Lung-monitoring Wearable with Low-power Sensors Seamlessly Integrated in a Garment

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Respiratory diseases like chronic obstructive pulmonary disease or lower respiratory infections rank among the top causes of death worldwide. Traditional surveillance schemes with intermittent disease follow-ups by physicians are not efficient enough at preventing exacerbations. In the EU project WELMO, comfortable vests with seamlessly integrated low-power sensors were developed to continuously monitor the health status of the lungs through electrical bioimpedance and chest sound measurements. Their performance was successfully verified and validated in benchtop tests and pilot clinical studies.

Lung diseases are classically monitored in clinical settings using stationary or portable approaches (e.g., chest radiography, spirometry, auscultation). WELMO developed and tested sensor vests for remote monitoring of the lungs. Each vest contains 18 sensors which record chest sounds and bioimpedances for electrical impedance tomography (EIT), a non-invasive medical imaging modality. Designers of wearables face three main challenges when integrating sensors in garments: (1) electrically connect the sensors to each other (2) power the sensors with a small battery for long-term measurements (big batteries reduce the wearing comfort); (3) integrate the sensors in the garment so that users perceive no difference to ordinary clothing. Challenge (1) has been solved with CSEM's patented cooperative sensors (CS), a solution which allows connecting a multitude of bio-signal sensors with one or two wires only while at the same time not compromising the signal quality. Connecting biosensors with one or two wires only is far from trivial, since the same wire(s) simultaneously convey multiple electrical impulses, whose amplitudes differ by magnitudes. Employing CS, WELMO tackled challenges (2) and (3) by developing ASICs which reduce the sensor volume by a factor of ~3 and the power consumption by a factor of ~20 when compared to the sensors built with discrete electronic components. As shown in Figure 1 the small sensor size enables their seamless integration in a garment.

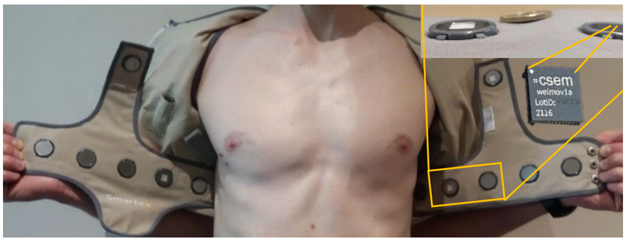

Figure 1: WELMO harness containing 18 sensors. Inset: Side view of 2 of the ultra-flat sensors. The packaged ASIC is 6 × 6 mm small.

The ASIC (die size: 1.8 × 2.2 mm) amplifies the bio-signals as well as communicates with and harvests power from a central recording and powering unit. The die is produced in a mature 180 nm mixed-signal CMOS process, which offers both low-cost production and sufficient performance for a mostly analog circuit working at frequencies up to 1 MHz.

For EIT, the ASIC must be able to both inject an AC current into the electrode and measure the resulting potential of the electrode versus the ground node ("Fabric connection B" in Figure 2) at defined times of the imaging sequence. Both operations need to be performed while maintaining a very high impedance on the electrode terminal. The signal current injection is optimized for high impedance and additionally decoupled by an external capacitor to avoid DC leakage. The receiver uses as a first input stage a unity gain buffer, which connects the high impedance input of the buffer to the electrode. The digital state-machine, which is synchronized to the central unit, activates and controls the current sources in the injection circuit and the operation of the receiving chain. All functions of the ASIC have been successfully verified in benchtop tests.

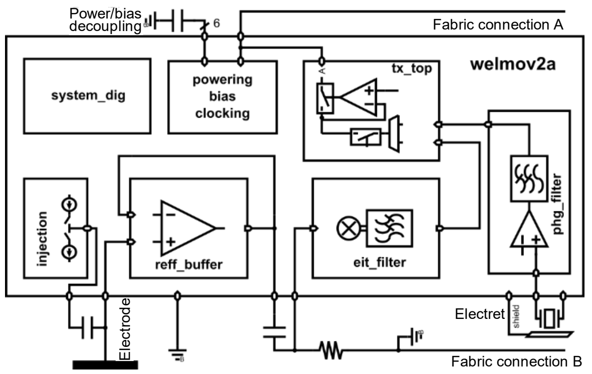

Figure 2: ASIC block schematics and external components. system_dig: digital state machine; tx_top: transmission; phg_filter: sound filter.

In addition to the ASIC, CSEM also developed sensors with discrete components and integrated them in vests (Figure 3). The WELMO sensor vests were validated in two pilot clinical studies which confirmed the WELMO concept (e.g., plausible EIT images present in > 80% of study participants) and highlighted its great potential for long-term monitoring of lung function.

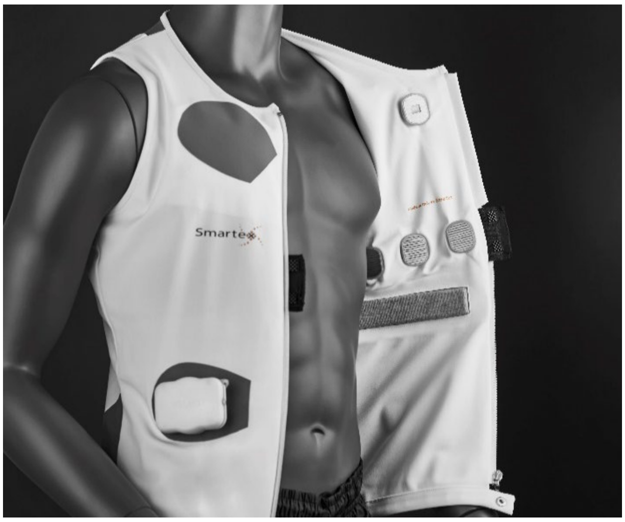

Figure 3: WELMO vest with sensors made of discrete electronics components.

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