MONIMIP – Wearable EIT System with Cooperative Sensors

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Cooperative sensors are a new technology developed by CSEM that allows simultaneous measurement of high-quality biopotentials (e.g., ECG) and impedance with dry-electrode low-power button-sensors. One advantage is the extremely low connection requirement that allows the integration of the electronics in textile easy and 'seamless', especially for systems with large numbers of sensors. The MONIMIP demonstrator features 50 sensors simultaneously measuring 25 ECG-leads (each at 500 #/s) and 25×25 tetrapolar complex impedances (each at 80 #/s).

The key to successful wearable systems is ergonomics and signal quality. Unfortunately, the classical approach for ECG/EIT metrology cannot simultaneously fulfil these two requirements: either a system has good signal quality, but poor ergonomics (mainly due to shielded cables, cumbersome high-power electronics, and gel electrodes) or better ergonomics, but lower signal quality (*e.g.*, crosstalk, noise, mains disturbance, motion artefacts, etc.).

A few years ago, CSEM proposed a new approach that solved the issue for a single ECG lead and impedance channel thanks to two cooperative dry-electrode sensors connected with a single unshielded and weakly insulated electrical connection. It can be theoretically shown and has been experimentally verified that the signal quality is equivalent (also in electromagnetically noisy environment) to what can be obtained with the best shielded cables or with active electrodes. This patented technology has been transferred to the Swiss startup company SenseCore (left of Figure 1).

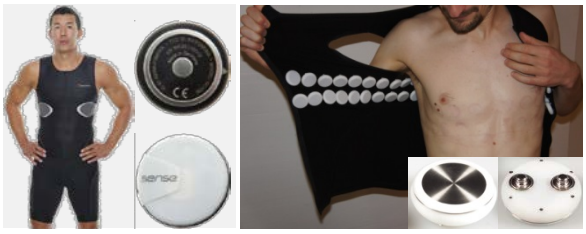

Figure 1: (left) SenseCore's product; (right) EIT system made of cooperative sensors.

Among other goals, MONIMIP intended to go a step further by: 1) extending the number of measured biopotential and impedance signals beyond one; 2) reducing the size and packaging complexity of the sensors; and 3) eliminating the sensitivity of the measurements to impedance variations of the electrical connection linking the two sensors (which is an issue if the electrical connection is made of conductive textile).

The solution to these three challenges has been found and a patent filed. A first demonstrator is shown in Figure 1 (right). It comprises a vest (with central zipper for easy donning and doffing) in which are clipped 25 sensors injecting a current and 25 sensors measuring the skin potential (with respect to the vest electrical connection). The principle of the MONIMIP approach is shown in Figure 2. The two sensors in the middle represent two of the 25 sensors injecting a current. They basically consist of a current source injecting a current j_2 in one sensor which is counterbalanced by the current source $j_1 = -j_2$ of another sensor. Any mismatch between the two sources would result in a leakage current j_0 that is measured in the leftmost sensor so that one of the two sources can be automatically adjusted. Each current source can be programmed to inject a current resulting from a linear combination of 25 sine and cosine carriers at 50'000±k·80 Hz with $k \leq 12$.The skin potentials are measured with respect to the electrical connection by the rightmost sensor—which is one among 25 sensors dedicated to this function. The potential of the electrical connection is controlled to equal the average of all measured potentials by the controller *G*. Therefore, the voltage between the electrical connection and the body is of the order of fractions of millivolts (instead of several volts in classical cables). Hence, the skin impedance itself suffices to ensure the insulation between the vest and the body core (no shield needed). The measured voltage u_3, … is a) the ECG for the low frequency band and b) the impedance when demodulated at the carrier frequencies.

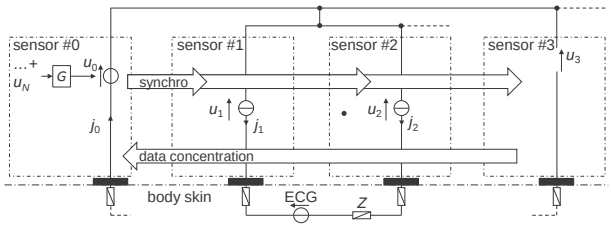

Figure 2: Principle of the MONIMIP approach (patent pending).

Of course, this can work only if all sensors work in concert, *i.e.*, share the same time base and exchange information. This is achieved thanks to the voltage source u_0 in the leftmost sensor that sends synchronization and other information to the other sensors at high frequency (2 MHz)—so not to interfere with ECG and impedance measurements. The other sensors *i* received this information by the voltages u_i. The communication in the other direction is achieved thanks to the current sources j_i that inject a current, also at high frequency, which is picked up by the leftmost sensor. This mechanism solves the first of the aforementioned challenges.

The goal of further miniaturizing the sensors is achieved by endowing each sensor with only one contact with the skin. The previous technology required two contacts and a minimum distance between them limiting the size reduction. With the newly developed technology, the size of the sensor mostly depends on the degree of integration and therefore can be substantially reduced.

The last challenge is mastered thanks to a subtle arrangement of the electrical connection (see Figure 2) resulting from the following method: considering the frequency band about 50 kHz, 1) connect together the sensors crossed by a current; 2) connect together the other sensors; and 3) connect the two groups at a single point (see Figure 2).

We expect the cooperative-sensor technology to be a major future breakthrough in the domain of ergonomic complex humvan vital sign monitoring systems and we would like to thank the Swiss Confederation for their financial support.