Continuous Non-invasive Measurement of Core Vital Signs on the Hospital Ward

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VITAL+ aims at combining continuous monitoring of blood oxygen saturation, pulse rate, blood pressure, and respiration rate with a non-invasive upper-arm-worn device on the hospital ward. This automation empowers caregivers to focus on caring for patients, while improving safety and comfort.

Vital signs monitoring in hospital ward is critical to provide valuable information to predict patient deterioration or treatment efficiency. The frequency at which patients' vitals should be assessed is a compromise between insufficient monitoring and work overload. This core hospital process is indeed time-consuming and expensive (>10 million inpatients have their vitals taken 3x/day meaning ~150 million minutes of manual measurement per day), is not frequent enough for robust predictive analytics (measuring 3x/day, but not at night, is not enough to provide reliable early warning of patient changes [1]), and suffers from uneven quality with an error rate up to 19% [2].

The VITAL+ project, in collaboration with the company rheo, aims at providing a photoplethysmography (PPG) based solution for continuous monitoring of oxygen saturation (SpO2), pulse rate (PR), blood pressure (BP) and respiratory rate (RR) using a unique and non-invasive upper-arm-worn device (Figure 1).

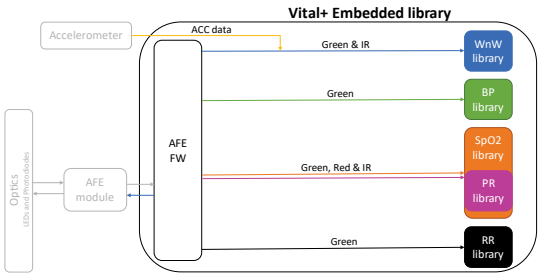

Figure 1 - General architecture of the Vital+ embedded library.

In this collaboration, CSEM developed and evaluated an embedded library, optimized in memory and computational cost for real time processing. This library includes an analog-front-end (AFE) driver controlling the optics for high-quality PPG signal acquisition as well as the following CSEM-proprietary algorithms: (1) a worn-not-worn detector based on accelerometer and PPG signals; (2) a BP algorithm [3], (3) a RR algorithm based on PPG spectral analysis (developed in this project), (4) a PR algorithm based on a detector extracting interbeat intervals, and (5) an SpO2 algorithm [4]. Multiple PPG channels are acquired and controlled by the AFE driver and fed into the different algorithms (Figure 2).

Optics control by AFE driver was assessed by PPG quality evaluation over 10 recordings of ~1h and compared with specific requirements for accurate vital sign estimation. A dedicated clinical data collection campaign (BASEC 2023-01925), made in collaboration with the Pourtalès Hospital (RHNe), has been conducted to pre-validate all algorithms (Table 1). Except for the ongoing BP investigations, all other vital signs were compared against medically validated references.

Figure 2: Pictures of the Vital+ device.

Table 1: Vital signs and their respective protocol and population.

Vital sign	Protocol	Population	Reference
SpO2	1h hypoxia 70-100%	N = 10 healthy subjects	Blood sampling
PR	1h hypoxia 70-100%	N = 21 healthy subjects	ECG
RR	1h controlled RR 5–30 cpm	N = 24 healthy subjects	Flow sensor

PPG signal quality evaluation showed quality metrics compliant with requirements. The SpO2, RR and PR performance (Table 2) meet all medical requirements.

Table 2: Clinical study results per vital sign.

Vital sign	Performance	Acceptance rate [%]	Medical requirements
SpO2	1.98 ± 1.08%	94 ± 8	RMSE ≤ 3.5%
RR	0.7 ± 0.5 cpm	38 ± 11	RMSE ≤ 3 cpm
PR	2.08 ± 0.7 bpm	93 ± 9	RMSE ≤ 5 bpm

This study demonstrates the feasibility of CSEM's approach to embed all algorithms into one single non-invasive device. The 3 validated vital signs reach the expected medical requirements. The next steps are (1) to pre-validate BP estimates, (2) increase the acceptance rate of the RR algorithm, and (3) evaluate CSEM's approach in real conditions (rheo's use case).

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