A Wearable Dietary Monitor using a PPG-based Chewing Sensor

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CSEM has developed a novel wearable dietary monitoring system using a photo-plethysmography-based chewing sensor. Non-invasive, compact, and unobtrusive, it is dedicated to monitoring eating behavior and daily activity of teenagers and young adults with the aim of providing personalized guidance to tackle the ongoing obesity epidemic or eating disorders.

Obesity and eating disorders are a major health concern in the Western world: obesity has reached epidemic proportions globally, with 400 million obese adults worldwide and one billion who are overweight. Meanwhile, the prevalence of eating disorders, such as bulimia and anorexia, has essentially remained at about 3% across the population over the years.[1] Most treatments are marginally effective, having minor clinical or sociological impact. Monitoring and modification of dietary behavior has been shown to be a significantly more promising approach for the treatment of obesity and eating disorders. Within the framework of the European project SPLENDID,[2] CSEM has developed a novel wearable sensor for dietary monitoring, namely a photo-plethysmography (PPG)-based chewing sensor.

The system is composed of two parts: a PPG-based chewing sensor to detect chewing events and a dedicated data logger to store, process, and transmit the acquired optical data via Bluetooth. In addition, an activity sensor based on a triaxial accelerometer has been embedded in the data logger to monitor the movements and physical activity of the user. An associated smartphone application running specific algorithms allows personalized guidance to train users to improve their eating and activity behavior through the data transferred by the data logger. In order to have an unobtrusive and cost-efficient system as well as to promote its diffusion among teenagers and young adults accustomed to listening to music, the chewing sensor has been successfully embedded into a custom-designed in-ear headset. The chewing sensor is connected via a cable to the data logger (45 × 78 × 14 mm), as shown in Figure 1.
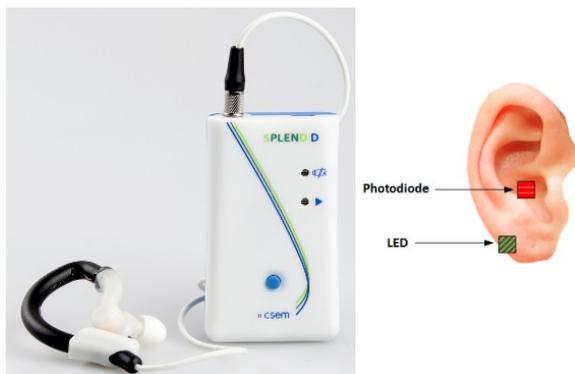

Figure 1: Wearable sensory eating tracker developed by CSEM. (Left) PPG chewing sensor connected to the data logger; (Right) PPG sensor placement.

Physiologically, the jaw and the ear are closely related. The mastication and the muscles which control the jaw are also related to the ears. There is indeed strong experimental evidence that chewing activity significantly affects the PPG signal measured at the ear. The proposed PPG sensor is positioned in the ear concha with a Light-Emitting Diode (LED) placed behind the ear and a photo-diode inserted in the ear canal. Traditionally, measurement of heart rate or blood oxygen saturation by PPG is highly sensitive to movement artefacts; in our application, the signal of interest is in fact the signal captured due to movement caused by mastication.

The acquired optical signal is pre-amplified, filtered, and sampled at a fixed sampling frequency of 21.3 Hz. In order to avoid signal saturation due to high density of ambient light, a proprietary compensation technique is applied. Figure 2 depicts the signal-processing block diagram.
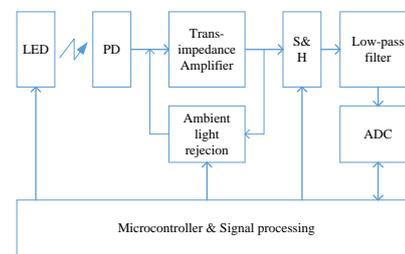

Figure 2: Signal-processing block diagram of the PPG sensor.

This in-ear PPG sensor is small and highly non-intrusive. As it does not capture sound, it is not affected by ambient noise, talking, or other types of parasitic signals.

The monitoring system has been evaluated on a dataset recorded at Wageningen University (the Netherlands). It contains recordings of 21 individuals wearing the PPG sensor. A segment of signal related to chewing events is shown in Figure 3. The sensor has yielded satisfactory results, especially for snack detection, where values of over 91% are achieved for both precision and recall.[3] We thus believe that it can be used for robust, objective dietary monitoring in real-life conditions.
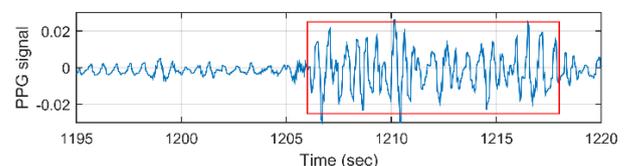

Figure 3: DC-free signal from the PPG chewing sensor. The red box indicates chewing activity.

[1] http://www.world-heart-federation.org/cardiovascular-health/cardiovascular-disease-risk-factors/obesity/

[2] http://splendid-program.eu/

[3] V. Papapanagiotou, C. Diou, L. Zhou, *et al.*, A novel approach for chewing detection based on a wearable PPG sensor, in *Proc. EMBC 2016*, 2016.