Optical Heart Rate Monitoring – Continuous Improvement Strategies

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Optical heart rate monitoring (oHRM) has become a staple in today's wearables. Measuring heart rate in daily life is challenging: algorithms must track pulses at rest, during rhythmic activities (e.g., walking, running, biking), and non-rhythmic activities (e.g., typing, cooking). Accurately measuring heart rate requires a robust algorithm that can handle these different use cases in real-time. At CSEM, the development of oHRM algorithms has undergone continuous improvement and development for the past 2 decades, keeping up with and anticipating user needs in the realm of physiological tracking. In this report, we describe our continuous improvement strategies and the most up-to-date results of our oHRM library.

CSEM's work on optical heart rate monitoring (oHRM) goes back to the early 2000s, with the first patent on PPG granted in 2001 [1]. As a main pillar of CSEM's Digital Health activities, oHRM is used in different fields ranging from lifestyle to sports to medical applications. Consequently, the maintenance of CSEM's oHRM algorithm library became a must to ensure high accuracy with respect to commercially available devices.

The oHRM algorithm library was developed for low-power embedded, real-time applications [2]. To cover the widest possible array of use cases, the algorithm extracts information from photoplethysmography (PPG) and accelerometer signals, as shown in Figure 1. The library fuses the classification of physical activity (including movement rhythmicity) and PPG signals to output instantaneous heart rate (HR) values.

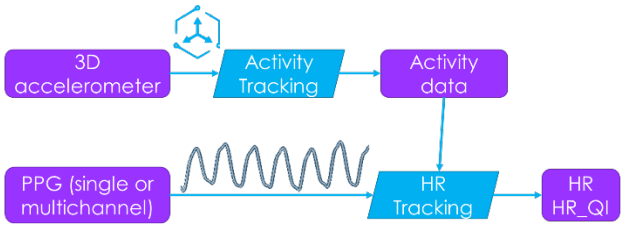

Figure 1: oHRM algorithm block diagram.

The oHRM library is validated on a large database consisting of more than 740 hours of simultaneous PPG/accelerometer and ECG (electrocardiogram) data obtained from 391 subjects. The database includes a wide range of activities: walking, running, biking, skiing, daily activities, and sleep. The ECG-derived heart rate serves as the reference for comparison.

Over the years, the library has undergone several improvements to ensure high accuracy in widespread use cases, especially during sports and activities of daily life. Therefore, strategies were put in place to automatically track these improvements. The sequence shown in Figure 2 describes this process: when an improvement is identified, the corresponding code development is pushed to a source control management system that performs code verification. Then, the statistical performance of the library's HR output is verified against ECG reference data to ensure that the modifications improve the results. Finally, computation costs and memory footprints are evaluated (Table 1).

Table 1: oHRM library computational and memory requirements (RAM: Random Access Memory, KIPS: kilo-instructions/s).

RAM	Flash	KIPS	KIPS_MAX
6 kB	30 kB	10.5	13.5

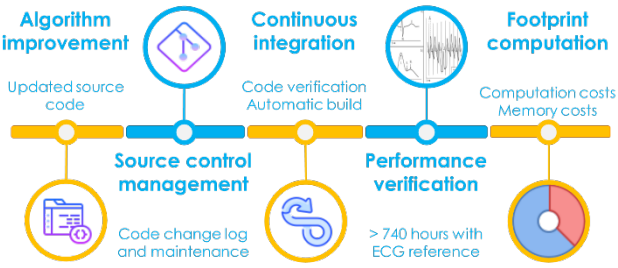

Figure 2: Continuous improvement strategies applied to oHRM.

Recently, the following improvements were made on the library:

- Removal of double beat detection at low frequencies
- Stability improvement during activity transitions and sports
- HR estimation improvement during rhythmic activities (walking, running, biking)
- Improvement of HR convergence time

The most recent algorithm performances against ECG reference are shown in Table 1. The performance metrics, especially for lab and outdoor, reveal a decrease in mean absolute error and increase in reliability.

To conclude, CSEM's oHRM technology is undergoing constant improvements to maintain high performance and anticipate novel use cases and wearable users' needs. The current results exhibit low errors and high reliability that are perfectly suited to embedded, real-time HR tracking on commercial devices

Table 2: oHRM algorithm performance. MAE: Mean Absolute Error, Reliability: % of results < 10 bpm error, both in as mean±standard deviation. Lab and outdoor activities mainly include sports, whereas daily activities may include any type of activity. Bold: results after implementing the improvements.

	Lab	Outdoor	Sleep	Daily activities
#subjects	87	146	117	41
#hours	72.4	123.3	483.5	62.3
MAE (bpm)	4.5±2.1 **4.3±1.9**	6.3±5.1 **6.1±4.8**	1.6±1.0 **1.6±1.0**	4.7±3.2 **4.8±3.3**
Reliability (%)	89.6±7.1 **90.1±6.6**	83.0±18.2 **83.6±17.3**	97.8±2.4 **97.8±2.5**	87.9±12.2 **87.3±12.9**

[1] C. Verjus, R. Vetter, P. Celka, P. Renevey, "Portable equipment for heart rate measuring and monitoring," EP1374763, Sep. 26, 2007 [Online]. https://patents.google.com/patent/EP1374763

[2] R. Delgado-Gonzalo, J. Parak, A. Tarniceriu, P. Renevey, M. Bertschi, I. Korhonen, (2015), Evaluation of Accuracy and Reliability of PulseOn Optical Heart Rate Monitoring Device. In Conf Proc IEEE Eng Med Biol Soc (pp. 430–433).