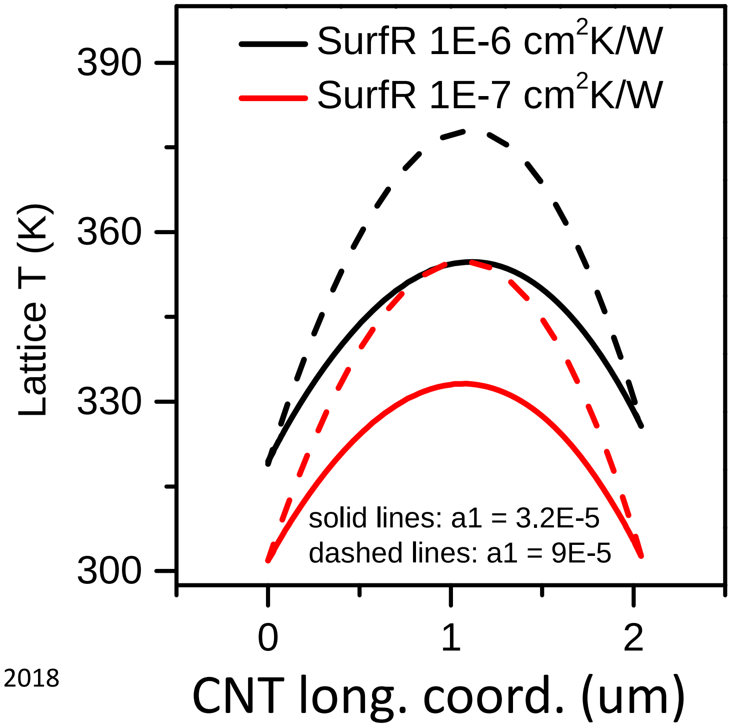
- **Carbon nanotube NOx gas sensor** ASIC in UMC 180nm CMOS (tape-out Jul 2018, chips back Mar 2019)
- Up to 4 multiplexed CNT sensor channels
- Novel TIA architecture, 160nW, 56dB SFDR, 109dBOhm – **Accepted at ISCAS 2020**
- SAR ADC, 7.57bit ENOB, 0.22pJ/conv. FoM
- Programmable (8bit) Ambipolar Gate bias (-5,5)V based on Dickson charge pump
- Programmable (6bit) V_{sd} bias
- **Blocks tested. Full-system demonstration with CNT gas sensor in progress (June 2020)**

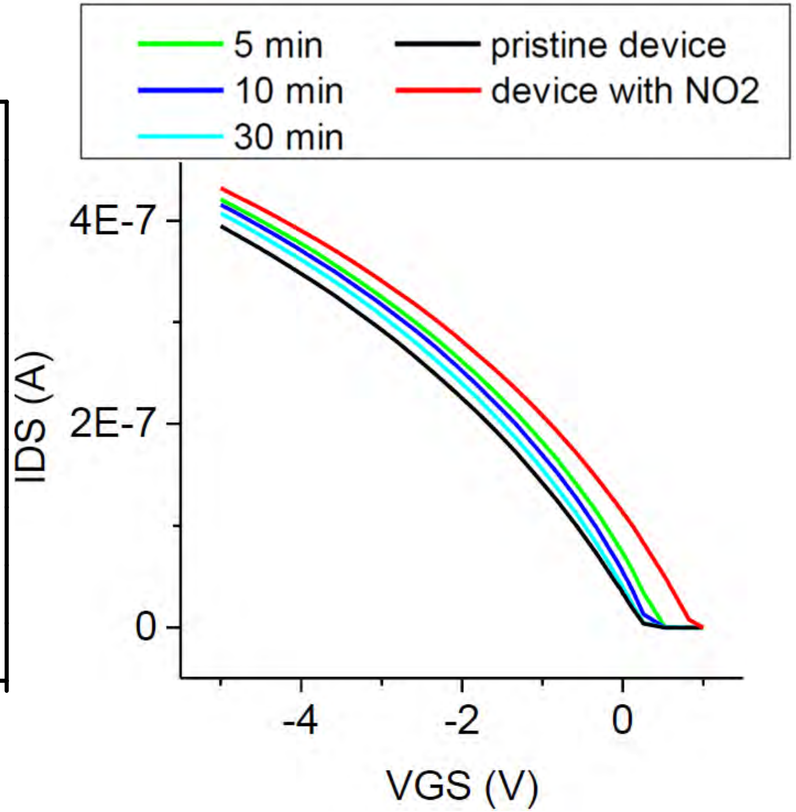
WP2: Sensor device M&S (IUNET-UniBO)

Goal: Multi-physics simulation through TCAD tools (SDevice by Synopsys) of the $NO_{2/x}$ CNT sensors by ETHZ (T2.1)

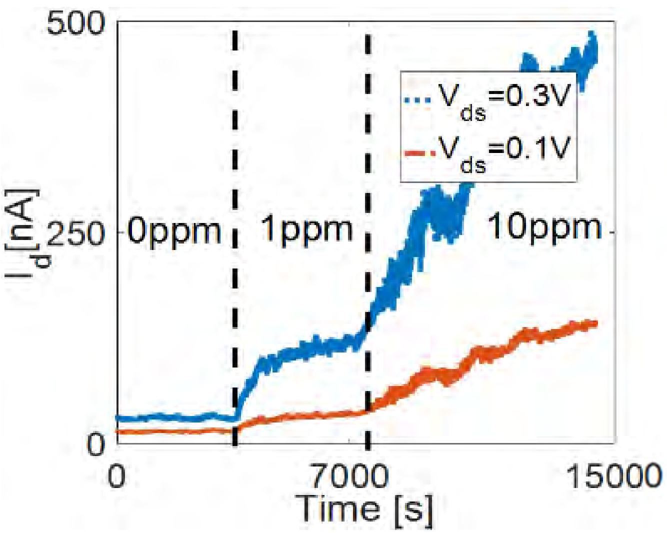
Last year results
electrothermal simulations of CNT self-heating, accounting for temperature-activated desorption of gas molecules and CNT reset process

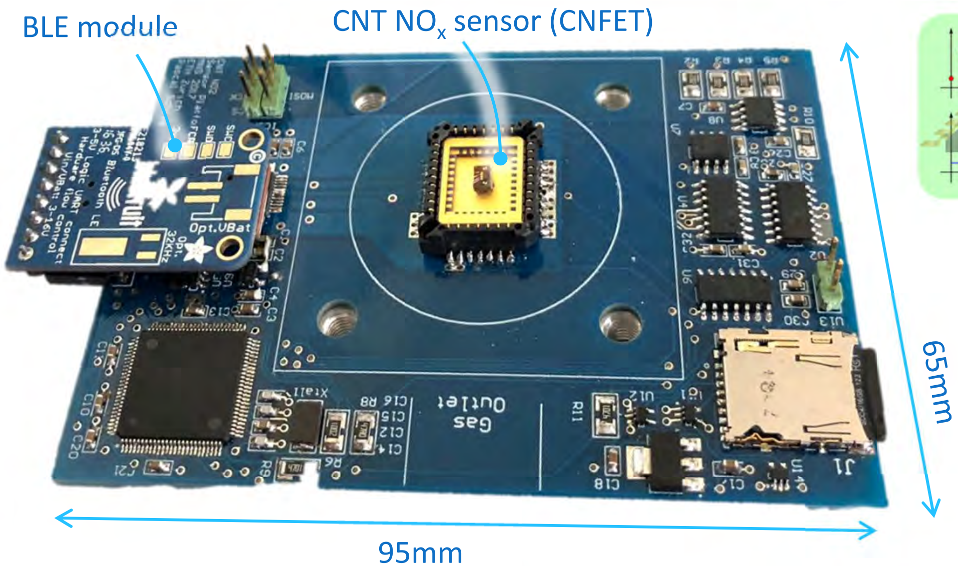
UniBO – ETHZ joint publication.: S. Carapezzi et al., ESSDERC 2018

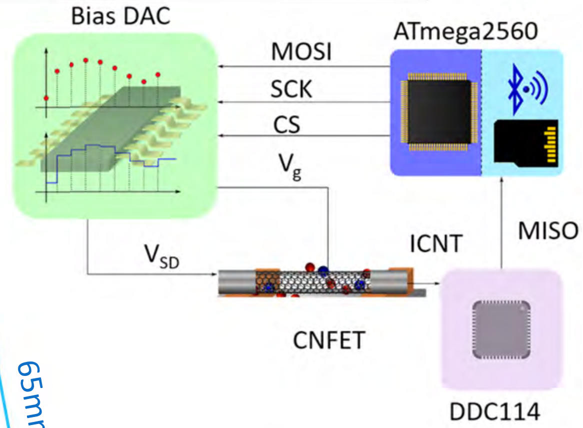


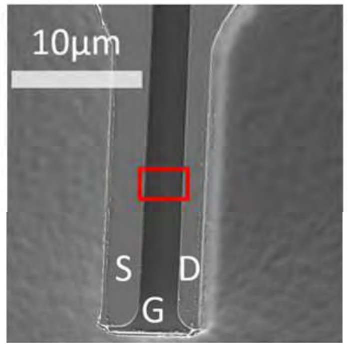


ETHZ-MNS: Overall scientific results



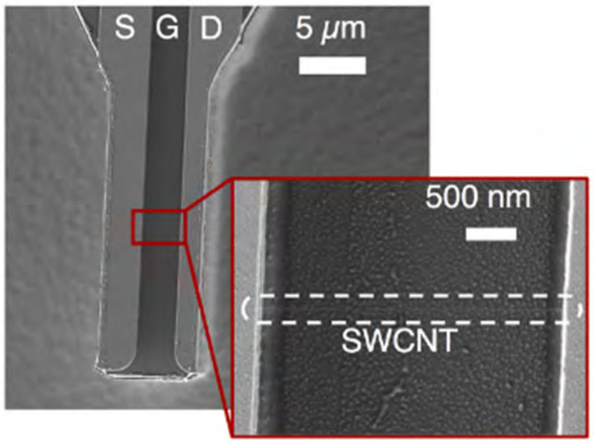


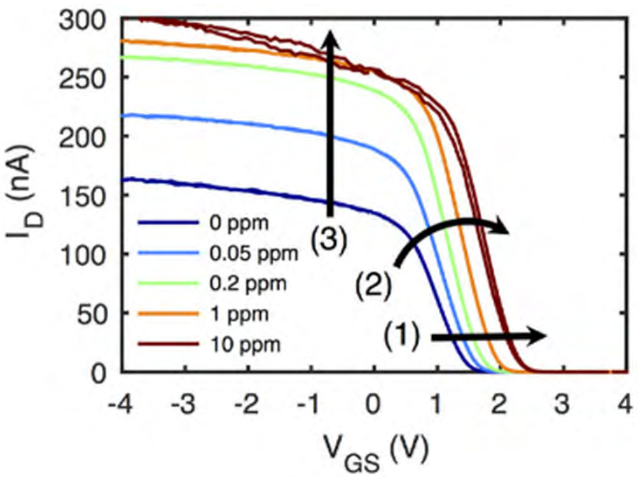


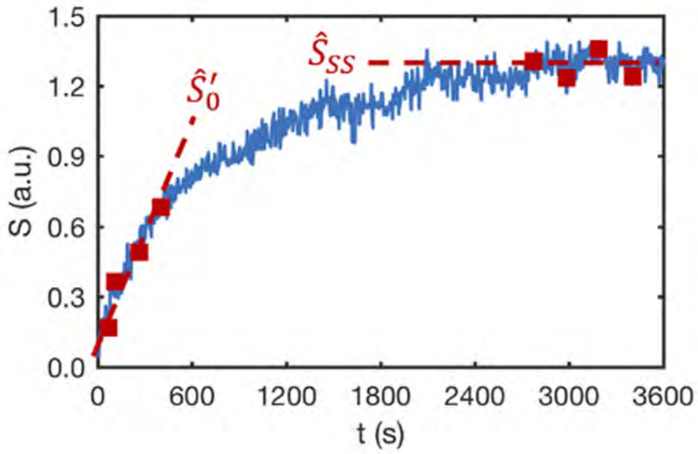


- **Portable Carbon Nanotube NOx Sensor**, nA to µA range, 20bits resolution, 3.12 kSPS, 5.2 ppm FSR noise factor, 76 mW average power (incl. BLE), 50 ppb NO_2 LoD.
- **Accepted at nanoFIS 2020. Extended paper invited to mdpi Sensors (june 2020)**

ETHZ-MNS: Overall scientific results



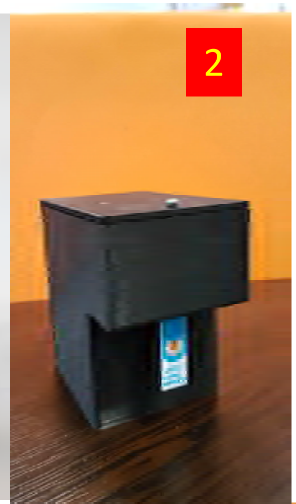




- Initial-slope and steady-state sensing strategies have been systematically compared
- **Initial-slope reduces response time from ~30min to a usable 5min. It is also superior in linearity. RMS ~12ppb NO_2**
- **Results published in Satterthwaite *et al.*, SNA B 297 (2019) 126674** [10.1016/j.snb.2019.126674]
- **Two successful doctoral dissertations at ETHZ**
  - Eberle [10.3929/ethz-b-000391248] on *Ultra-clean suspended carbon nanotube gas sensors*
  - Jenni [10.3929/ethz-b-000394631] on *Optimization of Contacts in Suspended CNTFETs*

WP2: UCBM overall scientific results

Date	Results
April 2017	**First** release of the CO_2 sensor Supply Voltage: ±6V Input Signal: Triangular Wave ±1V Dimensions: 15x12,5x6 cm + cables + external power supply — 1
October 2017	**Second** release of the CO_2 sensor Supply Voltage: ±1,8V Input Signal: Triangular Wave ±1V Dimensions: 8x8x1.8 cm (including battery and electrochemical cell) — 2
July-August 2018	**Calibration at ENEA laboratories** RMSECV of 192 ppm; measure duration 30” — 3
January 2020	**Final device** **Calibrated, ready to use, managed by smartphone** — 4



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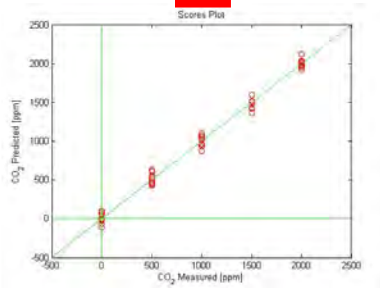


UCL: Characterization of UCL and ENEA devices

- The resistance interface has been used for characterization into the gas chamber.
- The characterization of the functionalized PPy-based dies (from Umons) have shown a detection threshold of 500 ppb to NH_3. The goal is 100ppb. Fig.1 shows an example of measurement.
- The graphene-based dies (from ENEA) have a detection threshold of 50 ppb (see fig.2). The objective is 10 ppb.

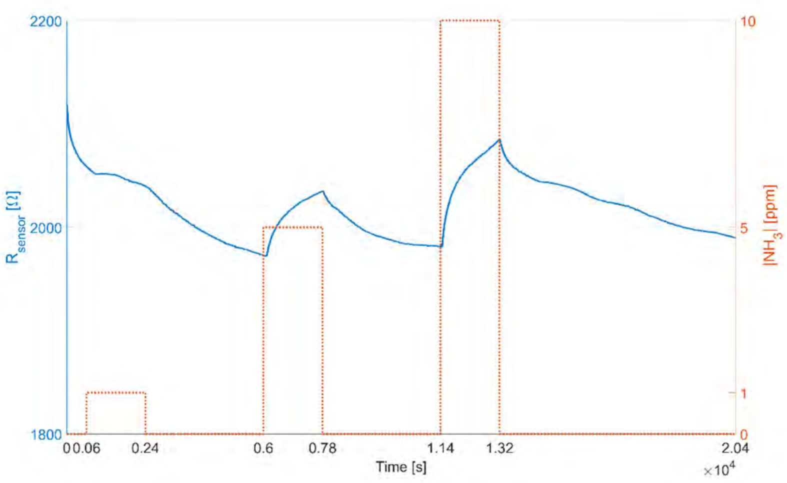


Fig.1. Response of a polypyrrole sensor to 1, 5 and 10ppm of NO_2 in air with 50% RH and a flux of 2nlpm.

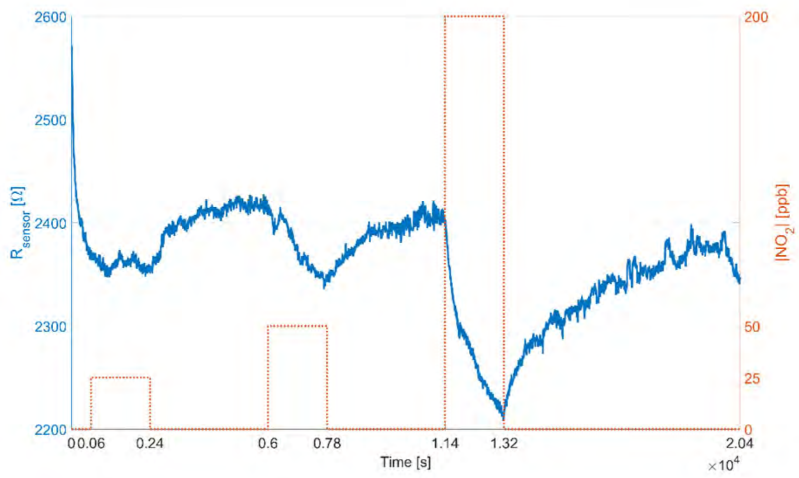
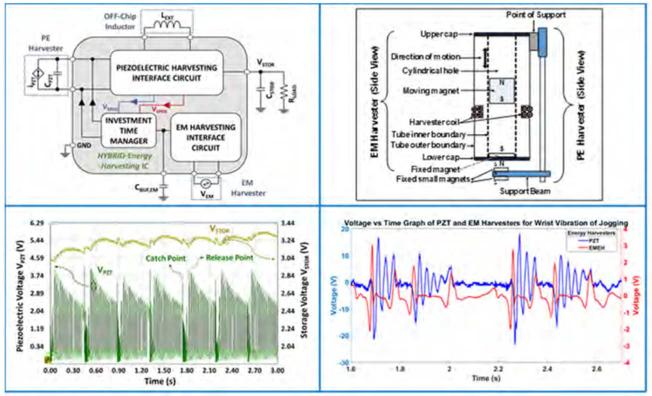


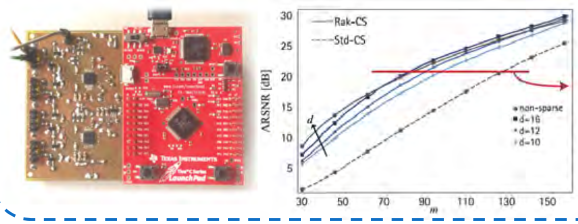
Fig.2. Response of a graphene sensor to 25, 50 and 200ppb of NO_2 in air with 50% RH and a flux of 2nlpm.

WP3: Energy Management (lead: IUNET)

WP3:Major achievements

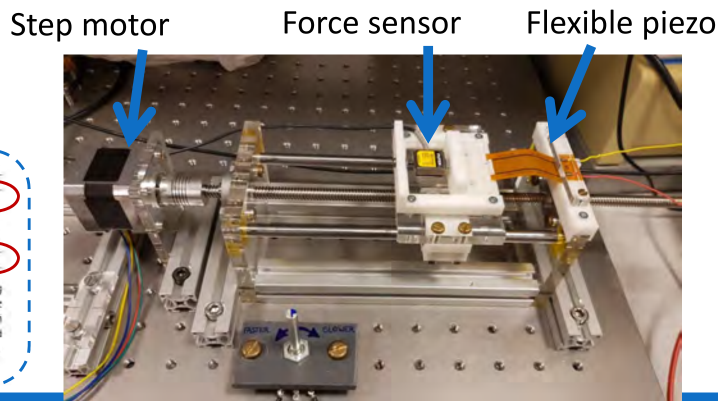
- **Development of ASICs**
  - Low-power energy-efficient interface IC in 180 nm for synergistically harvesting from piezoelectric and electromagnetic harvesters (**METU**)
  - Battery management IC, voltage regulation and wireless charging in 0.35 µm CMOS (**IUNET**)
- **Development of micropower management modules**
  - Emphasis on multi-source energy harvesting in sensor nodes (**IUNET**)
- **Development of electromechanical harvesters**
  - Optimization of frequency up-conversion properties of EM and PZT Harvesters (**METU**)
  - Development of automatic test-benches for flexible piezoelectric transducers (**G-INP**)
  - Piezoelectric Force Microscopy) characterization of Piezoelectric nanowires (**G-INP**)
  - Validation of models of piezoelectric composites (ZnO NWs in polymer matrix) (**G-INP**)
- **Energy management at the acquisition system level** based on microcontrollers for the acquisition/decoding of ECG signal with Compressed Sensing for reducing energy usage (**IUNET**)





	d	m_{min}	BSR	ESR
sparse	4	148	1.13	41.27
sparse	8	129	1.20	30.85
sparse	10	98	1.48	33.71
sparse	12	90	1.61	31.38
sparse	16	83	1.75	27.28
sparse	20	85	1.60	[illegible]
non-sparse	256	85	1.51	1.51

Bit Saving Ratio (**BSR**) and Energy Saving Ratio (**ESR**) are the reduction achieved by the (sparse) Rak-CS with respect to Std-CS in terms, respectively, of number of bits and energy required for measurements encoding.



New bending characterization set-up available at G-INP

WP3: Power/Energy Management

Partner contributions

IUNET:

- Development of a **power management ASIC**, with voltage regulation capabilities, battery management and wireless charging, interfaceable with unregulated energy harvesting ASICs (IUNET-UNIUD)
- Development of **battery management modules** based on off-the-shelf components interfaceable with energy harvesting circuits (IUNET-UNIUD)
- **Development of PCB modules** including single- and multi-source energy harvesting ASICs (IUNET-UNIBO)
  - Tested energy harvesting with 1st CONVERGENCE sensor board
- **Acquisition system** based on conventional microcontroller for the acquisition/decoding of ECG signal based on Compressed Sensing for reducing energy requirements in data acquisition and transmission (IUNET-POLITO/UNIBO):

WP3: Energy management – (IUNET UNIBO + UNIUD)

Last period

Development of a new PCB module (tested on CEAs first) hosting the multi-source energy harvesting ASIC and load management circuitry

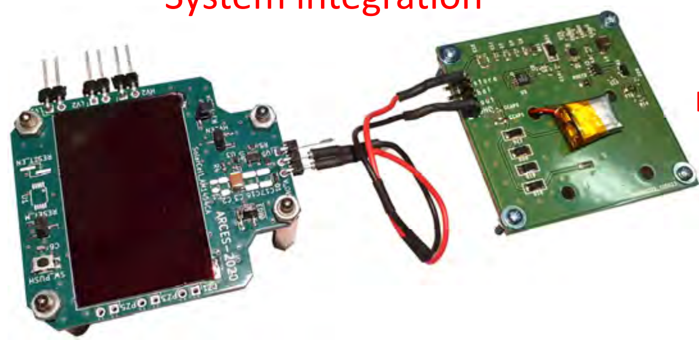
Experimental validation

Joint tests with IUNET-UNIUD's battery management module for providing a harvester-to-battery-to-load solution

EH – Multisource (Top)

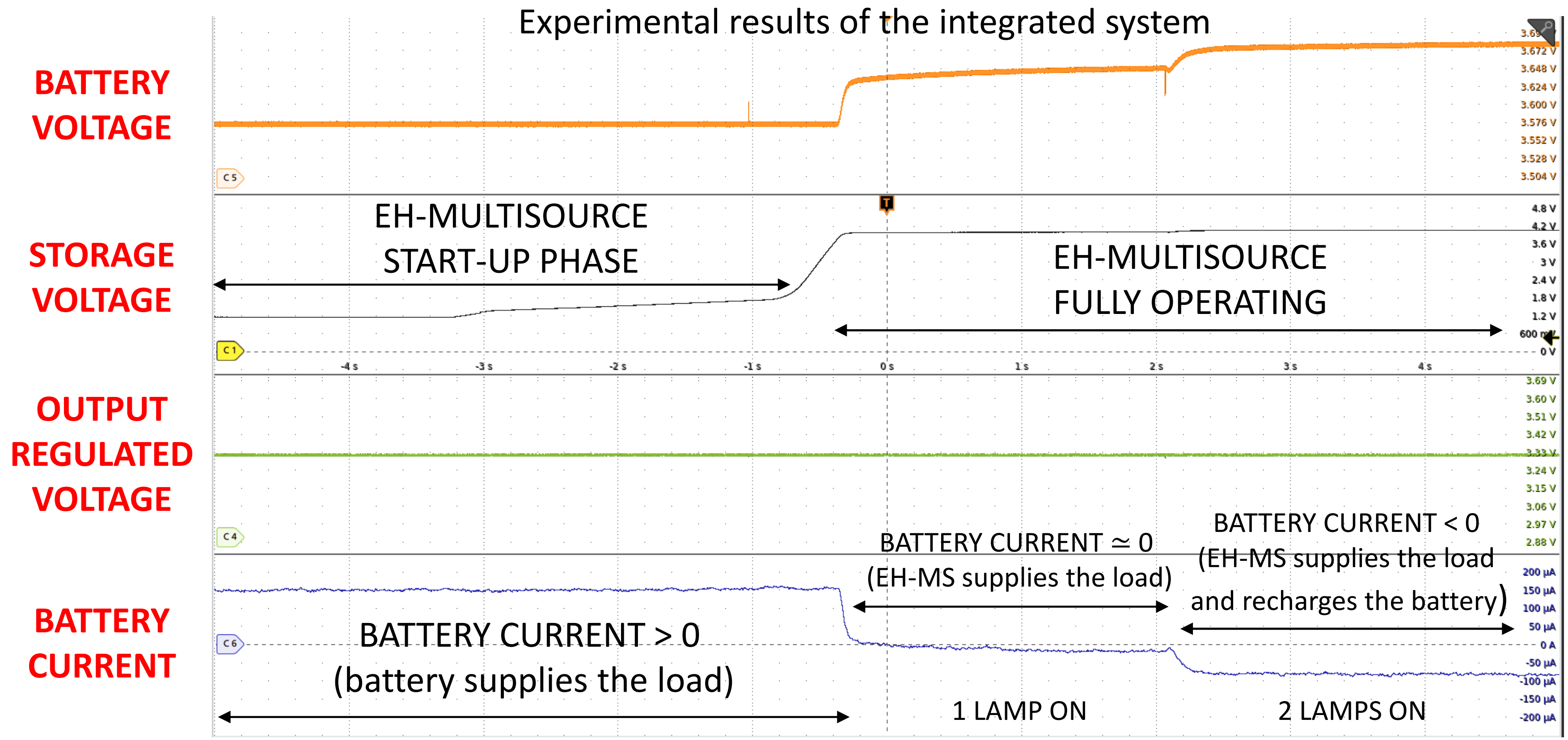
EH – Multisource (Bottom)

System integration



Battery management module

WP3: Energy management – (IUNET UNIBO + UNIUD)



WP3: G-INP Piezoelectric NW Harvesters

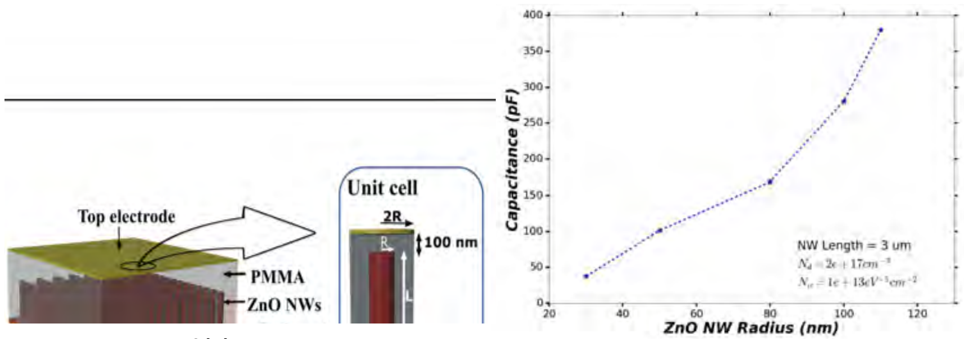
A new automatic **test-bench was developed to characterize flexible piezoelectric transducers** (Necessary for accurate and comparable characterization):

- The new set-up reduces errors related to the clamping of devices, integrates a force sensor and allow the bending of more rigid devices

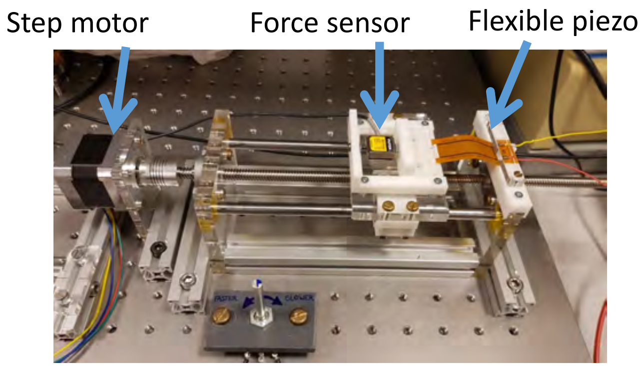
PFM (Piezoelectric Force Microscopy) characterization of Piezoelectric nanowires

Development of models of piezoelectric composites (ZnO nanowires immerged in polymer matrix) and experimental validation:

- Models including piezoelectricity, semiconducting properties and surface traps
- Validation via measurements on rigid devices under compressive forces (~5N)



Structure of (a) the piezo composite integrating ZnO NWs into a PMMA matrix.
(b) Simulation results: capacitance of the piezoelectric composite. The Experimental capacitance of a device with NWs with R= 110nm is ~300pF



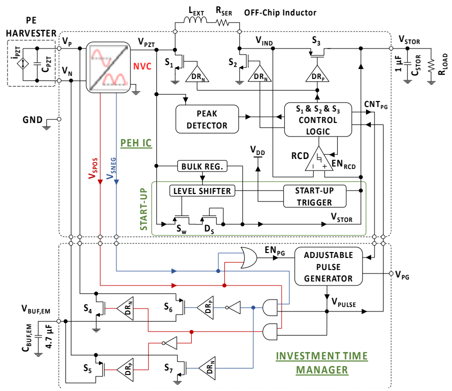
New bending characterization set-up available at G-INP

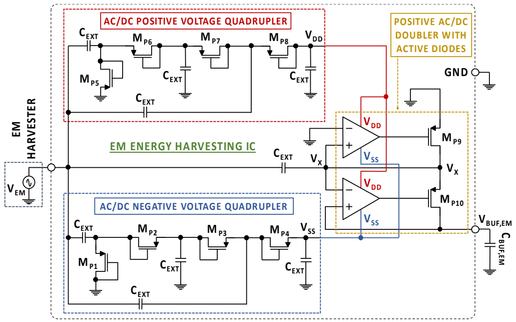
2

WP3: METU piezo and EM sources

Development of energy harvesting ASIC:

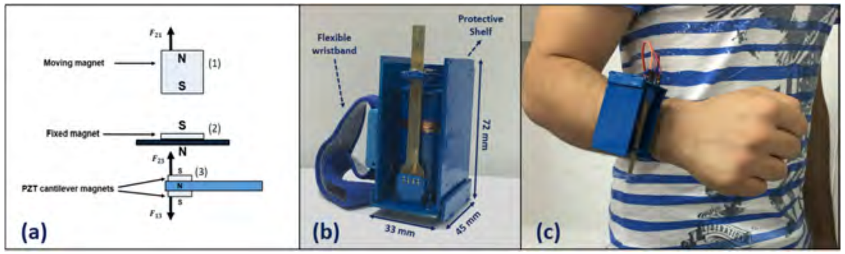
- Low-Power Energy-Efficient Interface IC Designed in 180 nm HV CMOS Process Capable of Synergistically Harvesting Energy from Both PE and EM Harvesters
  - ✓ Achieves More than 60% Power Conversion Efficiency with Load Independency

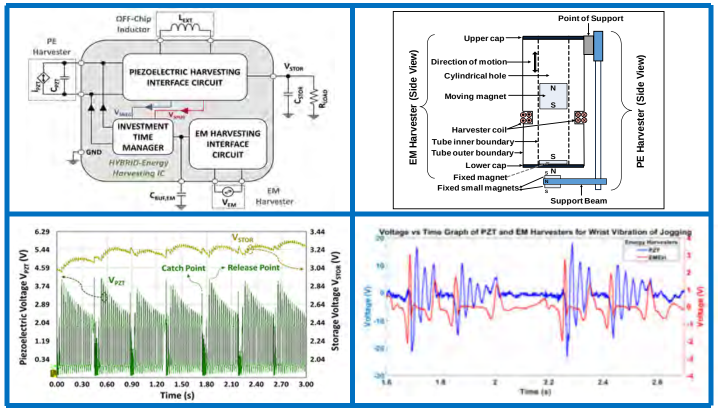




Prototyping and experimental validation of electromechanical energy harvesters suitable for wearable configurations:

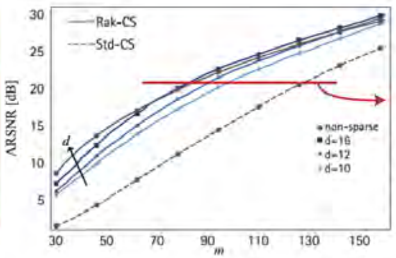
- Frequency up-conversion properties of EM and PZT Harvesters are optimized
  - ✓ EM Harvester converts 1.8 Hz input vibration to 12 Hz and generates 3.4 mW power
  - ✓ PZT Harvester converts 1.8 Hz input vibration to 35 Hz and generates 0.12 mW power.





WP3: Efficient energy management algorithms and subsystems (IUNET UniBO-PoliTO)

IUNET-BO/IUNET-PoliTO: Acquisition system based on conventional microcontroller for the acquisition/decoding of ECG signal according to the Compressed Sensing paradigm



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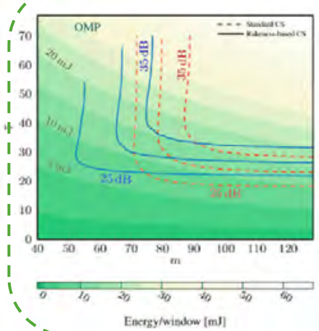
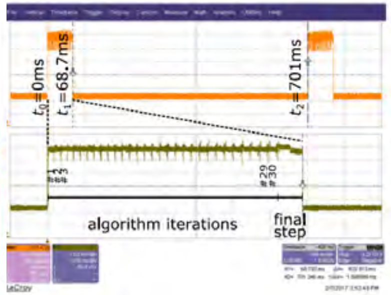
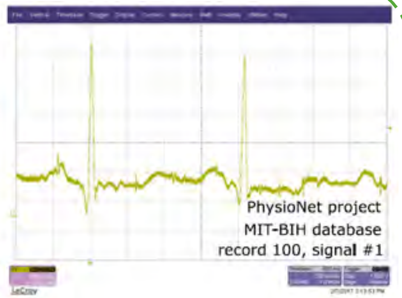
sparse	12	90	1.61	31.38
sparse	16	83	1.75	27.28
sparse	20	85	1.60	22.23
non-sparse	256	85	1.51	1.51

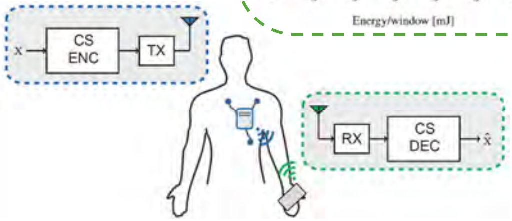
Bit Saving Ratio (**BSR**) and Energy Saving Ratio (**ESR**) are the reduction achieved by the (sparse) Rak-CS with respect to Std-CS in terms, respectively, of number of bits and energy required for measurements encoding.







Encoder side: Applying developed optimized techniques (*rakeness, zeroing*) the energy required to compress the signal can be reduced, shutting down sensors and ADC when not needed, **by a factor from 1.5 to 40 at a given performance level**



Decoder side: Optimal trade-off (*energy vs reconstruction quality)* explored in the reconstruction of ECG signal. **Identification of the OMP algorithm as the best trade-off reconstruction strategy**

Results will be included in D 3.4 “Report on energy management policies, algorithms and sub-systems compatible with planned demonstrators”, expected at M36 (leader: IUNET)

WP4: Energy efficient wireless communications

Cellular Narrow Band-IoT communication technology for BAN (**G-INP**)

Results of the last period

Measurements with a real 4G NB-IoT network (1NCE-Munich)

Application of software techniques for power optimization: eRDX, PSM (Power Saving Mode)

Non IP data transfer over the LTE Control plane.

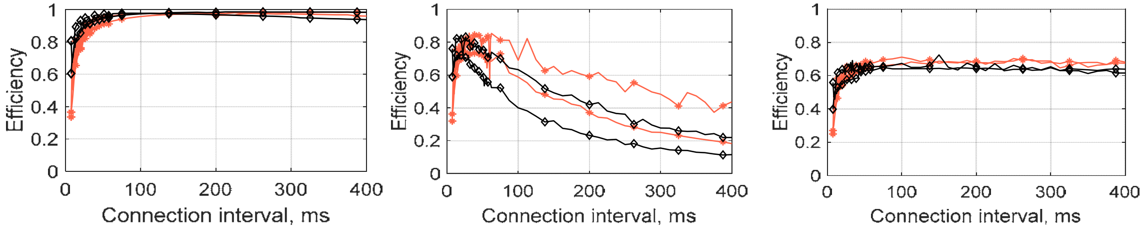
Overall Scientific results

Power and energy consumption evaluation. For 128 bytes block: standard mode 1000µWh, with Release assistance: 100µWh !

The NB-IoT transceiver can be used for 10 years with a 2.5 Ah AA battery.

Setup for BLE tests (**EDI**)

BLE performance evaluation in densely deployed radio environment (2.4 GHz)



No background **4 BLE devices in background** **WiFi in background**

Antennas for radio communication and energy harvesting were designed and integrated on CEA substrate (**G-INP**)

WP5. Signal processing and data mining specific to wearables /BAN

Participants: ETHZ, IUNET, ENEA, Tagliafferi, EDI, IMT, UBVT, TTU

Deliverables Status

D5.1 Report on algorithms for sensor data fusion from WP1 and WP2 (ETHZ) - M24 – **Completed**

D5.2 ***Report on predictive models*** **and personalized feedback strategies** (TTU) – M30 – **Completed** – Coordinator revision. D5.2 sections related to T5.2 tasks are:

- **5.2.1 Cardiovascular signals (TTU)**
- **5.2.2. Cardiovascular system Cardiovascular System: Models and Modelling (UBVT)**
- **5.2.3. Anomaly detection and situational awareness algorithms (ENEA)**
- **5.2.4 Algorithms to Expose the Personal Activity Index (ENEA, Tagliaferri)**

D5.3. Design of data processing centralized architecture, including data security and privacy (ENEA) - **Completed** – Coordinator revision

D5.5 Report on acquisition schemes devised in T5.4 with regard to the saving in the number of bits needed to identify the signals and to the level of security intrinsically achievable. (IUNET) – M30 **- Completed** – In revision

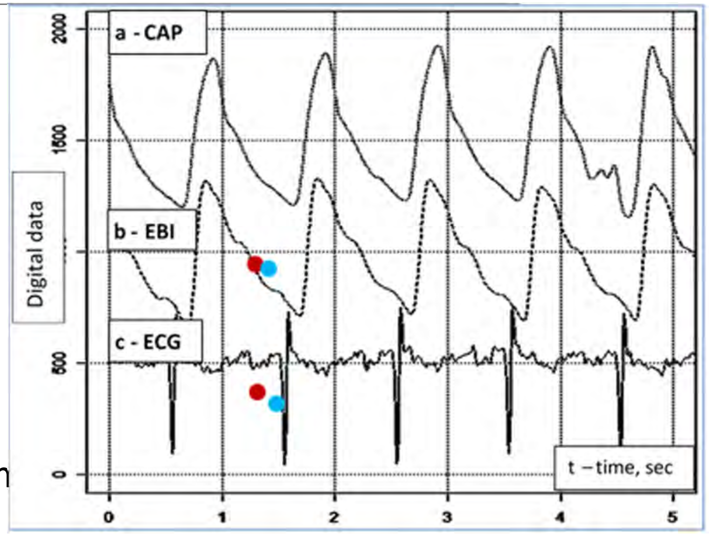
D5.4 Algorithms optimisation and models validation by using real data from WP7 (UTBV) – M36 - **In progress**

WP5. Signal processing and data mining specific to wearables /BAN

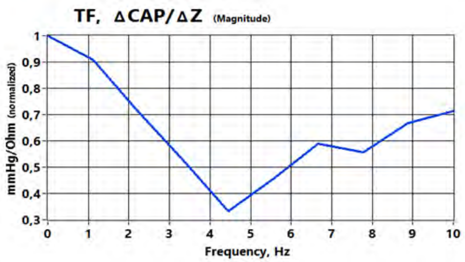
Major achievements

Providing Cardiovascular Blade pressure Waveforms: Measurements, Parameter Extraction, Clinical indications

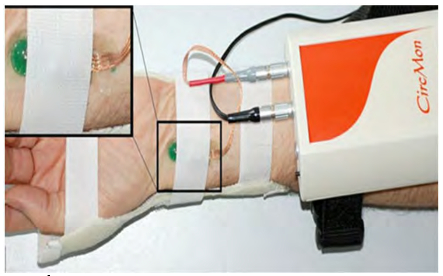
- Measurement of radial bioimpedance radial form and Clinical experiments. The algorithms has been developed so as to enable continuous monitoring of the signals of interest: blood pressure (radial / central arterial), heart rate, arterial tension, cardiac output, breathing rate
- New solutions of measurement electrodes provided
- Transforming of Radial Bioimpedance Waveforms into Aortic Blood Pressure Waveforn

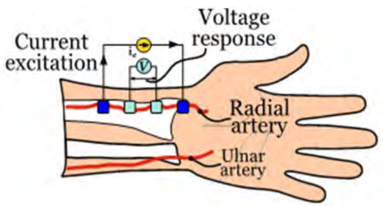


A waveform sample of measurement results from the database of East-Tallinn Central Hospital: a - central aortic blood pressure CAP(t), B - electrical bioimpedance EBI of radial artery, $Z_r(t)$, and c – electrocardiogram ECG(t), where ● indicates the timing of ECG excitation signal and ● indicates the moment of response to the excitation (certain delay exists between the excitation and response)



Aortic blood pressure transfer function (TF) in frequency domain





Measurement of radial bioimpedance

WP5. Signal processing and data mining specific to wearables /BAN

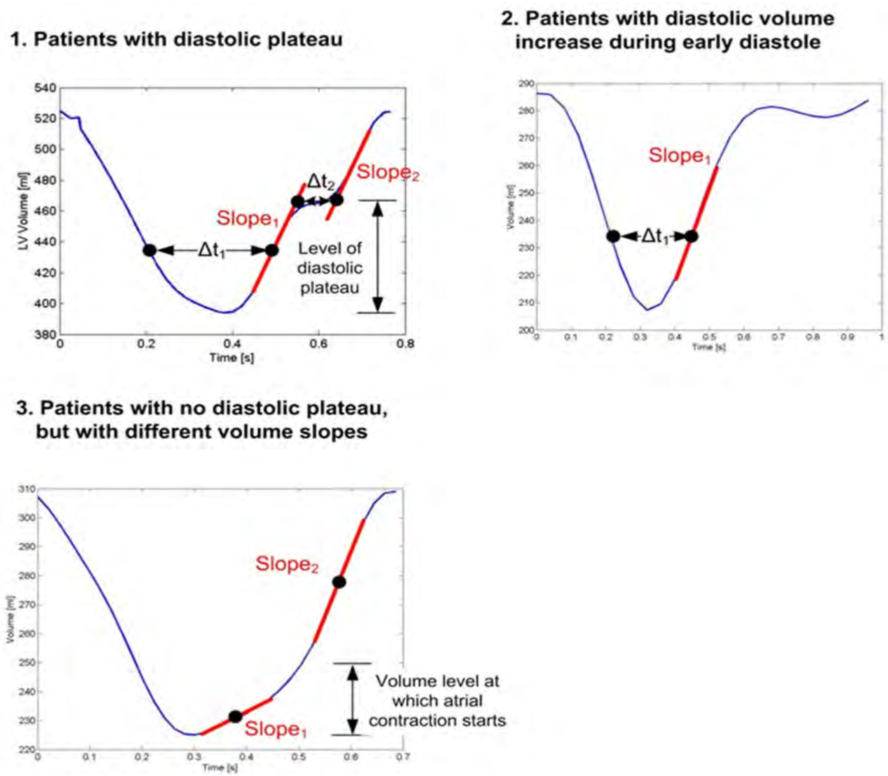
Major achievements

- **Models and Modelling of Cardiovascular System**

The reduced-order 0D model employed is a whole-body circulation model. It contains a heart model, the systemic circulation and the pulmonary circulation models.

An advanced personalized model working **under patient-specific conditions** has been implemented, able to compute various clinically relevant measures of interest: *arterial resistance, arterial compliance, dead volume of the left / right ventricle, stroke work, ventricular / atrial / arterial elastance, arterial ventricular coupling, pressure-volume loop*, etc and **to provide early prediction and categorization of risks** cardiovascular diseases (Fig.)

- **Anomaly Detection and Situational algorithms development**
- **Algorithms for Personal Exposure indexes extraction** for the correlation between the physical human body parameters and environmental parameters (pollutant gases, RH, temperature and particles)



WP5. Signal processing and data mining specific to wearables /BAN

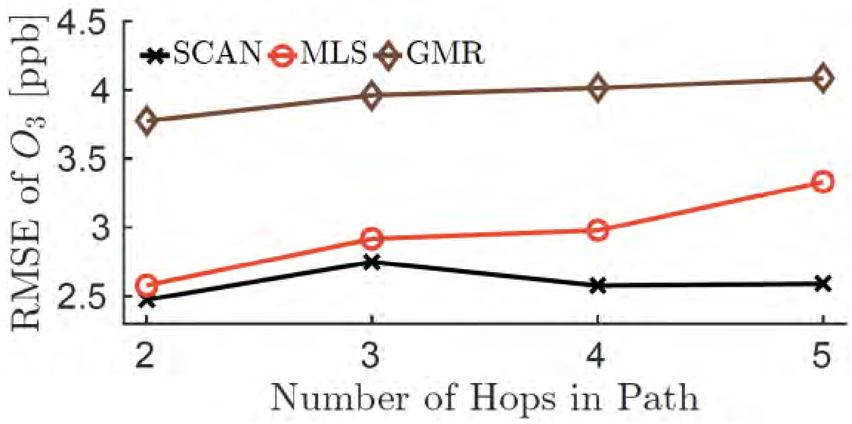
Major achievements

Data Fusion Algorithms for Environmental Sensors

A data-fusion based node-level calibration algorithm was developed and evaluated for commercial O_3 and CO_2 sensors aiming to eliminate human interference on the accuracy of the sensors when used as a wristband as requested in WP7.

Results show *(i)* the need for sensor arrays (O_3, VOC and temperature) for accurate gas (O3 and CO2) sensing in a wristband setting; and *(ii)* the algorithm measures ambient O_3 and CO_2 concentrations with an error of **4.3 ppb and 64 ppb** respectively, achieving a data quality sufficient for personal air pollution monitoring

A network-level rendezvous based environmental sensor array calibration algorithm developed by ETHZ is aiming to reduce error accumulation in multi-hop sensor array calibration in order to support potential gas sensor calibration in a mobile sensor network deployment.



Calibration error of sensor arrays depending on the number of hops in the rendezvous path

WP5. Signal processing and data mining specific to wearables /BAN

Major achievements

***Cloud* and *Fog algorithms* for data fusion from Environmental sensors**

Algorithms evaluation- A dataset collected by sensor arrays which are mounted on top of streetcars, of the public transportation network in the city of Zurich. The 7 sensor arrays include an O3, a CO and a temperature sensor. References for these phenomena are provided by two governmental monitoring stations.

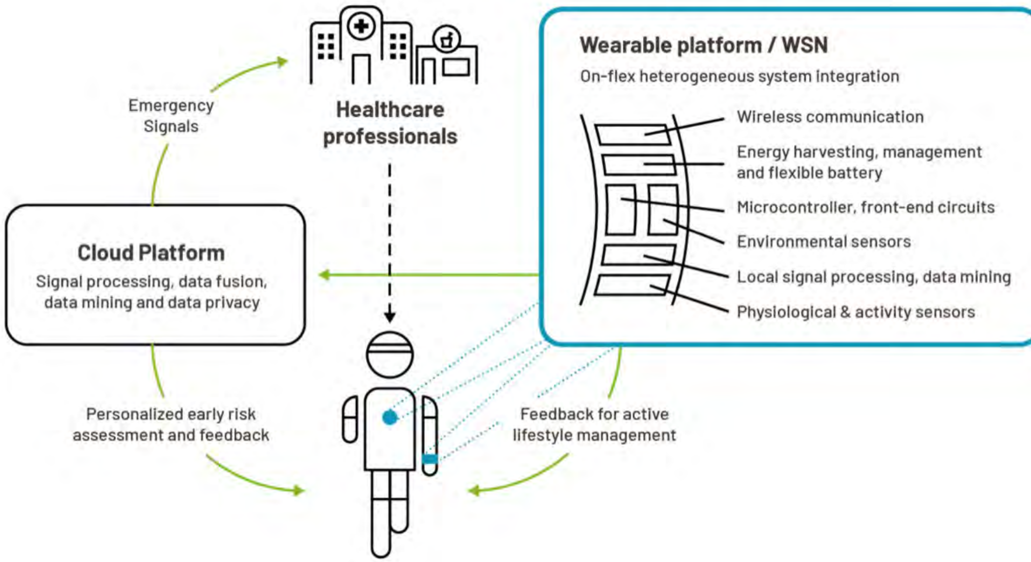
Evaluation setup for multi-hop calibration (from left to right): sensor arrays inside a sensor box; sensor box mounted on top of a streetcar; locations of sensor measurements and rendezvous between sensor arrays

WP5. Signal processing and data mining specific to wearables /BAN

Major achievements

High efficiency data processing architecture for development of a unified platform

- *This Cloud Platform have to gather all the data streaming resulting from each monitoring device*. These devices will be part of IoT and related services for a Quality-of-Life and/or for paradigm changes in the medical field.
- The *approach* proposed by *CONVERGENCE* dictate that *part of the information processing and storage could be local, while another part is communicated and processed in the cloud,* letting the user to decide the optimal solution always granting a high level of privacy and security of the data.
- *By their associated data collection and data analytics, the CONVERGENCE systems are expected to enable personalized advice and assistance, concerning health and interaction with the environment.*



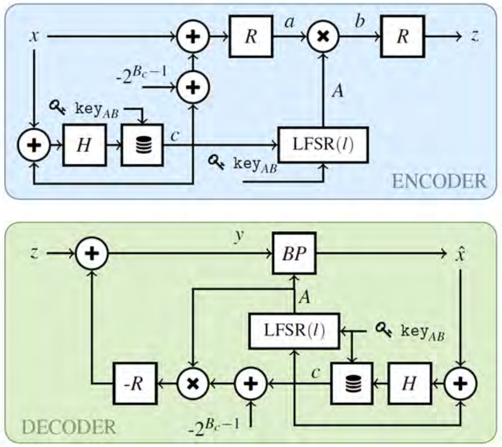
Architectural Design

WP5. Signal processing and data mining specific to wearables /BAN

Major achievements

Efficient sampling and compression (IUNET, EDI)

- Evaluation of the compression level introduce by the *Compressed Sensing (CS)*, and comparing with conventional DSC schemes in the case study of a single-lead ECG signals. The results highlight how the proposed DSC scheme is *capable of attaining low code rates with a minimum amount of digital hardware.*
- *The possibility of using CS as a physical-layer method* to embed security properties in the acquisition process. An encryption strategy is relying on the fact that any receiver attempting to decode the CS measurements must perfectly know the sensing matrix used to encode the original signal in the acquisition block.
- Application *of chaining techniques* (the idea that every piece of encoded information incorporates a summary of previous pieces of information) that will improve the privacy level of CS acquisition, and will provide a *solution for secure data transmission between an IoT node and the gateway.*
- *Development of computation framework for IMU sensor data based physical activity classification for active life* scenario. *Reduction the amount of transmitted IMU sensor data* to achieve higher energy efficiency at the same time not sacrificing the activity classification accuracy. *Several classification algorithms were evaluated, and Random forests classifier was selected as most efficient* in terms of classification accuracy and computational complexity . This classifier was used for WP 5.4. tests. Several combinations of sensor node placements are evaluated.



Block scheme of an encoder and a decoder based on chained CS

Italian National Agency for New Technologies, Energy and Sustainable Economic Development

TAGLIAFERRI Srl

IUNET – Consorzio Nazionale Interuniversitario per la Nanoelettronica

Elektronikas un datorzinātņu institūts

University Campus Bio-Medico of Rome

WP7: Applications scenarios, validation and planning of field trials

ENEA + UCBM + UNICA + IUNET + TAGLIAFERRI SRL

Saverio De Vito
ENEA Energy Dept. – Smart Networks Division
saverio.devito@enea.it

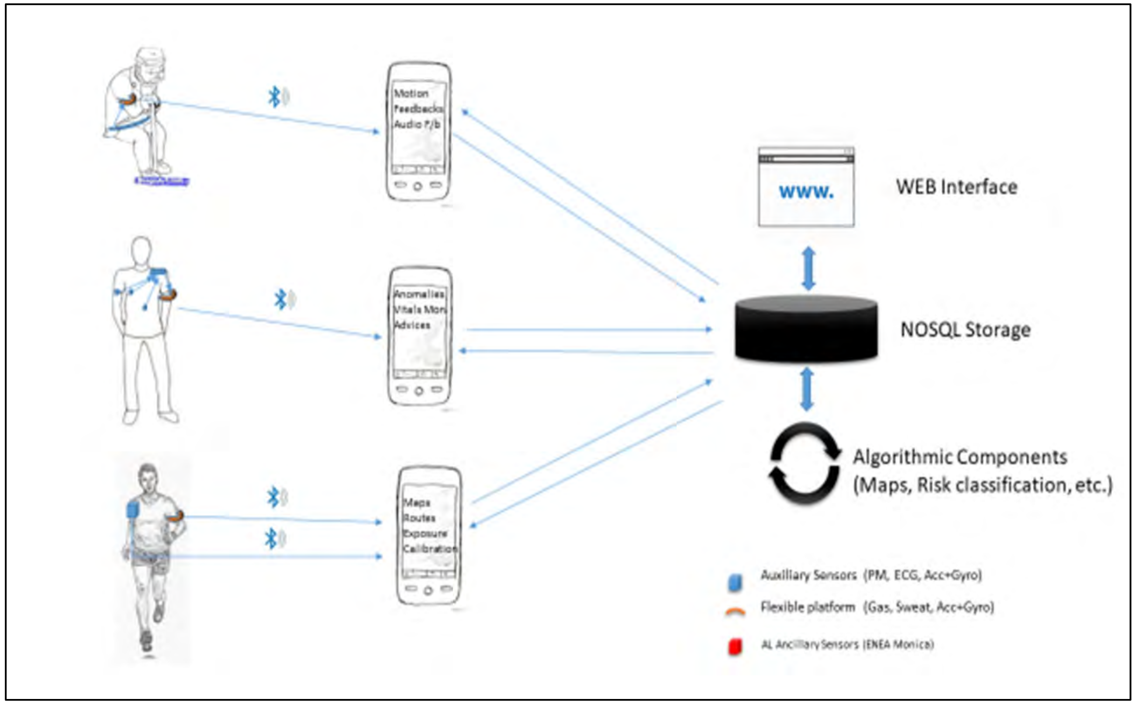
Wp7 Concept & Technological framework

3 Different scenarios…. A unified framework. Development using baseline sensor tech.

Frailty: Monitoring frail people gait for assisted living and rehabilitation purposes based on IMU sensors.

Coronary Artery Disease: Monitoring CAD patients with non-contact wearable ECG for extended follow up

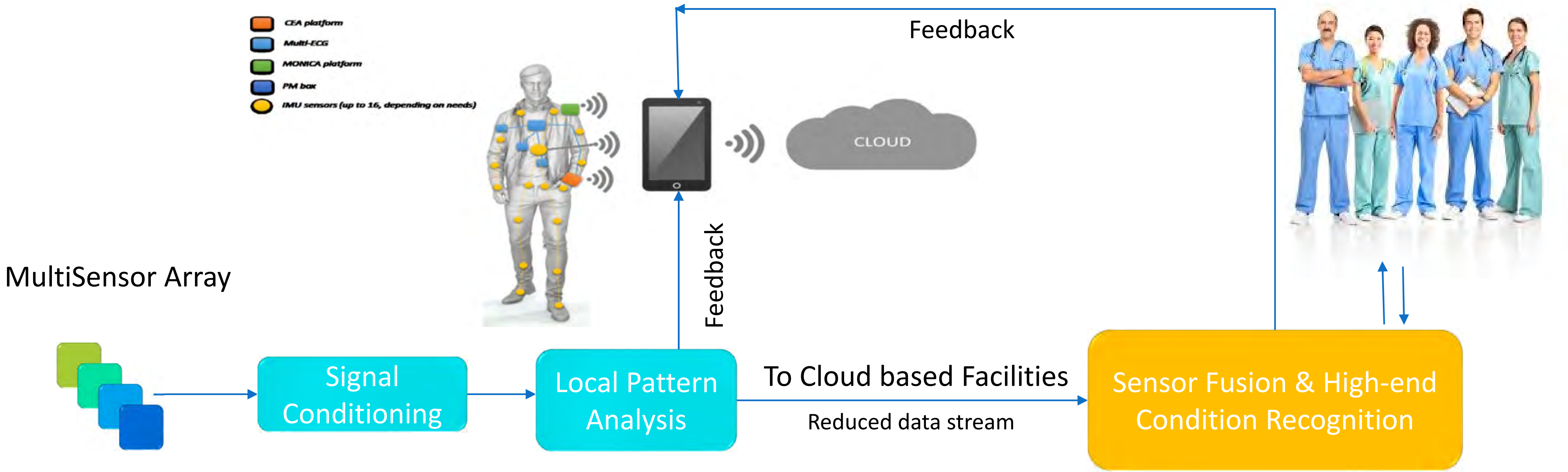
Active Life: Promoting & Improving Active life for asthma patients, elderlies and active population removing air pollution barriers



WP7 benefit from WP2, WP5 and WP6 Technologies

Convergence include a multistage signal processing chain.

From sensor raw data….. To high semantic value information for the user… exploiting edge computing paradigm.



Active Life: Goals

Active Life: Improving and promoting Active life for childrens, elderlies, asthma patients and active population

Where do I practice?
Where can I have a walk?

What is/has been my exposure during activity/commuting?

Is it safe to go out today?

What is the best route?

Obtaining information on

- Personal Exposure
- Condition triggering for Asthma patients
- Pollutant distribution

…. Trough air volume intake +

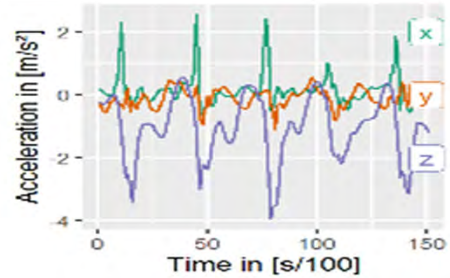
local pollutant concentration analysis…

&

Pollutant intake by Activity identification

Active Life: Research & Technology Outcomes

Long term deployment in WP1/2 have allowed to develop:
- Testing and assemblying IMUs for EDI activity recognition platform
- Optimal calibration length and location **(see De Vito et al., Sens and Act, B. Chem, 2018, and De Vito et al., Sens and Act, B Chem 2020)**
- A neural dynamic calibration have been developed using 3 weeks of calibrating data (parameters optimized through long term deployment outcomes)



Algorithmic and SW devolpment in WP5 have allowed to develop:
- Accurate machine learning components for Activity recognition in EDI
- Adaptive recalibration strategies that can be implemented for long term mobile (and fixed) **deployments (see De Vito et al., Submitted to Pattern Recognition Letters, 2020)**
- A personal activity aware exposure index have been developed joining activity related breath rates and pollutant concentrations
- A MongoDB + NodeJS + Leaflet based IOT device management backend and Geo-Front ennd
- 2 separate Apps developed by ENEA and EDI will be refactored for interacting so to build geolocalized personal exposure and pollution maps

Active Life: Validation Plan

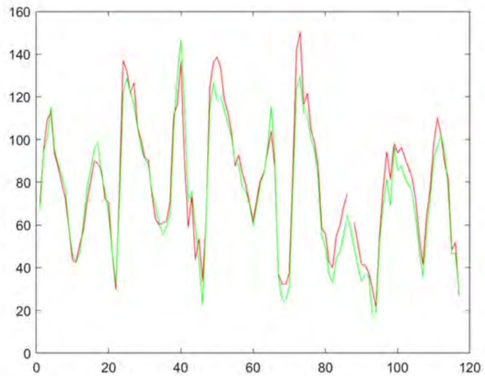
4 MONICA Devices have being co-located with mobile truck analyser in Portici (NA) DEC-FEB

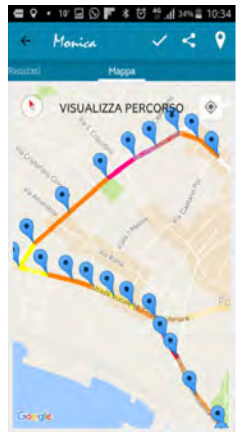
Devices have been calibrated and will be sent in RIGA where….

12 Volunteers will carry MONICA during their mobility sessions (including running activities)

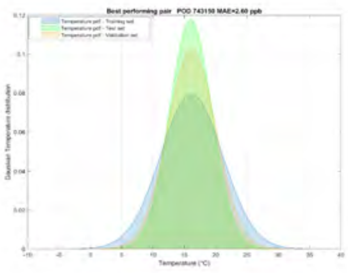
Data will be stored in remote backend facilities in ENEA

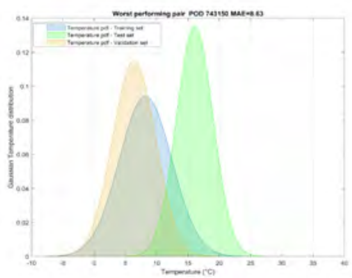
Local functional validation will be carried out for Convergence integrated platform.

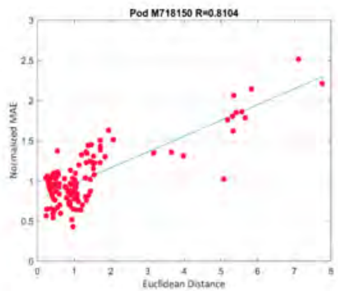


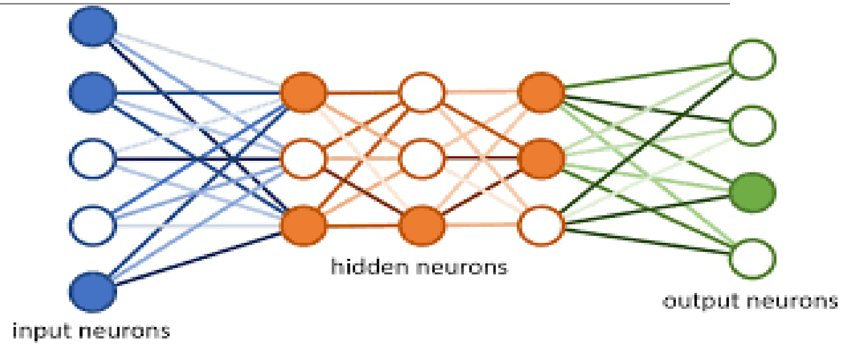


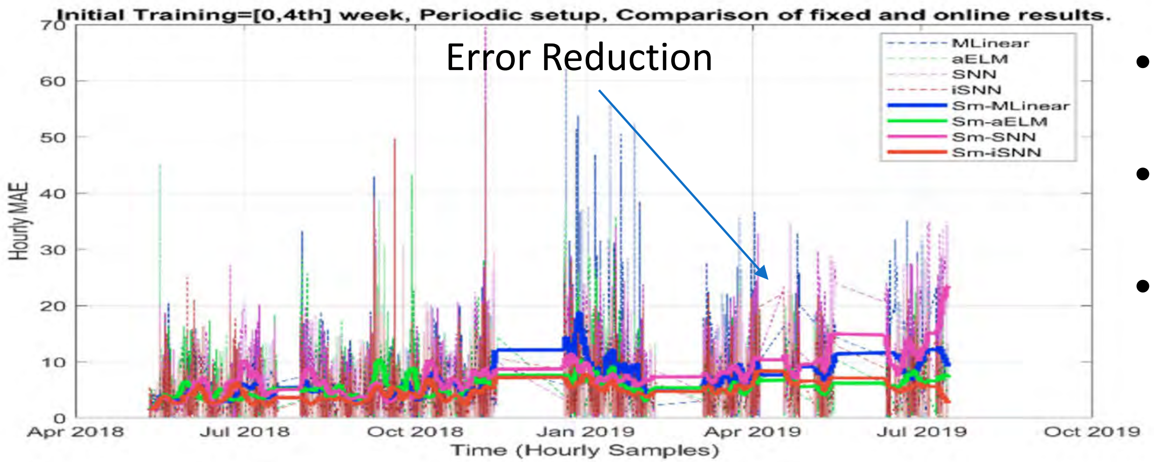
Adptive Calibration Results





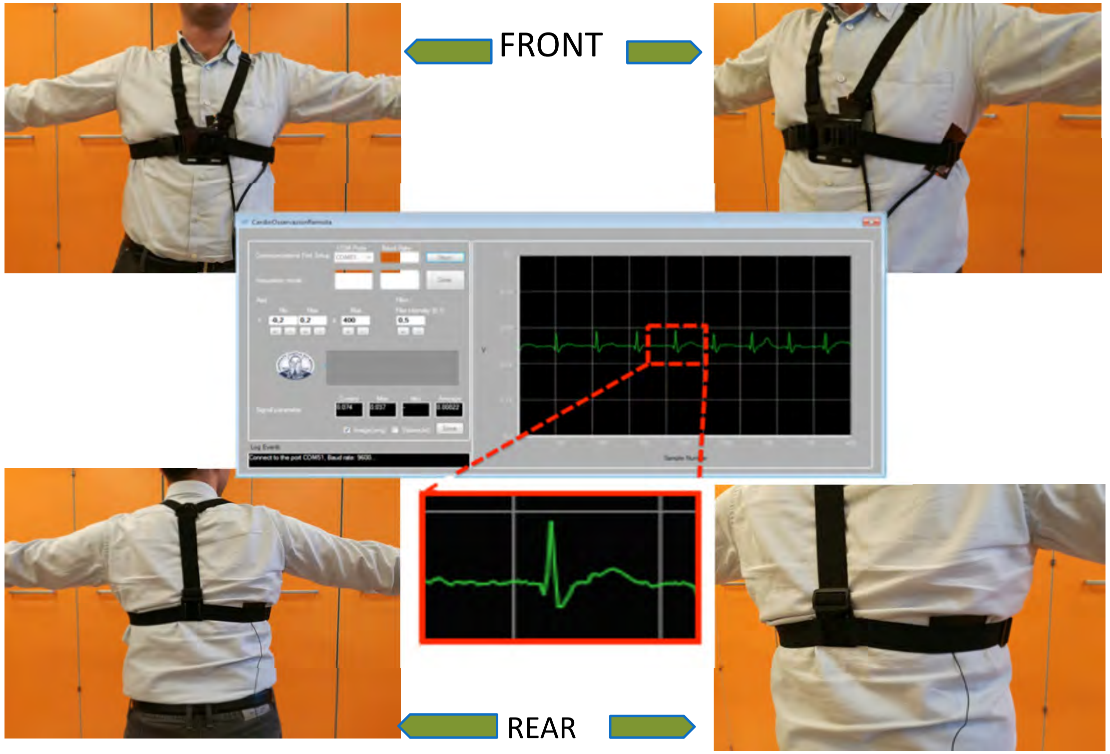






- Multivariate calibration through neural networks
- Performance worsening due to sensors and concept drifts
- Calibration adaptation receiving regular or opportunistic updagtes by rendez vous with more performing instruments or, remotely, by pollutant concentration prediction models

Cardiovascular Diseases Scenario



A novel contactless ECG Monitoring device, wearable

Test conducted vs conventional SoA Device

Cardiovascular Diseases Scenario: Performance and comparison

		UCBM device	SoA
Electrodes	**Number**	3	3 and more
	Typology	Capacitive	Conductive/capacitive
	Interaction	Applicable onto tissue	Skin-contact
Size		Comparable	
Power		Comparable	
Validation for active life		No	Available for some prototype
Validation for specific diseases		Running	Not significant
Signal		ECG-like	ECG-like (*ECG with at least 9 electrodes*)

power consumption 0.01 W
supply voltage of ± 1.8 V
Size 20 cm^2

Clinical Trial: next slide

Cardiovascular Diseases Scenario: Clinical trial

UCBM Ethical Committee approved the trial on March 2018 the 5th
Protocol number 28/18OSS ComEtCBM

Number of patients tested so far: 10

Signals registered with the UCBM device have been compared with the ECG signals acquired using a portable device based on the AD8232, a commercial integrated signal conditioning block for ECG monitoring.

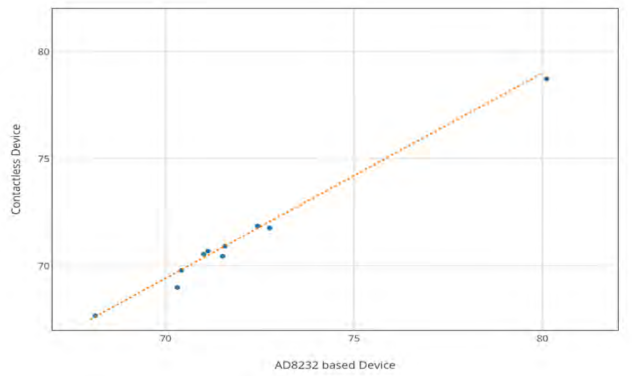
It uses 3 standard wet electrodes and is designed to extract, amplify, and filter small bio-potential signals in the presence of noisy conditions, such as those created by motion or remote electrode placement.

Comparison between ECG and ECG-like
Sinus rythm detection
Pacemaker complexes
Supraventricular extrasystoles
Ventricular extrasystoles
Heart rate
PR Interval (ms)
QRS complex (ms)
QT interval (ms)
ST tract anomalies
T wave anomalies
Significative Q wave
Signal quality for diagnostic purposes

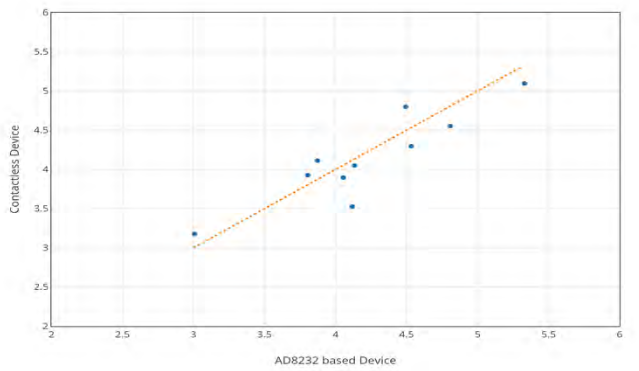
Cardiovascular Diseases Scenario: CT Results

A good correlation between HR and HRV values obtained analyzing the data recorded using both the contactless device and the AD8232-based device: HR correlation presents a coefficient of determination R^2 of 0.9 and HRV correlation presents a R^2 of 0.81.

Correlation between HR obtained analyzing data from contactless device and AD832 device



Correlation between HRV obtained analyzing data from contactless device and AD832 device



Neurdegenerative Diseases Scenario

During the last year, **UniCA** worked on three main aspects:

•Definition of the details of the protocols to be followed for the platform trial with patients, including the adoption of surrogate systems for the unavailable parts (in a sufficient number), if needed. The clinicians that can be involved in the project have been identified and the protocol is being written (not finished)

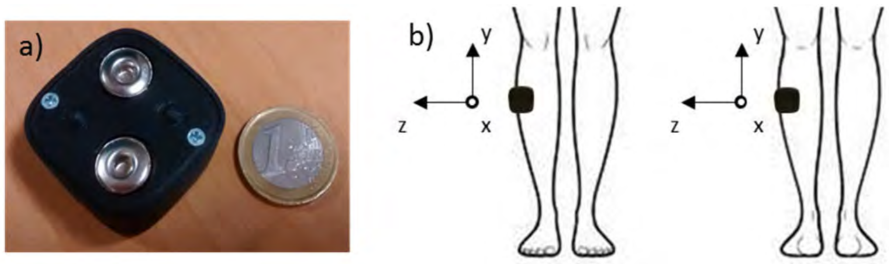
•Possibility of using textile electrodes for the EMG signal acquisition

•Development of Android apps able to capture data in real time from commercial magneto-inertial measurement units (Muse, 221e, Italy) and custom ECG monitoring device, exploiting Bluetooth classic connection, to be eventually used as surrogate devices for the high-level tests of the framework.

Pani, A. Achilli, A. Spanu, A. Bonfiglio, M. Gazzoni, A. Botter “Validation of polymer-based screen-printed textile electrodes for surface EMG detection”, has been accepted for pubblication in IEEE Transactions on Neural Systems & Rehabilitation Engineering.

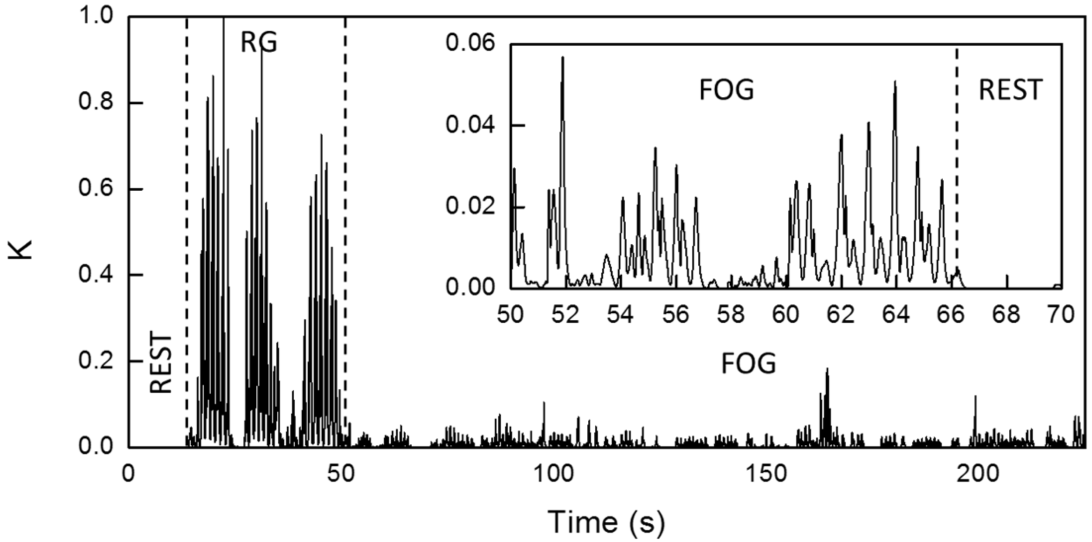
Neurdegenerative Diseases Scenario

- Multiple sensors (inertial and sEMG) were used by IUNET for evaluating the risk of fall associated to involuntary blocks of patients affected by neurodegenerative diseases (freezing of gait in Parkinson's Disease)
- Tests were performed on a group of 32 PD patients of different age, gender and disease stage, and on a control group of 10 healthy persons.
- Patients were enrolled at the Hospital Policlinico Umberto I of the Sapienza University. They were monitored under the supervision of two doctors, during a 7 m long Timed Up and Go (TUG) test, under (ON state) and not under (OFF state) dopaminergic treatment. The test was carried out in a free living-like environment reproducing a domestic setting, characterized by the presence of obstacles which usually elicits FOG (e.g. narrow corridor, open door, furniture).



Neurdegenerative Diseases Scenario

Classification of three gait states (regular gait –RG-, rest, FOG) was obtained implementing algorithms based on the use of two thresholds in the amplitude of K.



Rest (0-14 s), regular gait (14-50 s) and long FOG (50-225 s) intervals of a typical recorded trace.
The distinction of the rest state and the FOG from the RG is trivial.
Furthermore, in the rest state the K amplitude is negligible also respect to FOG, as outlined in the inset of Fig. 2.

Deliverables Status

Deliverables

D7.1 Requirements Definition Document for Wearable systems –*[M6]* ***Done,*** **report**

D7.2 Validation Planning for Active Life Scenario– *[M24]* ***Done,*** **report**

D7.3: Validation Planning for CAD Scenario– *[M24]* ***Done,*** **report**

D7.4: **Validation Planning for Frailty Scenario** [M24] ***Done,*** **report**

D7.5 Validations Report on wearable systems [M32] ***Delayed***

Prolongation objectives

03/20: High temporal resolution colocation acquisition (2Months) for mobile sensors calibration

05/20: Calibrated Monica Platform Delivery to EDI for Active life validation purposes (together with EDI Activity recognition)

06/20: Validation of neurodegenerative scenario finalization

07/20: Final assessment of validation outcomes from Active life and Neurodegenerative diseases scenario.

9/20: Final Review and Dissemination event (Summer Schort course in Naples co-sponsored by Italian Association for Sensors and Microsystems and International Society for Olfaction and Chemical Sensing).