Wrist-worn Optical Heart Rate Monitoring: a Comprehensive System Approach

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Optical heart rate monitoring has become a commodity in today's smartwatches with a limited measurement precision and reliability, especially during the presence of motion. Expertise in physiology, optical skin interface, electronics, mechanics, industrial design, and signal processing are essential to achieve high accuracy. CSEM solution has demonstrated excellent performance not only for heart rate (HR) monitoring during outdoor activities and exercising, but also for RR interval detection, heart rate variability analysis, perfusion, sleep analysis, and speed assessment.

While sports watches with an integrated optical heart rate sensor technology (OHR), based on photoplethysmography (PPG) have been commercialized for more than two years now, the market has seen recently a widespread use of such functionality within the smartwatch products of the microelectronic and smartphone giants such as Apple, Samsung, Huawei, LG and Sony. Unsurprisingly, not all of these smartwatch products reach the same accuracy and reliability, especially during the presence of motion. Actually, a comprehensive system approach is required to achieve the best heart rate measurement quality, and is even more critical to be able to measure additional parameter like RR intervals, heart rate variability (HRV) or perfusion, using a PPG sensor.

PPG is based on the measurement of the changes in light absorption of the subcutaneous tissue of the skin, typically illuminated with a LED. The light is actually modulated by capillary blood flow, which is used to monitor heart rate. However, even with well-designed sensor interfaces, two major issues are sources of error: ambient light and movement artefacts. Ambient light fast variations can become a major issue when its fluctuations show a high amplitude above the sampling frequency, which can occur with bright indoor lighting or when moving in sunny conditions. Today's available state-of-the-art solutions do not prevent the saturation of the input stage in every use case.

CSEM has been active in the OHR domain for more than 15 years now, and its first granted patent on this issue dates back to 2001. Multidisciplinary know-how and expertise in physiology, microelectronics, opto-mechanics and signal processing is key to success, and CSEM developed an innovative solution to overcome the ambient light variations, and which is implemented in the analog front end, using its latest application-specific integrated circuit (ASIC) generation.

Table 1: Mean performance of PulseOn HR Monitor in outdoor activities (N=number of recorded events).

Main activity	PulseOn	
	Reliability (%)	Accuracy (%)
Walking (N=3)	94.1	96.6
Running (N=17)	99.1	97.9
Cycling (N=4)	95.2	97.3
Mean (N=24)	97.8	97.6

Moreover, motion artefacts lead to small displacements in the sensor-skin contact and in the tissue, or induce variations in the blood flow itself. Advanced algorithms apply integrated 3D-accelerometer data to reduce motion artefacts and provide accurate HR estimation even during very intensive training, spanning up to full running speeds and maximum HR levels. An experimental evaluation of the performance of CSEM's algorithms implemented in the PulseOn[1] HR monitor on 19 healthy subjects obtained a mean accuracy and reliability above 97% for outdoor activities, as detailed in Table 1[2].Today's research activities at CSEM on PPG measurement at wrist target future health and medical applications. Figure 1 shows the HRV accuracy based on CSEM's proprietary RR interval detection algorithm and which performs within a standard deviation of 12ms when compared to ECG devices[3].

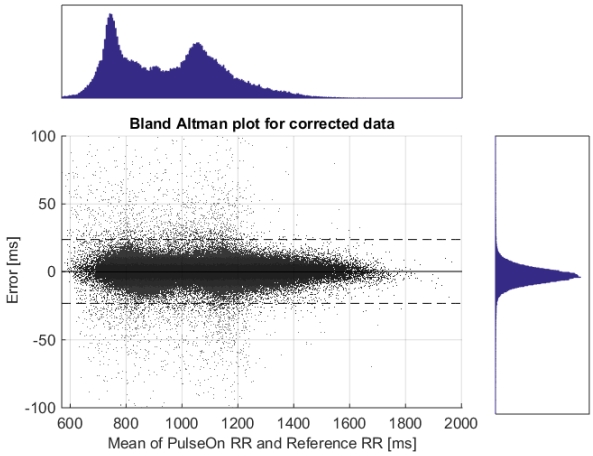

Figure 1: Bland - Altman plot comparing the reference ECG-obtained RR intervals to the PPG-obtained RR intervals. The confidence interval ($\mu \pm 2\sigma$, depicted by the dashed lines) is [-23.15,23.83] ms.

CSEM's health watch prototype is shown in Figure 2 and is providing not only HR, R-R intervals, perfusion, activity, and user's posture and speed but is also able to record and stream wirelessly raw PPG and accelerometer data during a period of more than 24hours before recharging.

Figure 2: Health watch prototype developed at CSEM for the monitoring of motion related and cardiac activity parameters.

The smartwatch activities are executed in the frame of CSEM's Medtech research activity and CSEM acknowledges and thanks the Swiss Confederation for its financial support.

[1] www.pulseon.fi

[2] R. Delgado-Gonzalo, *et al.* "Evaluation of accuracy and reliability of PulseOn optical heart rate monitoring device" EMBC 2015

[3] J. Parak, *et al.* "Evaluation of the Beat-to-Beat detection accuracy of PulseOn wearable optical heart rate monitor", EMBC 2015