Chest-based PPG for Pulse Oximetry and Non-occlusive Blood Pressure Monitoring

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With the global increase of healthcare cost a solution to continuously and inconspicuously monitor the main vital signs is needed to provide an early diagnosis, personalized medical care, and predictive insights. To this aim, CSEM has developed a proprietary chip for dry-electrode electrocardiograph (ECG) and transthoracic impedance measurements [1]. To complement the monitoring capabilities of this solution, and obtain a unique wearable system, a reflective photoplethysmogram (PPG) sensor was added to allow the measurement of peripheral oxygen saturation (SpO_2) and blood pressure by oBPM™ (CSEM's proprietary technology). The present document depicts the prototype allowing multiple signal monitoring at the chest and the performance of SpO_2 estimation from corresponding PPG signals.

Acquiring PPG signal, from a reflective sensor, with sufficient quality to extract physiological parameters such as SpO_2 or blood pressure is recognised as challenging and in certain conditions, the origin of the pulsatile waveform is still discussed [2]. To tackle this challenge CSEM has worked on the design of the sensor geometry and on dedicated algorithms to estimate these parameters.

The system shown in Figure 1 combines the advantages of CSEM's dry-electrode technology with the measurement of green, red, and infrared PPG channels, altogether providing a unique system for the monitoring of several vital signs, including ECG and transthoracic impedance,and parameters, such as heart rate, breathing rate, SpO_2, and physical activity.

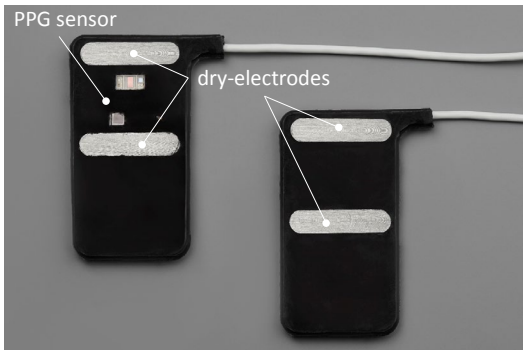

Figure 1: Illustration of the multi-parameter wearable device.

Both sensors contain an own electronics (including a proprietary ASIC) and a battery for 24 hours of autonomy. Data can be stored locally and transferred via Bluetooth for real-time streaming or for download.

Targeting medical application, the system was designed according to the applicable regulations. All materials in contact with the skin are biocompatible according to ISO 10993-1, the system is compliant with the electrical safety standards: IEC 60601-1, and the ECG complies with the medical standard for Holter devices: IEC 60601-2-47.

SpO_2 is estimated from the ratio between red and infrared lights: $R = (AC_{red}/DC_{red}) / (AC_{IR}/DC_{IR})$, with AC and DC being the magnitude at cardiac frequencies and non-modulating components of the PPG signals. SpO_2 is then obtained from the ration R using a calibration function. The performance metric recommended by the ISO 80601-2-61 standard is the accuracy (A_{rms}), defined as the root-mean-square difference between the estimated and reference SpO_2 values.

By taking advantage of the information of the multiple signals acquired at the chest of adult volunteers and by introducing a specific quality index, in a recent study [3], we were able to reduce the SpO_2 estimation accuracy (A_{rms}) from 6.7% to 3.1%. These performances were obtained after an automatic rejection of low-SNR signals by our dedicated quality index (see table below and Figure 2).

Performance metrics	
A_{rms} without data rejection	6.7%
A_{rms} after data rejection	3.1%
Data rejection rate	30%

These results highlight the challenge to acquire reliable PPG signals with a reflective sensor located at the chest – since 30% of the data were rejected – and the importance of our automatic rejection algorithm, as only the results after automatic rejection of noisy data comply with the requirements set by the ISO 80601-2-61 standard (A_{rms} to be ≤4%).

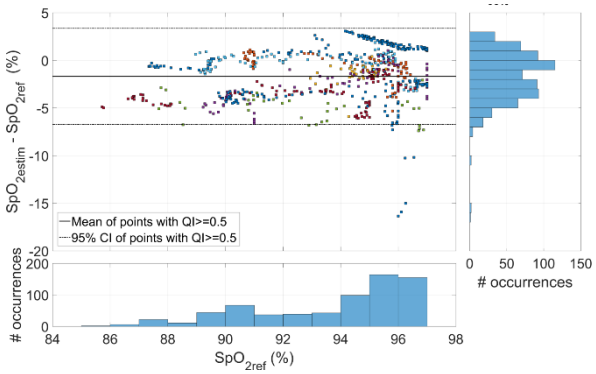

Figure 2: Bland-Altmann analysis, each color represents a subject.

Future work should focus on validation under deeper hypoxia since our hypoxia were limited to values >85%. However the promising results and in particular the capacity of the algorithm to rejected noisy PPG demonstrates the possibility to estimate SpO_2 from reflective PPG and pave the way towards oBPM™ estimation at the chest.

[1] P. Theurillat, *et al*., "Demonstration of a Proprietary Chip for Dry-electrode ECG and Impedance Measurements", CSEM scientific and Technical Report (2017), 118.

[2] A. Kamshilin, *et al*. (2017) "Origin of photoplethysmographic waveform at green light." Physics Procedia 86: 72-80.

[3] M. Proença, *et al*. (2018), "Performance Assessment of a Dedicated Reflectance Pulse Oximeter in a Neonatal Intensive Care Unit", IEEE EMBC 2018 Annual International Conference.