Novel Ambient Light Rejection System for PPG-based Measurement Devices

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Photoplethysmography (PPG) is becoming the standard technology for heart rate measurements in wearables because of its ease of use. Nowadays, numerous commercial off-the-shelf (COTS) analog front end (AFE) components dedicated to PPG are available. However, in everyday use cases, insufficient ambient light rejection (ALR) leads to poor AFE performances and subsequent inaccurate heart rate estimations. The results of a novel approach that solves ALR issues in daily life use cases are presented herein. CSEM has been active in the domain of PPG sensing and processing for more than 15 years, covering R&D activities ranging from optical design, AFE development, and embedded algorithms to application-specific integrated circuit (ASIC) implementation.

Current trends in photoplethysmography (PPG) measurement rely on the use of integrated analog front end (AFE) components. Advanced COTS AFEs have been designed to automatically cope with all known PPG variables and make them easy for the system architect to embed. Unfortunately, the performance of existing AFEs is not optimal in several real use cases, in particular when referring to ambient light rejection (ALR).

PPG is based on the use of light emitting diodes (LEDs) and photodiode (PD) sensors. The output signal modulation results from variations of light absorption of subcutaneous tissues due to the change of blood volumes originating from heart strokes and therefore enables heart rate (HR) assessment. The weak point of PPG is that the PD is actually mixed with two other components, [1] namely a motion artefact signal (which depends on body movements and system fixation) and an ambient light perturbation (which varies in intensity and pattern depending on indoor and outdoor environments, completely masking the signal of interest most of the time).

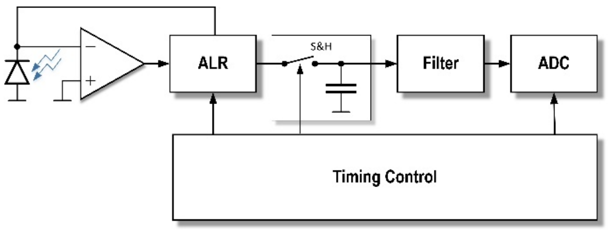

Figure 1: Simplified schematic of the novel ALR approach for PPG AFEs. Note that ambient light is directly removed at the first amplification stage, providing optimal PPG measurement performances in realistic indoor and outdoor scenarios.

The ALR state of the art for COTS AFEs is based on high-pass filtering of the output signal after a first amplification stage. More advanced implementations rely on sampling ambient light signals when the PPG-light source is switched off. A combination of both approaches is also known. Such implementations suffer from saturation of the first amplification stages when exposed to intense ambient light conditions.

CSEM has developed a new method that overcomes the aforementioned limitations by removing ambient light directly at the input of the first amplification stage, that is, on the PD itself. In addition to the advantages of 1) never saturating the analog chain and 2) avoiding the need for the microcontroller to sample ambient light, the major advantage is that the method allows for significantly higher analog signal gains. A simplified schematic of the implemented ALR is depicted in Figure 1. Additionally, Figs. 2 and 3 illustrate the performance of the novel ALR approach in a realistic use scenario.

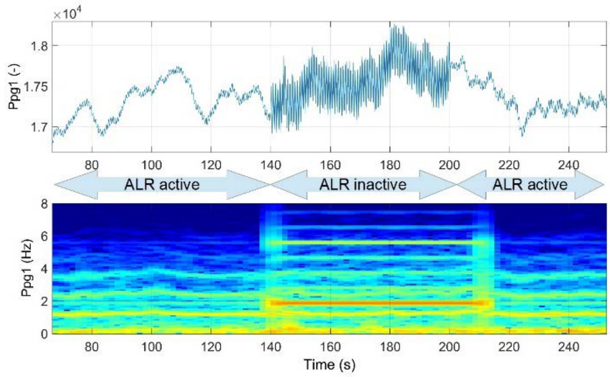

Figure 2: Performance of the novel ALR in a typical outdoor use case scenario; note the influence of ambient light on both the temporal and frequency signals during the 60-s disconnection of the ALR system. The user's pulse rate is 1 Hz and, during a walking exercise, the arm shadows the sun and produces a 2-Hz artefact.

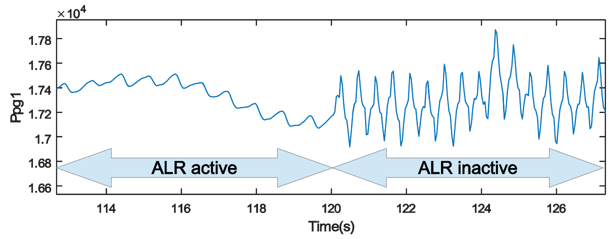

Figure 3: Detailed illustration of the performance of the novel ALR.

In order to set the novel ALR according to the benchmark of COTS AFEs, Table 1 provides a high-level benchmark comparison of performances, including: 1) the amount of saturation in the input stage, 2) the dynamic range accepted by the ALR, and 3) the power consumption.

Table 1: Performance of the novel ALR approach when compared to three competitor AFEs.

Feature	AFE 1	AFE 2	AFE 3	CSEM AFE
Saturation at input stage	GOOD	GOOD	MEDIUM	GOOD
Accepted light dynamic range	MEDIUM	BAD	GOOD	GOOD
Power consumption	GOOD	BAD	MEDIUM	GOOD

The novel ALR is now available at CSEM for demonstration purposes and is a main building block of the new generation of proprietary PPG-based wearables, measuring HR, SpO2, NIBP, and other vital signs. The ALR described herein has been implemented into CSEM's proprietary PPG-dedicated ASIC (application-specific integrated circuit), called PulseMon, whose datasheet is available on request.

[1] M. Lemay, *et al.*, Wearable Sensors, Elsevier, 2014, 105-129 ISBN 9780124186620.