ALLSENSORS 2020

IARIA

Emerging technologies for ubiquitous monitoring and transmission of physico-chemical variables and their application to biosignal acquisition

Dept. Electrónica y Tecnología de Computadores– Universidad de Granada
PEARL: Pervasive Electronics Advanced Research Laboratory

UNIVERSIDAD DE GRANADA

Valencia, November 2020

Speakers

ALMUDENA RIVADENEYRA received the master's degrees in telecommunication engineering, environmental sciences, and electronics engineering from the University of Granada, Spain, in 2009, 2009, and 2012, respectively, and the Ph.D. degree in design and development of environmental sensors from the University of Granada in 2014. She has been with the Institute for Nanoelectronics, Technical University of Munich and currently she is Marie Curie Fellow at the University of Granada, where her work is centered in printed and flexible electronics with a special focus on sensors and RFID technology. She obtained the Young Researcher Award in 2019 by the Consejo Social UGR.

FRANCISCO J. ROMERO received the B.Eng. in Telecommunication Engineering from the University of Granada (Spain) in 2016, and the M.Eng. in Telecommunications Engineering from the University of Granada in 2018, both with valedictorian mention. In 2015, he joined the Department of Electronics and Computer Technology at the University of Granada as Ungraduated Researcher, and in 2017 became a PhD Student with a national predoctoral scholarship. His current research interest includes graphene-based sensors, flexible electronics and IoT embedded systems.

UNIVERSIDAD DE GRANADA

PEARL
Pervasive Electronics Advanced Research Laboratory

Objectives

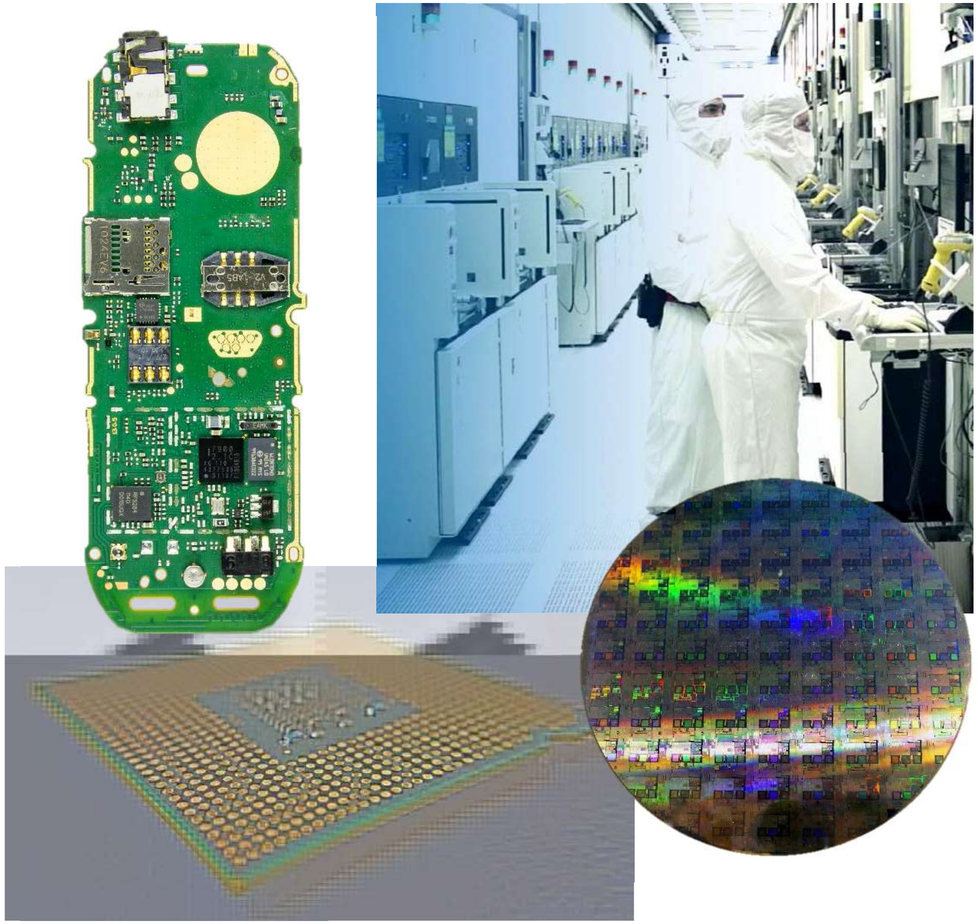
- In this tutorial, we will explore the main emerging techniques for the fabrication of printed and flexible electronics.
- We will show some practical examples of devices manufactured with such technologies, highlighting their features with respect to conventional fabrication techniques.
- After that, we will explain the use of these emerging techniques for the fabrication of electrodes and sensors for biosignal acquisition and how they can be integrated with other electronic devices. We will also explain a future perspective of such systems.
- Finally, we will show the production of cost-effective, simple and lightweight electrodes aimed to acquire the electrocardiogram.

Available Technologies

Silicon technology

Conventional IC-CMOS technology

- ✓ Miniaturization
- ✓ IC integration
- ✓ Well-established



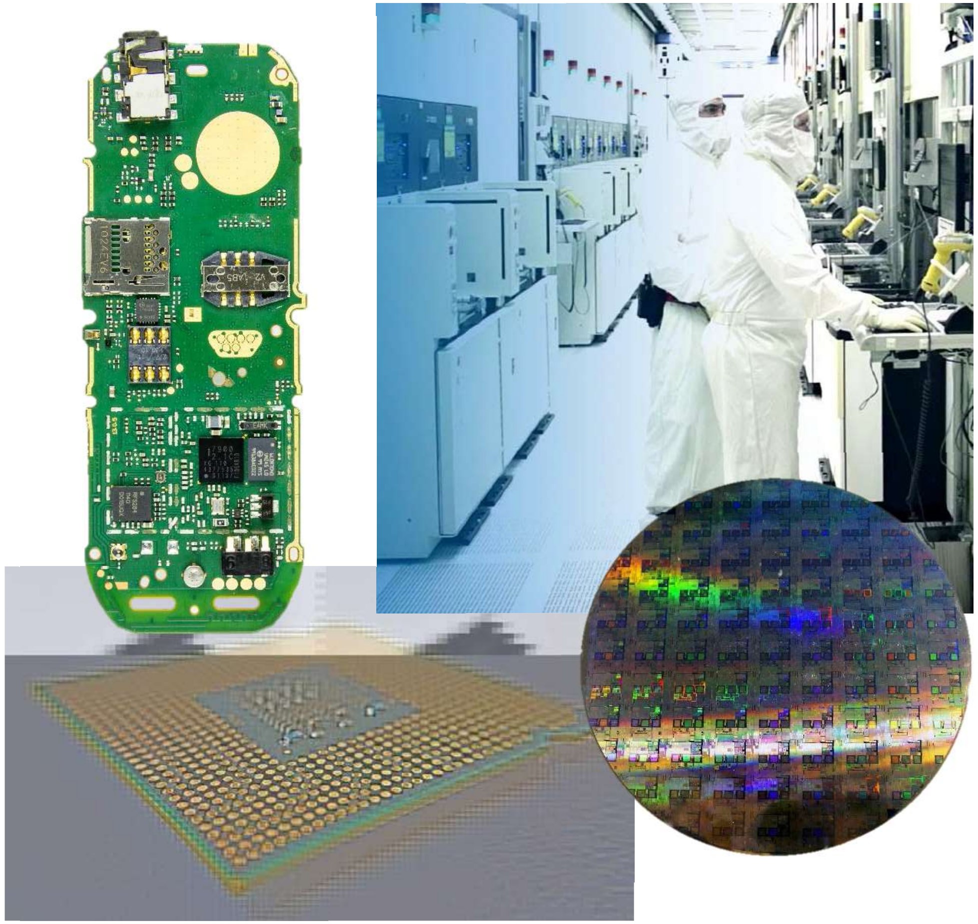
Available Technologies

Silicon technology

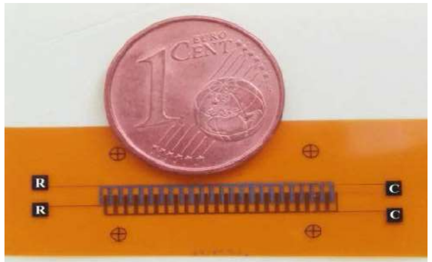
Conventional IC-CMOS technology

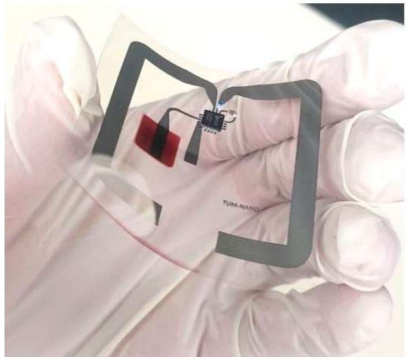
✓ Miniaturization
✓ IC integration
✓ Well-established

x Technology cost
x Fabrication conditions
x Sustainability



Available Technologies



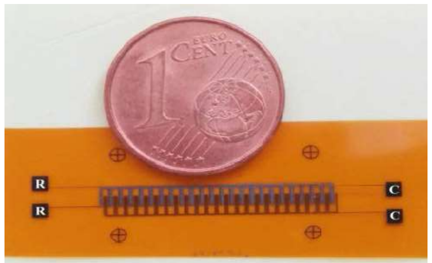


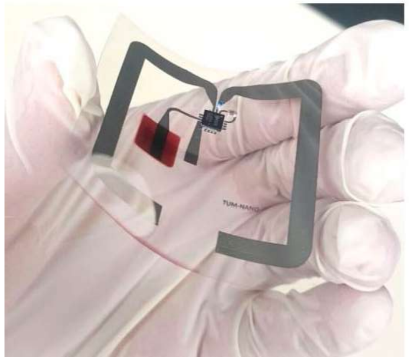
Printed Electronics

Traditional printing techniques

- ✓ Environmental friendly
- ✓ Large scale: Low-cost and ease of redesign
- ✓ Flexible substrates

Available Technologies





Printed Electronics

Traditional printing techniques

✓ Environmental friendly

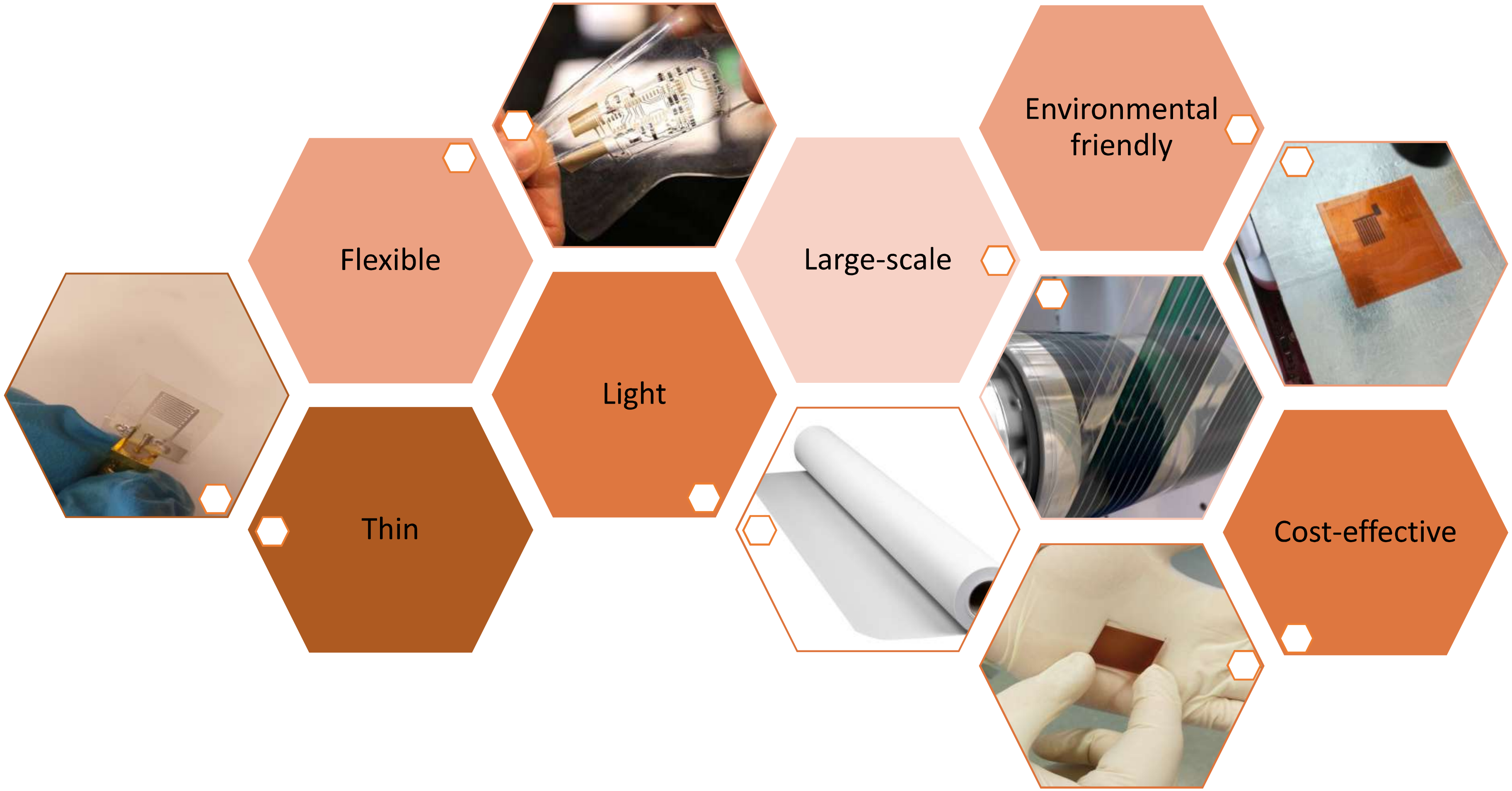
✓ Large scale: Low-cost and ease of redesign

✓ Flexible substrates

x Size

x Low performance

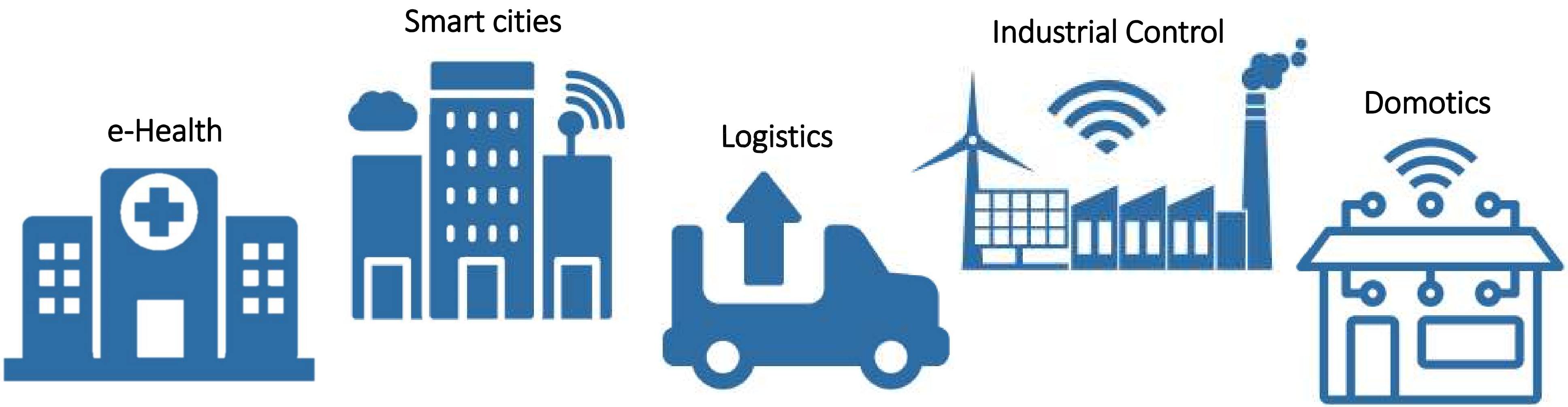
Why printed?



Flexible
Thin
Light
Large-scale
Environmental friendly
Cost-effective

Internet of Things (IoT)

Things connected to Things → possible to access data to remotely monitor and control our physical world



from $655.8 billion in 2014 to $1.7 trillion in 2020

Sensors in the IoT

- **Wide spectrum of parameters** to be covered — light, radiation, pressure, acceleration, temperature, gases, humidity, blood pressure, heart rate...

- **Rapid increase in the number of sensors**: In 2020, **25 Billion** connected "Things" will be in use

- **Desirable features**: Low-cost, environmental friendly, low power consumption

Technological solution

Silicon technology

Conventional IC-CMOS technology

✓ Miniaturization
✓ IC integration
✓ Well-established

x Technology cost
x Fabrication conditions
x Sustainability

Hybrid Electronics

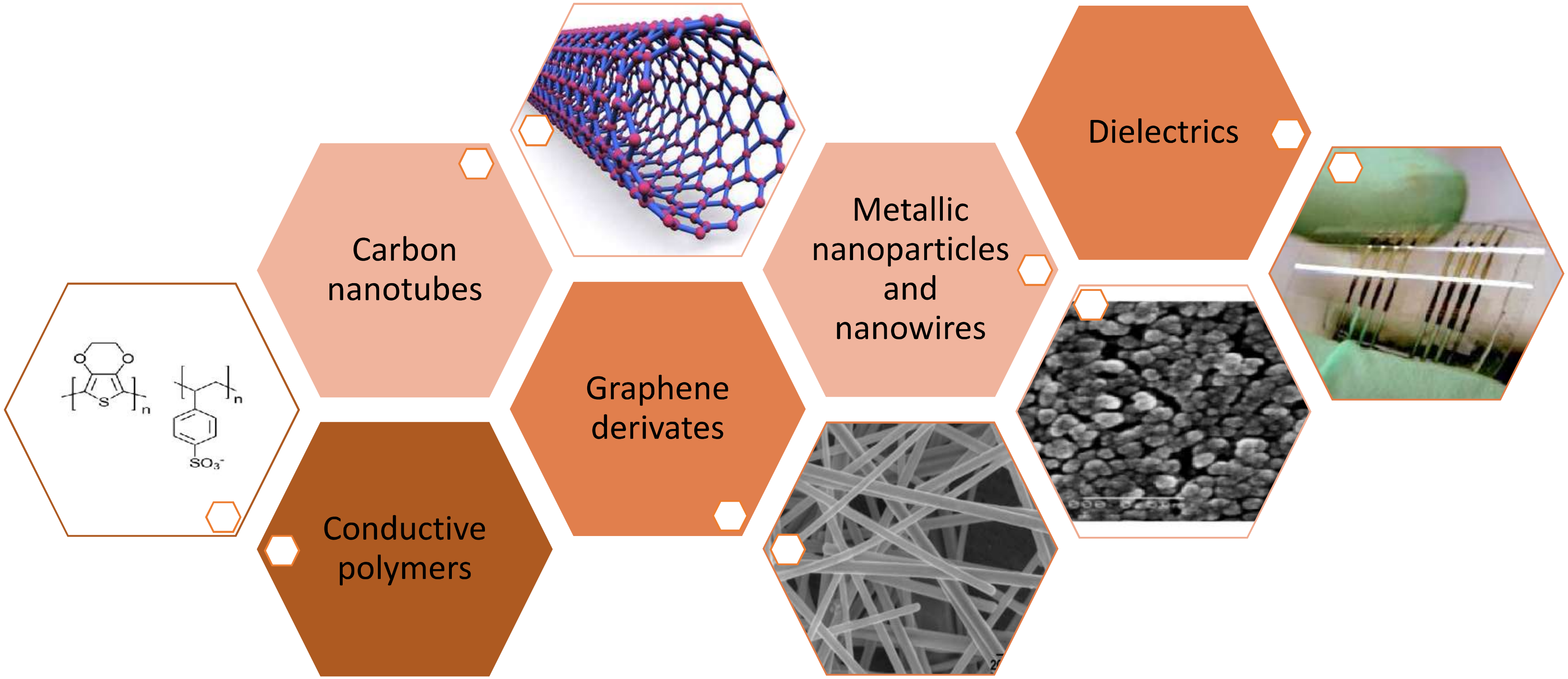
Printed Electronics

Traditional printing techniques

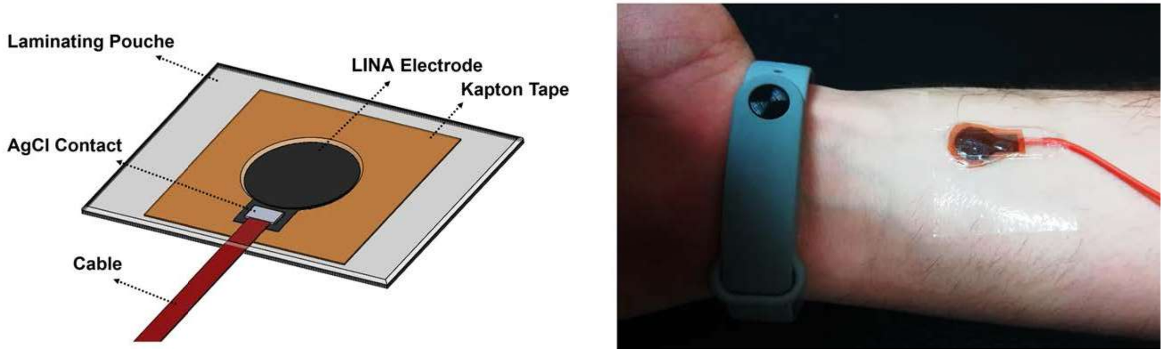
✓ Environmental friendly
✓ Large scale: Low-cost and ease of redesign
✓ Flexible substrates

x Size
x Low performance

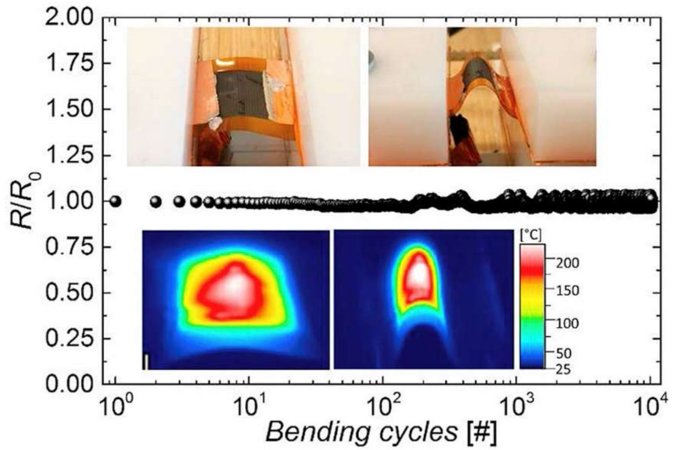
Novel Materials



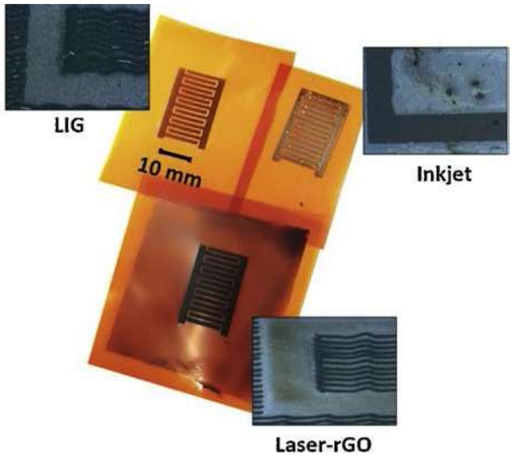
Examples of printed devices



Romero, Francisco J., et al. "Inexpensive and flexible nanographene-based electrodes for ubiquitous electrocardiogram monitoring." *npj Flexible Electronics* 3.1 (2019): 12

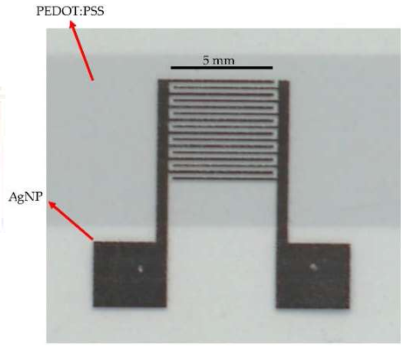


Bobinger, Marco R., et al. "Flexible and robust laser-induced graphene heaters photothermally scribed on bare polyimide substrates." *Carbon* 144 (2019): 116-126



Romero, Francisco J., et al. "Design, fabrication and characterization of capacitive humidity sensors based on emerging flexible technologies." Sensors and Actuators B: Chemical 287 (2019): 459-467

Goliya, Yash, et al. "Next Generation Antennas Based on Screen-Printed and Transparent Silver Nanowire Films." *Advanced Optical Materials* (2019): 1900995



Rivadeneyra, Almudena, et al. "Cost-Effective PEDOT: PSS Temperature Sensors Inkjetted on a Bendable Substrate by a Consumer Printer." *Polymers* 11.5 (2019): 824.

Application to biosignals

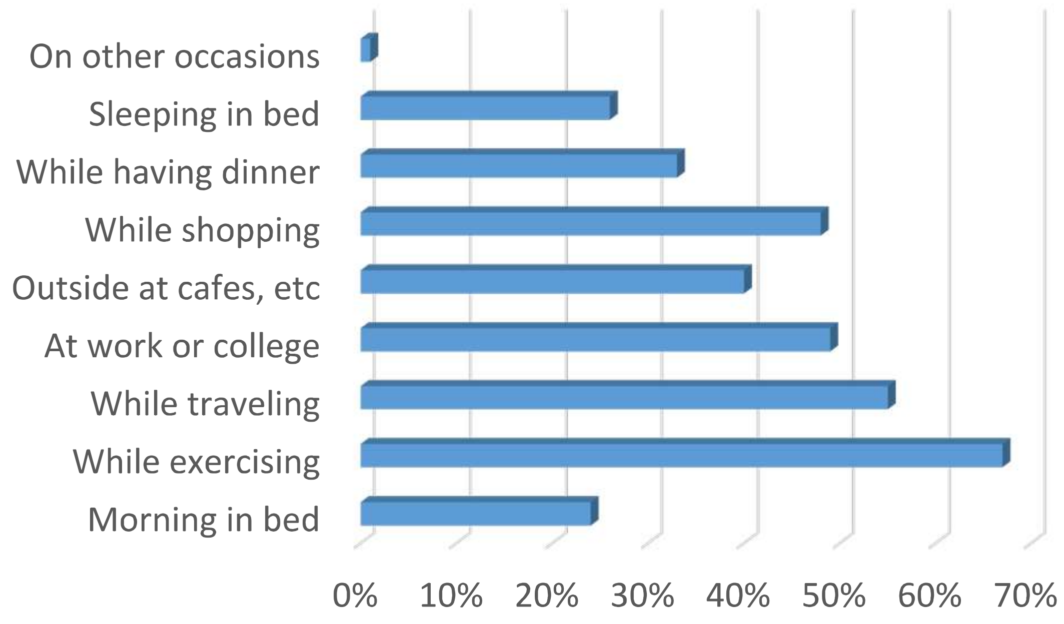
E-health applications

- Embedded systems for wearable and portable applications
- Health: self-monitoring, telemonitoring
- Analysis of physical activity
- Tracking professional activity

Application to biosignals

E-health applications:

Two out of five users feel naked when they don't have their wearables on, whilst around a quarter even sleep with them

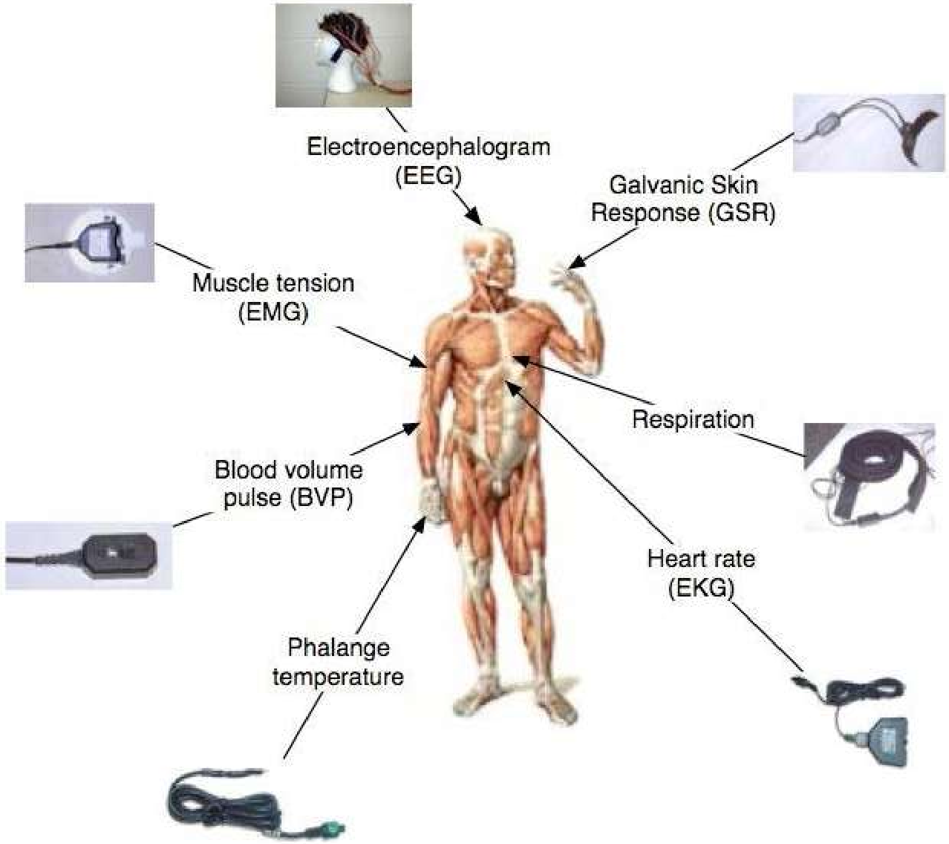


Source: Ericson ConsumerLab, Wearable Technology and The Internet of Things, 2016

Application to biosignals

Some types of biosignals:

- Electrocardiogram, ECG
- Electroencephalogram, EEG
- Electrooculogram, EOG
- Electromyogram, EMG

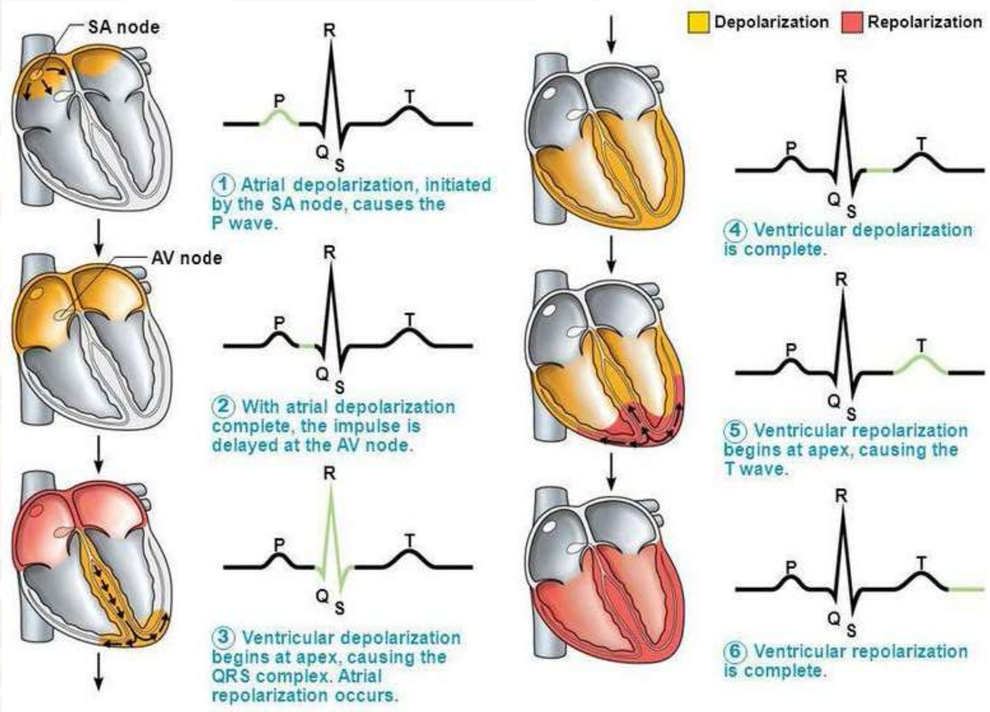


Electrocardiogram (ECG)

- Most important technique in the diagnosis of cardiovascular diseases
- Generated from electric fields resulting from cardiac muscle activity

- Requires systems with:
  - Analog interface for acquisition and filtering
  - Digital interface for processing and filtering parameter extraction

Generation of a typical ECG signal

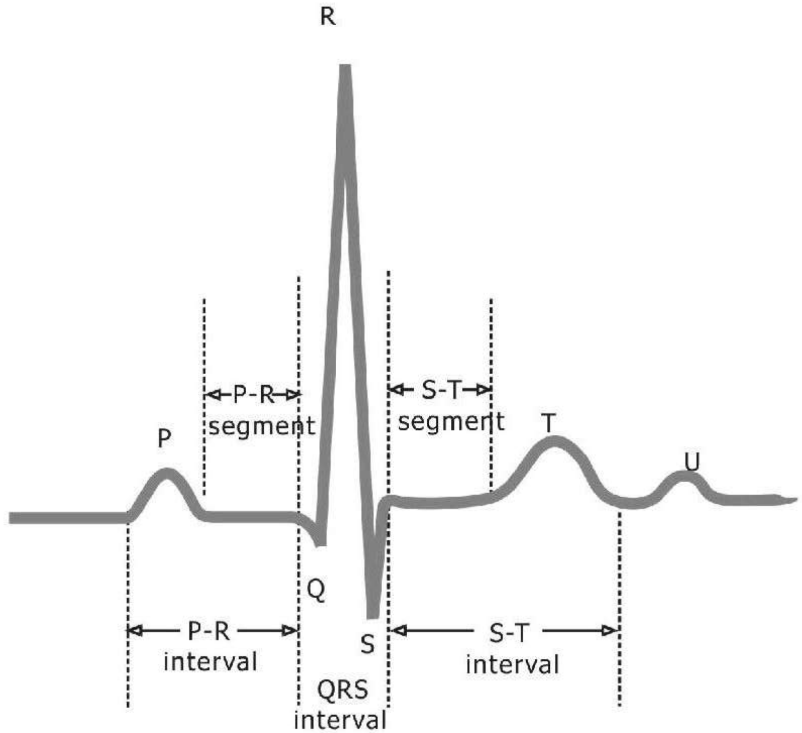


Electrocardiogram (ECG)

- Most important technique in the diagnosis of cardiovascular diseases
- Generated from electric fields resulting from cardiac muscle activity

- Requires systems with:
  - Analog interface for acquisition and filtering
  - Digital interface for processing and filtering parameter extraction

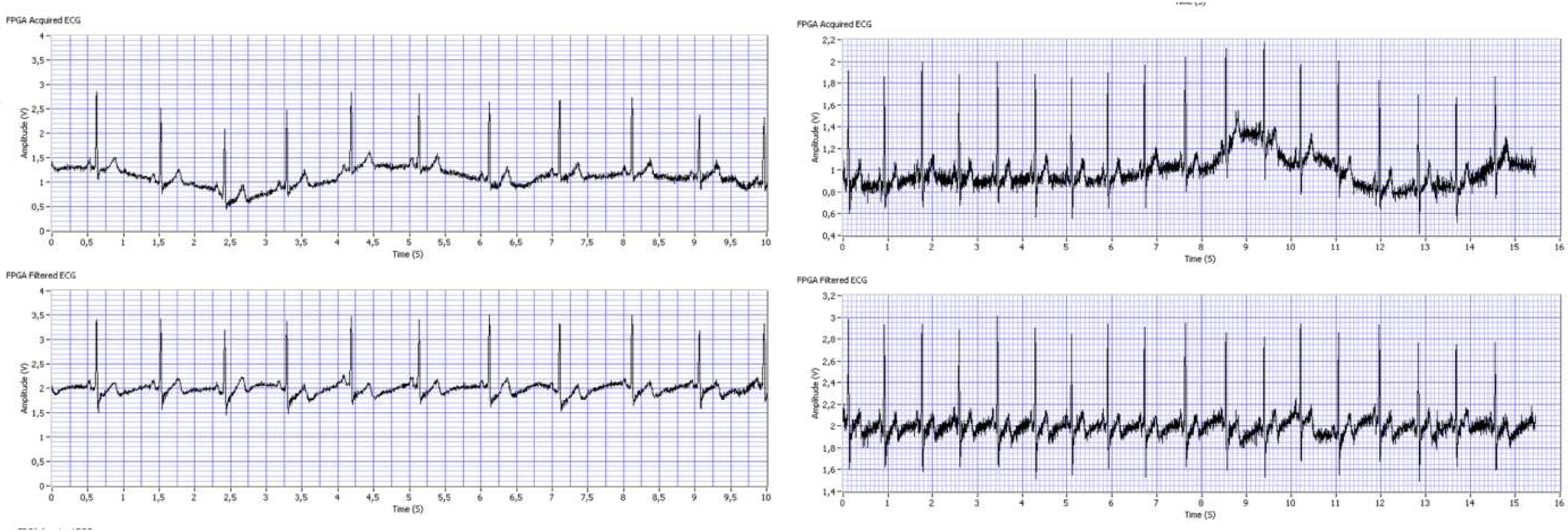
Typical ECG signal recorded on the skin surface



Acquisition systems

Acquisition of biosignals with low-cost reconfigurable technologies:

- ECG acquisition with FPAA and FPGA



Acquisition systems

Acquisition of biosignals with low-cost reconfigurable technologies:

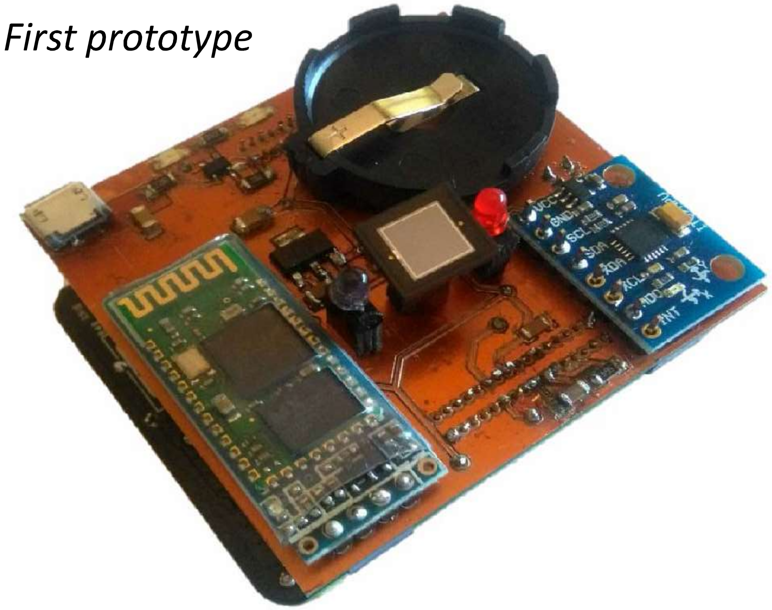
- Portable instrumentation for real-time fetal ECG signal acquisition (fECG)

Acquisition systems

- Prototype instrument for measuring:
  - Blood oxygen saturation
  - ECG

- The device includes data storage and transmission to a mobile phone via Bluetooth

First prototype

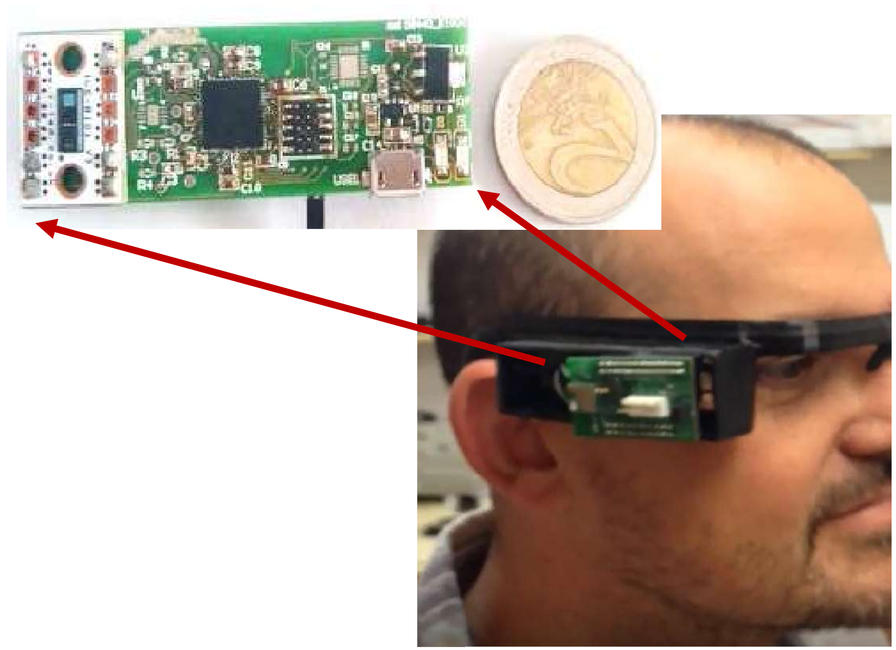


Acquisition systems

- Prototype instrument for measuring:
  - Blood oxygen saturation
  - ECG

- The device includes measurement storage system and transmission to a mobile phone via Bluetooth

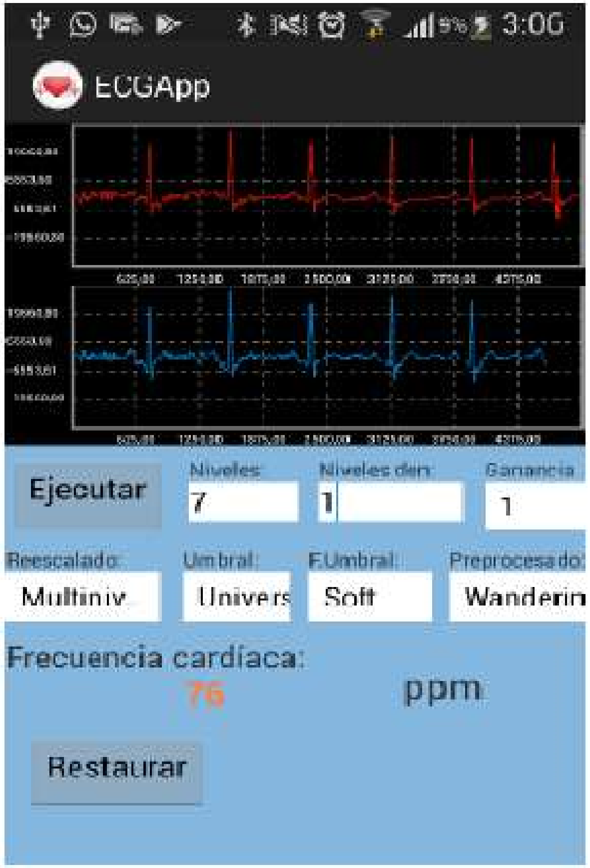
Second prototype



App for mobile phone

Android Apps:

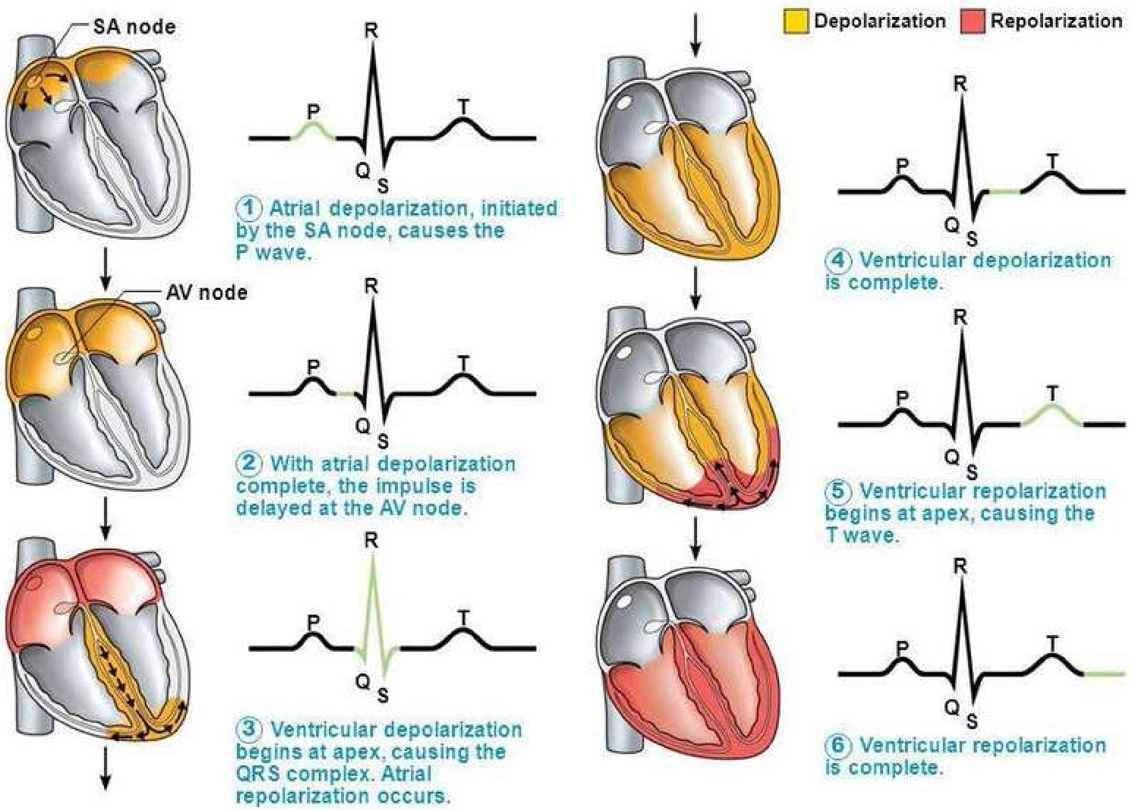
- Prototyping and testing
- BLE Connection



ECG Signal Processing

ECG processing amplitude:

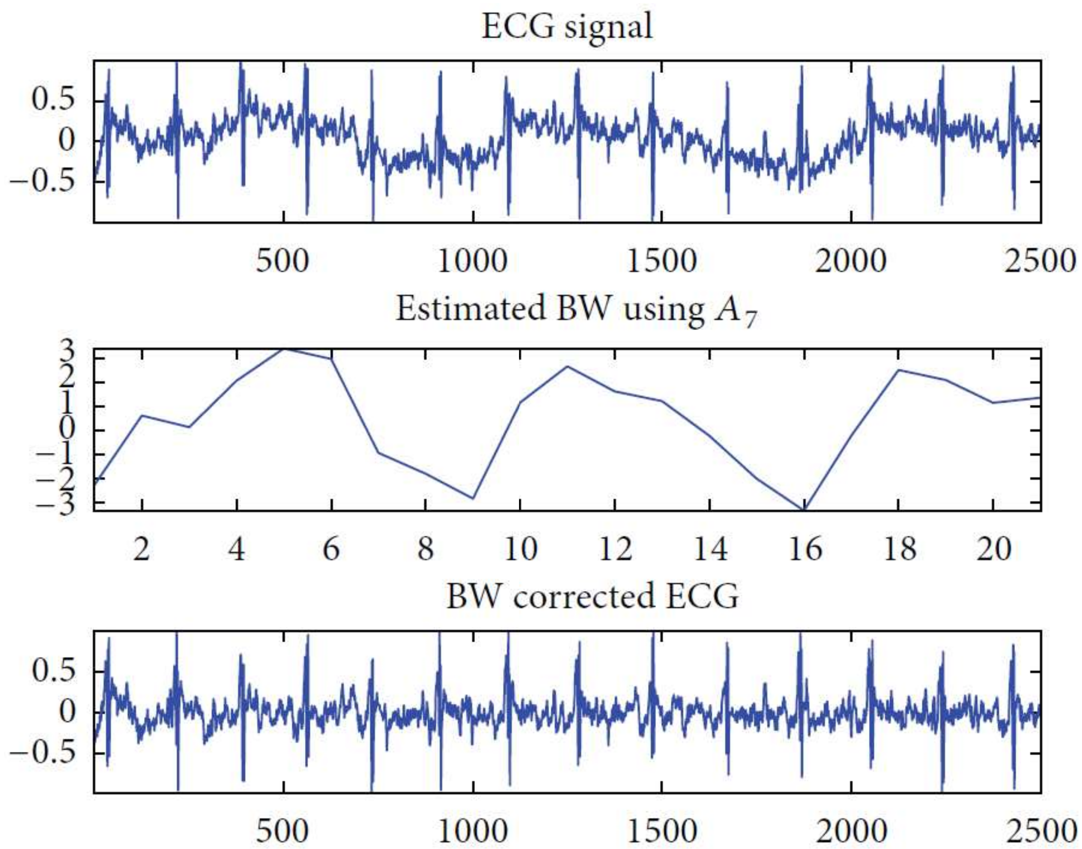
- Range: 0.1-5 mV
- Pulsations: 0.5-3.5 Hz
- BW: 0.01-250 Hz
- Artifacts and noise
- Interference movement
- Wandering



ECG Signal Processing

Development of digital ECG processing algorithms for:

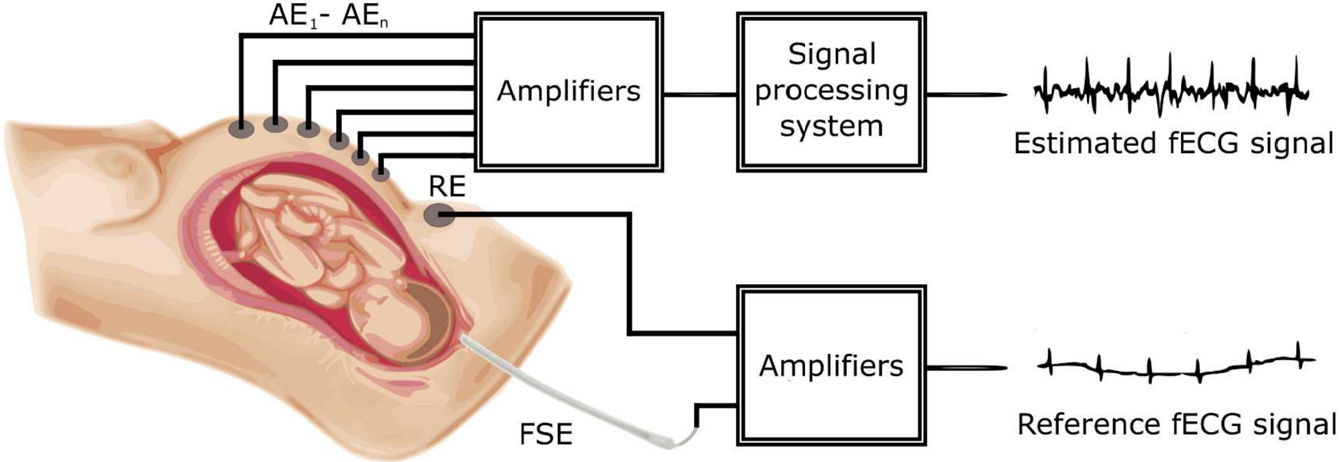
- **Heart rate detection:**
  - Threshold based technique
  - Technique based on classification by clustering
- **Noise removal:**
  - Techniques based on wavelet transform



fECG Signal Processing

Non-invasive fetal electrocardiography:

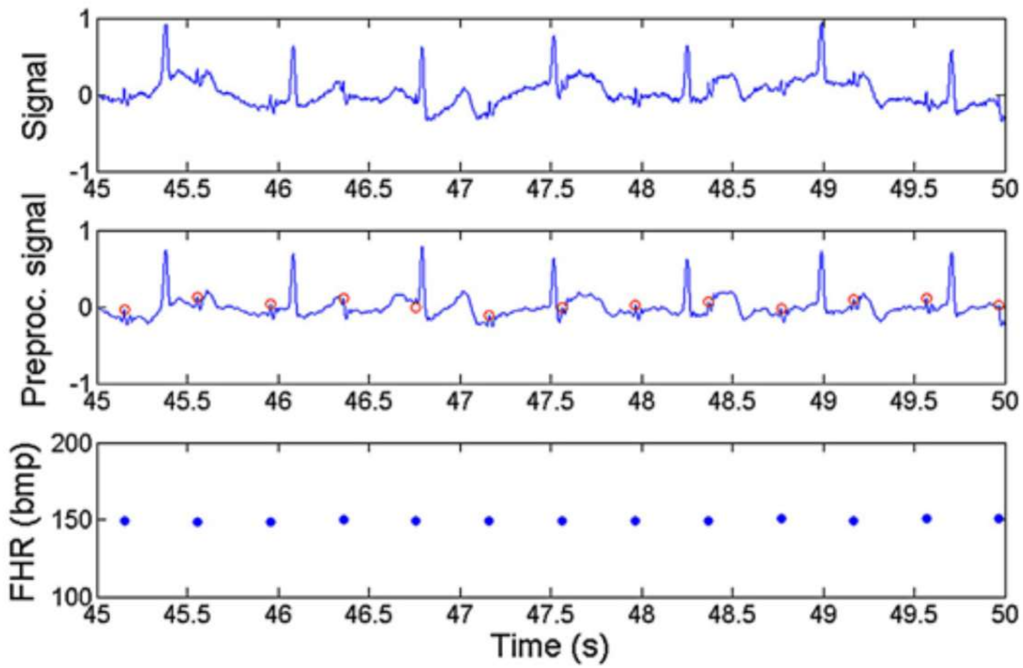
- Maternal ECG (MECG) and Fetal ECG (FECG) components in Abdominal ECG (AECG) signal



fECG Signal Processing

Non-invasive fetal electrocardiography:

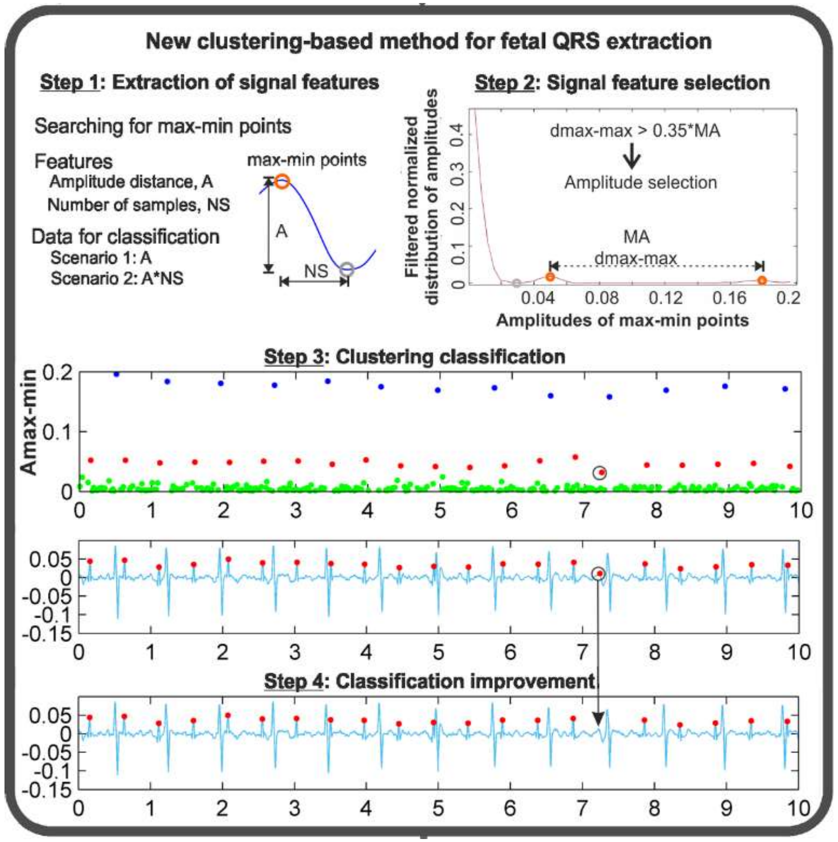
- Processing techniques similar to ECG:

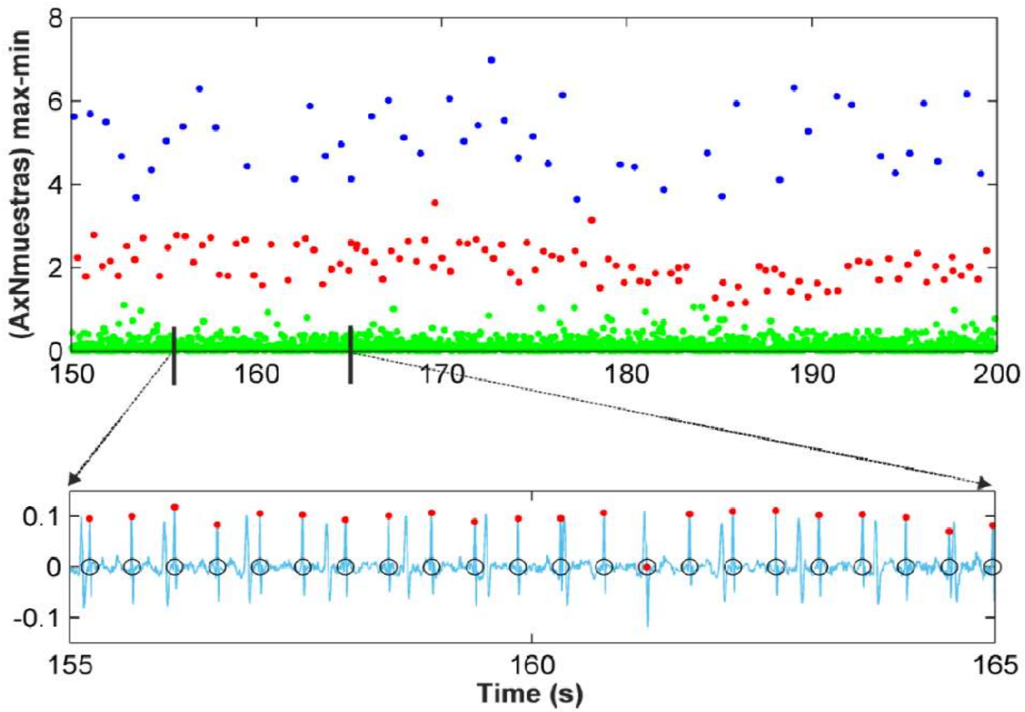


- Noise removal using wavelet-based techniques
- Detection of the fetal QRS complex using clustering-based techniques

fECG Signal Processing

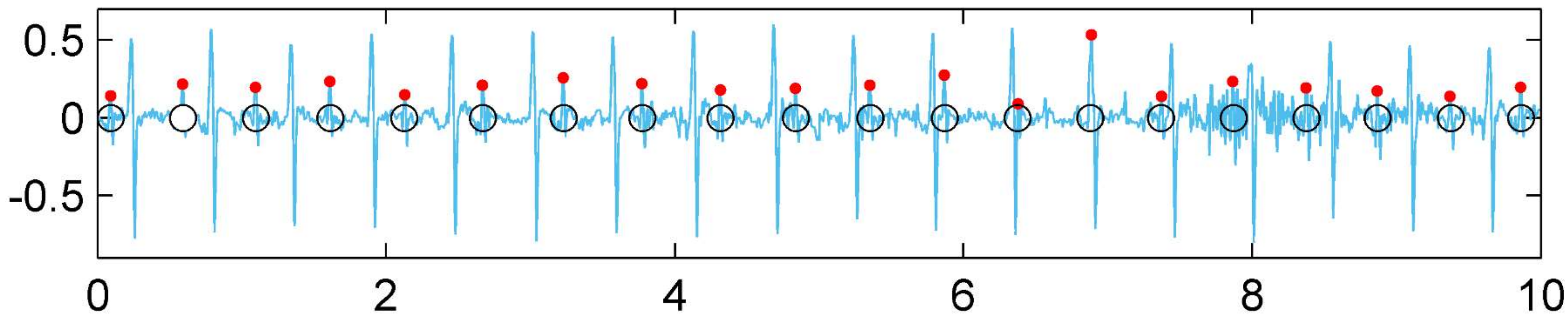
- Clustering-based technique for detection of fetal QRS complexes





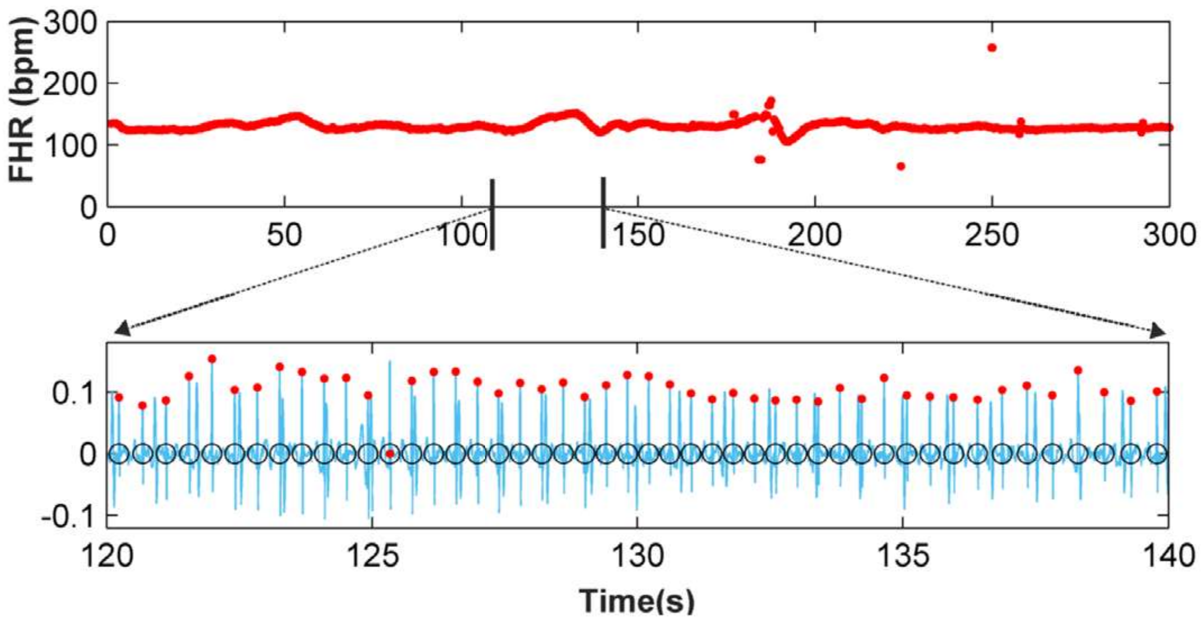
fECG Signal Processing

- Clustering-based technique for detection of fetal QRS complexes:
  - Capable of detecting in very noisy environments and/or in the presence of artefacts



fECG Signal Processing

- Clustering-based technique for detection of fetal QRS complexes:
  - Capable of monitoring the high variability of the fetal heart rate



Practical example

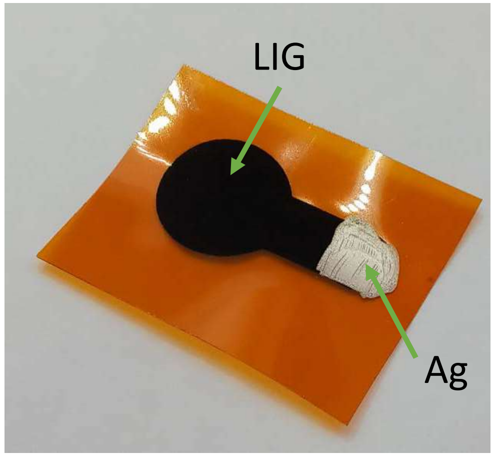
- Skin electrodes fabrication based on laser induced graphene on polyimide

Practical example

- Skin electrodes fabrication based on laser induced graphene (LIG) on polyimide

- After LIG, silver (Ag) paste is deposited on the edge of the electrode to enhance conductivity

- The electrodes are cutted and with adhesive film attached to the skin



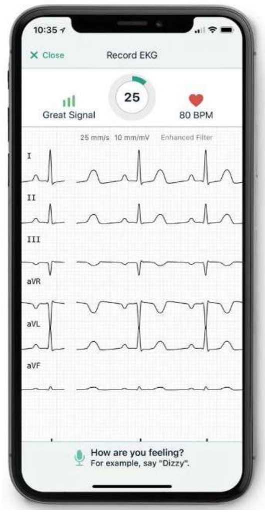
Fabricated electrodes

Practical example

- Skin LIG electrodes employed for ECG acquisition using Biosignalsplux

Future works

- Ubiquitous real-time fECG and mECG monitoring with a flexible and printed device with remote data access by wireless transmission



ALLSENSORS 2020

IARIA

Emerging technologies for ubiquitous monitoring and transmission of physico-chemical variables and their application to biosignal acquisition

Thank you

UNIVERSIDAD DE GRANADA

Valencia, November 2020