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

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Valencia, November 2020
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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 predotoral scholarship. His current research interest includes graphene-based sensors, flexible electronics and IoT embedded systems.
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

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Conventional IC-CMOS technology

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- ✓ IC integration
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✗ Technology cost
✗ Fabrication conditions
✗ 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
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- Size
- Low performance
Why printed?

- Environmental friendly
- Cost-effective
- Large-scale
- Light
- Flexible
- Thin
Internet of Things (IoT)

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

- e-Health
- Smart cities
- Logistics
- Industrial Control
- Domotics

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

- ✗ Technology cost
- ✗ Fabrication conditions
- ✗ Sustainability

**Printed Electronics**

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

- ✗ Size
- ✗ Low performance
Novel Materials

- Carbon nanotubes
- Graphene derivates
- Conductive polymers
- Metallic nanoparticles and nanowires
- Dielectrics
Examples of printed devices


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.

- On other occasions
- Sleeping in bed
- While having dinner
- While shopping
- Outside at cafes, etc
- At work or college
- While traveling
- While exercising
- Morning in bed

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
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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
Acquisition systems

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

- The device includes measurement storage system and transmission to a mobile phone via Bluetooth
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
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 cut and attached to the skin with adhesive film.

![Fabricated electrodes](image-url)
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
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Thank you

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