LONGECG—Low-cost low-power Cooperative Sensors

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A new architecture of cooperative sensors especially suited for their integration in clothes for the long-term measurement of multi-lead ECG is in development. All sensors are connected to the same wire used as potential reference, synchronization, and remote powering. The sensors are essentially a low-power ASIC that ensures low-cost, highest miniaturization, and high quality ECG signals with dry electrodes.

Medical diagnostics based on classical measurements such as ECG (electrocardiograph) are usually performed in clinical settings by means of numerous adhesive gel electrodes, all linked to a recorder by cumbersome cables. However, disease symptoms do not appear on demand and so patients can benefit from daily long-term monitoring which is only possible with wearable devices. Existing portable solutions (so-called Holter) are bulky with loose cables and hence not wearable in a modern sense (not integrated), as shown on the left of Figure 1.

CSEM proposed the concept of *Cooperative Sensor* to address the integration of dry electrodes in garments while keeping the highest signal quality. In the context of ECG, cooperative sensors are active electrodes (i.e., with in-situ amplification) *connected in parallel* to a bus in contrast to the classical approach that uses electrodes which are usually passive, rarely active, and always connected with shielded or multi-wire cables in a *star arrangement* to a central unit. Therefore, one of the major advantage of CSEM's cooperative sensors is a drastic reduction of connecting complexity, which is particularly advantageous for systems with many electrodes in a wearable form factor.

However, so far, cooperative sensors required to be powered by their own power supply, which limits the integration and made battery management difficult. In the so-called LongECG development, we focus on a variant of cooperative sensors that allows them to be centrally powered via the single wire to which all sensors are connected. The same wire is therefore used as reference potential for the ECG measurement, for synchronization, and for powering. The return of the powering current is achieved via the body. In order to comply with the medical standards that drastically limit leakage currents (i.e., currents flowing across the body) to a very low level, the sensors must be ultra-low-power. This feature is of course also beneficial for autonomy, thus enabling continuous multi-lead ECG recordings of 20 or more days. In order to make the sensors as small and flat as possible, all sensor electronics is integrated in an ASIC (Application Specific Integrated Circuit).

The recorder shown in Figure 2 is also connected to the wire linking the sensors. It includes a rechargeable battery and memory for 20 days of autonomy. When disconnected from the garment, the recorder can be connected to a computer for data download and battery recharging via a USB link.

Special attention has been paid to the ergonomics and usability in the early phase of the project. Several doctors were consulted to define the medical needs. Moreover, mockups of textiles and sensors have been designed and prototyped. A particularly interesting design (patent pending), shown on the right of Figure 1, features sensors that can be freely positioned by the doctor by clipping them in a similar way as buttons in one of the numerous holes offered by a textile mesh. In Figure 1 (right), two blue sensors with a diamond shape are visible. We designed the electronics so that up to 10 sensors can be inserted. The mesh is conductive on its outer surface and is therefore the connecting wire required for this new architecture of cooperative sensors. This design illustrates well the advantage of the approach, since free positioning would be virtually impossible for any architecture with more requiring connecting constraints (e.g., a shielded cable per electrode in the classical approach). The recorder is not visible in Figure 1, but is placed on the side.

Figure 1: Classical solution (called Holter) to measure medical multi-lead ECG (left) and wearable solution with dry-electrode cooperative (right) showing a mock-up of the targeted wearable (button sensor inserted in an electrically conductive mesh allowing free positioning of sensors).

Figure 2: Recorder with USB connector for connection to garment as well as download and recharging with a computer.

This activity follows a set of achievements progressively obtained at CSEM thanks to a close collaboration between the MedTech (medical technology) and Systems-on-Chip (SoC) research activities where several variants of CSEM patented cooperative sensors have been demonstrated and tested against medical standards. The presented architecture focuses on ECG, but other signals can as well be measured. Cooperative sensors are in particular well suited for a new generation of wearables that will allow multi-signal measurement from a large number of spots spread over the body paving the way to wearable imaging technology [1].

[1] M. Rapin *et al.*, “Wearable Sensors for Frequency-Multiplexed EIT and Multilead ECG Data Acquisition,” IEEE Transactions on Biomedical Engineering, July 2018.