Department of Biomedical Engineering

VI Semester

CBM 370 - Wearable Devices

Unit- 4 SMART TEXTILE

4.6 - Case study

Smart fabric for monitoring biological parameters - ECG

Smart fabrics for monitoring biological parameters like ECG (electrocardiogram) are an emerging field in wearable health technology. These fabrics integrate conductive fibers, sensors, and flexible electronics to enable real-time heart monitoring without the need for traditional electrodes and adhesive gels.

4.6.1 Features of Smart Fabric ECG Systems:

1. **Conductive & Biocompatible Materials**
   – Uses silver-coated fibers, graphene, carbon nanotubes, or conductive polymers.
2. **Flexible and Washable**
   – Designed to be comfortable, durable, and resistant to washing.
3. **Dry Electrodes**
   – Unlike traditional ECG systems, smart fabrics use dry electrodes embedded within textiles, improving user experience.
4. **Wireless Data Transmission**
   – Connects via Bluetooth, Wi-Fi, or NFC to smartphones and cloud systems for continuous monitoring.
5. **Real-time Monitoring & Alerts**

– Detects arrhythmias, heart rate variability (HRV), and other cardiac abnormalities.

6. **Integration with AI & IoT**
   – AI algorithms can analyze ECG patterns, predict anomalies, and provide insights.

7. **Energy Harvesting & Low Power Consumption**
   – Uses flexible batteries or energy harvesting from body movements.

4.6.2 Electrode Design and Materials:

- ❖ Smart textile ECG electrodes can be obtained by integrating conductive fibers or threads during the manufacturing process through weaving or knitting .
- ❖ Other approaches use electronic printing, where conductive inks are deposited on the textile substrate and the electrode is integrated on the substrate.
- ❖ Dry and. wet electrodes: Fabric electrodes eliminate the need for conductive gels, reducing skin irritation and enabling prolonged use.
- ❖ Dry textile electrodes rely on materials like silver-coated fibers, conductive polymers (e.g., PEDOT:PSS), and carbon nanomaterials, while wet variants use hydrogel coatings for enhanced signal conductivity.
- ❖ The dry electrode is composed of **four layers**.
  - ✓ The first layer insulates the electrode from the adhesive.
  - ✓ The second layer is a highly conductive material, silver ink, which facilitates the electrode function, as well as the connection with the snap connector.
  - ✓ The third layer consists of an insulating ink that prevents the electrode track from coming into contact with the skin.
  - ✓ And finally, a material deposited on the conductive electrode comprises the fourth layer.

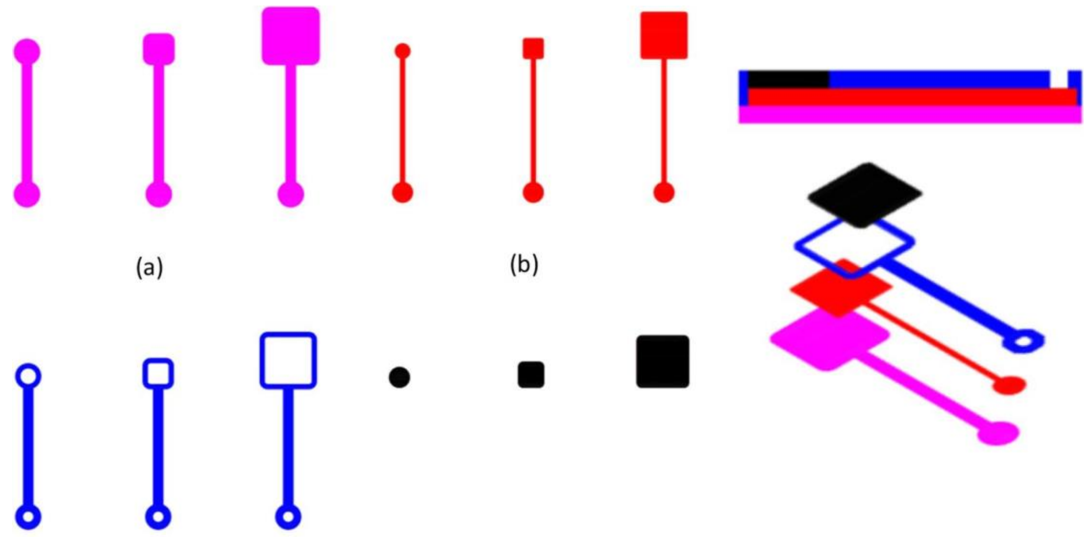

Fig. 1. Parts of the multilayer printed electrode for the three designs: (a) Insulating material to protect the electrode layer and prevent the electrode from coming into contact with the adhesive; (b) Electrode and track printed with a silver conductive ink; (c) Insulating material to prevent the conductive track from coming into contact with the skin; (d) Protection of the electrode made with carbon ink; (e) 3D layout of the electrode showing the different layers.

*[**Figure**: https://www.sciencedirect.com/science/article/pii/S1388248122000467]*

4.6.3 Fabrication techniques:

- Metal plating or magnetron sputtering to create conductive surfaces on textiles
  - ✓ Metal plating is a key technique used to enhance the electrical conductivity of smart fabrics.
  - ✓ Electroless Plating (Chemical Deposition)
  - ✓ Electroplating (Electrodeposition)
  - ✓ Physical Vapor Deposition (PVD) & Sputtering
- Conductive yarn integration during knitting/weaving for seamless electrode embedding.

  Integrating conductive yarns during knitting involves incorporating these yarns into the textile structure during the knitting process, allowing for the creation of conductive fabrics and e-textiles with applications like heating, sensing, and shielding.

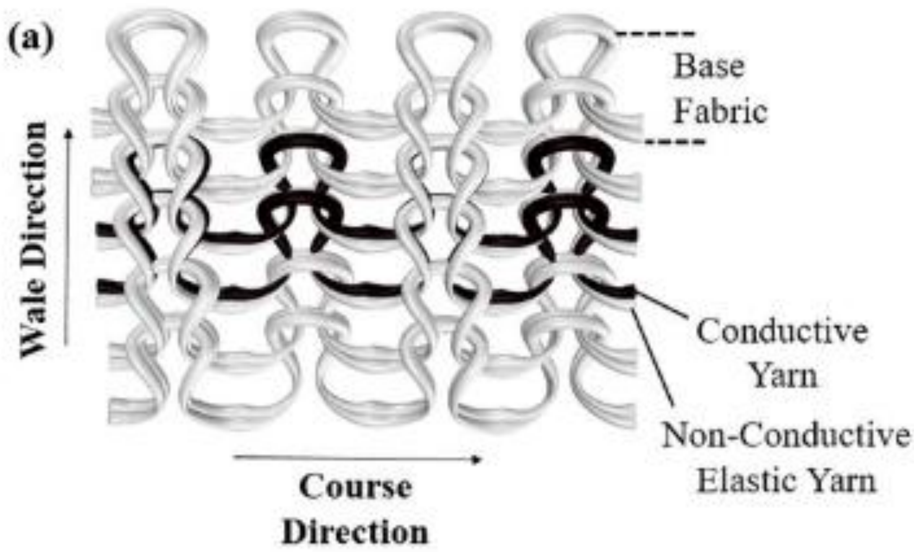

Figure 2. Conductive yarn integration during knitting

- ❒ Hybrid materials like silver-polyester-spandex blends that balance flexibility and conductivity

4.6.4 System Architecture:

Modern ECG smart clothing typically features:

- ❒ **Sensor layer**: 3–5 textile electrodes strategically placed based on body-surface potential mapping (BSPM) to optimize signal quality.
- ❒ **Data transmission**: Bluetooth/WiFi modules embedded in clothing for real-time streaming to smartphones/cloud platforms.
- ❒ **Analysis backend**: AI-powered algorithms on PC/cloud systems for long-term trend analysis and anomaly detection

The system mainly consists of three subsystems: smart clothing, smartphone, and PC terminal. The three subsystems are connected together by some wireless communication technologies, such as WiFi, Bluetooth, cellular network, and Internet.

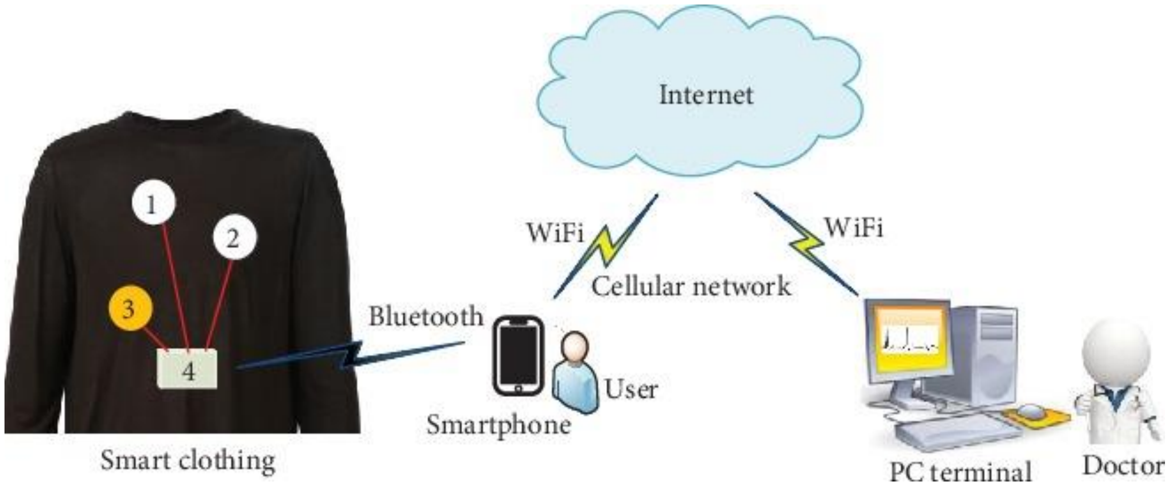

Figure 3. Wearable ECG measurement architecture based on smart clothing

The No. 1 and No. 2 electrodes are used to record the ECG signals on the body surface, while the No. 3 electrode fixed in the specific position on the user's body is used to obtain a reference potential that will help to reduce the common-mode interference between the two ECG signals. There is also a rectangle on the smart clothing marked as number 4 in Figure 3. It is a signal receiver that connects to the three ECG electrodes by conductive textile yarns, and it can transmit the ECG signals acquired to a smartphone. The block diagram of the signal receiver is described in Figure 4.

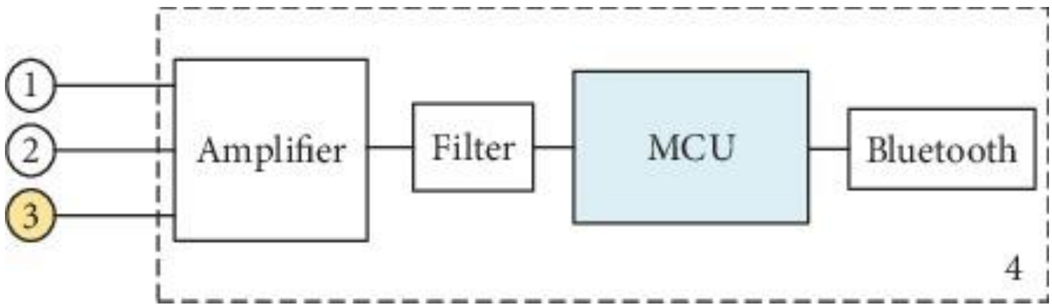

Figure 4. Block diagram of Signal Receiver

The signal receiver is designed based on an embedded system technology. Its components include a differential amplifier, a bandpass filter, a Microcontroller Unit

(MCU), and a Bluetooth module. The differential amplifier can suppress the common-mode noise and amplify the ECG voltage from the textile electrodes. The smartphone based on the IOS or Android operating systems will act as a portable device. When some special App programs designed for the processing of ECG signals are installed on the smartphone, the smartphone can display the ECG signals in real time for the user of the smart clothing, which allows the user to know his/her heart parameters anytime and anywhere.

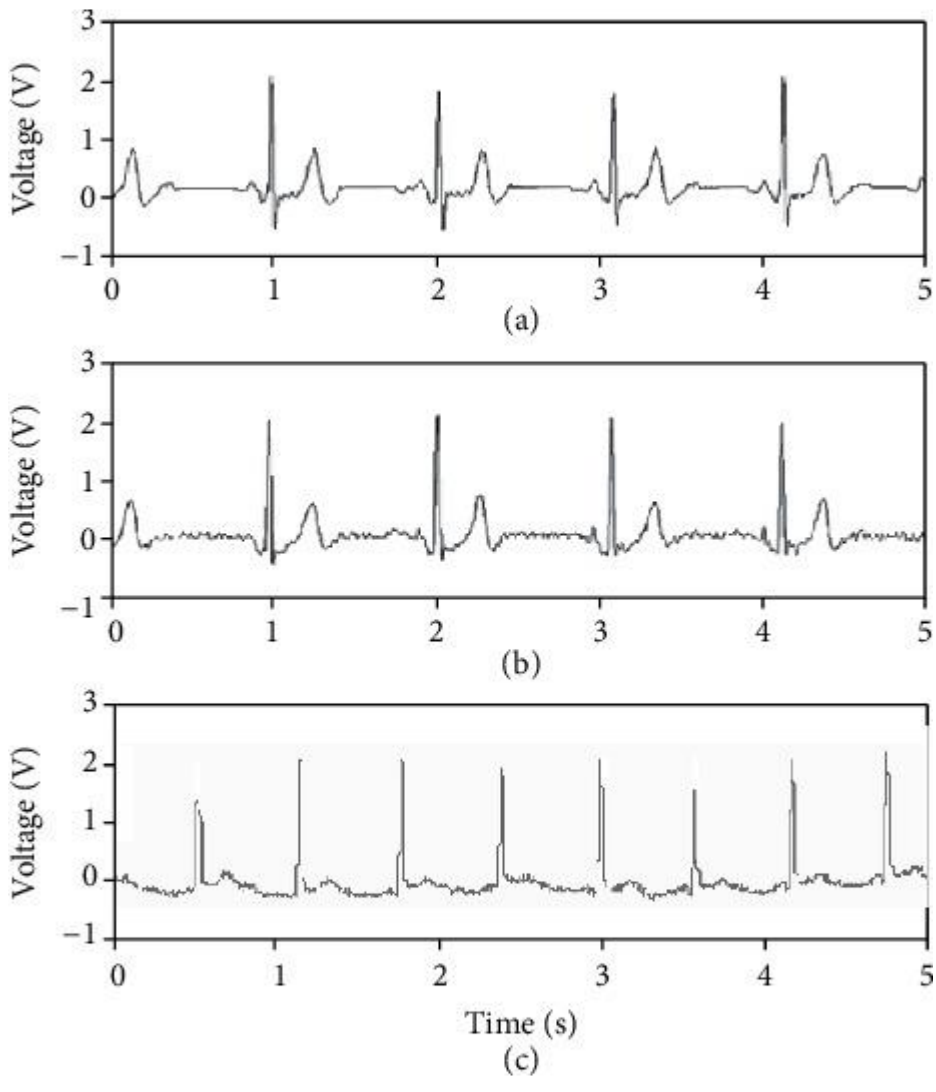

Figure 5: ECG waveform of conventional electrode and textile electrodes.

[Figure: https://pmc.ncbi.nlm.nih.gov/articles/PMC7201832/]

Figure 5(a) is the ECG signal measured by the conventional electrode while sleeping, and Figures 5(b) and 5(c) are the ECG signals measured by the textile electrode while sleeping and jogging.

4.6.5 Signal Quality and Comfort :

Factor	Advancement
Skin contact	Reduced impedance through elastic conductive fabrics conforming to body contours.
Motion artifacts	Machine-washable electrodes with <10% signal degradation after 50 washes.
Wearability	Breathable, moisture-wicking fabrics supporting 12+ hours of continuous use

4.6.6 Applications:

i. **Remote Patient Monitoring:**
   a. Smart textile ECG systems enable healthcare professionals to monitor patients remotely, reducing the need for frequent clinic visits.

ii. **Preventive Healthcare:**
   a. Continuous monitoring can help detect early signs of cardiovascular problems, allowing for timely intervention.

iii. **Sports and Fitness:**
   a. Athletes can use smart textile ECG systems to monitor their heart rate and cardiac function during exercise.

4.6.7 Challenges:

i. **Signal Quality:**
   a. Maintaining consistent and accurate ECG signal quality in dynamic conditions (e.g., during movement) is a challenge.

ii. **Durability and Washability:**
   a. Smart textiles must be durable and washable to withstand regular use.

iii. **Data Security and Privacy:**

   - Protecting the privacy and security of sensitive medical data is crucial.

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