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ZenPPG: A Modular Multi-Channel Photoplethysmography System

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Background

In recent years, photoplethysmography has generated renewed interest among researchers. In particular its potential use as a diagnostic tool has been demonstrated as well as the possibility of its use for measuring physiological variables beyond arterial oxygen saturation and heart rate. These variables include venous oxygen saturation [1], vascular tone [2], fluid response [3] and blood pressure [4]. Progress in these areas is dependent on the ability to record raw photoplethysmographic (PPG) signals, ideally at more than one wavelength, for real-time or retrospective analysis.

'ZenPPG' is a system designed and developed at City University London, for use by researchers, which combines the advantages of standardization of instrumentation, compatibility with commercial probes and the ability to customize the system for specific projects. The ZenPPG system comprises two independent PPG/pulse oximetry channels which allow the raw AC and DC PPG signals to be accessed and recorded using a data acquisition system. The system was calibrated using a commercial SpO_2 simulator, and evaluated on a set of healthy volunteers.

Materials and Method

The design of the ZenPPG system was based on previous instrumentation developed by the group [5], and was designed to be flexible and modular, allowing incremental improvements during subsequent development. The main parts of the system are: a system bus, PPG modules (current supplies, probe connector board and transimpedance amplifiers) and power supply conditioning board (Figure 1a)

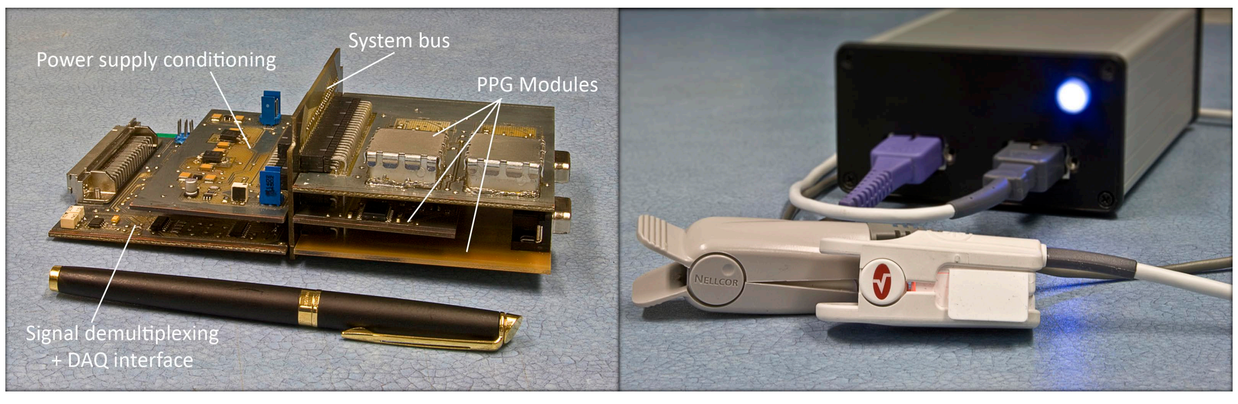

Figure 1 (a): ZenPPG instrument unit. (b): ZenPPG system bus and PCB modules.

The system is housed in a portable unit (Figure 1b) measuring 16.0 x 10.3 x 5.4 cm. The front of the unit incorporates 2 standard D9 connectors for connecting two probes, and the rear panel contains a 68-pin serial bus connector for interfacing to a National Instruments data acquisition card. A custom LabVIEW (National Instruments, Austin, TX, USA) virtual instrument (Figure 2) facilitates data acquisition, device control and real time estimation of SpO_2 and heart rate.

The prototype system was calibrated using an Index 2 SpO_2 simulator (Fluke Biomedical, Everett, WA, USA) with a commercial pulse oximetry finger probe (Masimo Inc., Irvine, CA, USA). In order to validate the functionality and accuracy of the ZenPPG system, signals were recorded using commercial pulse oximeter probes placed on the first and second fingers of the right hand in six healthy volunteers. The signals were used to calculate SpO_2 values, which were compared with simultaneously-recorded SpO_2 values from a Masimo Radical-7 commercial pulse oximeter used on the first finger of the left hand

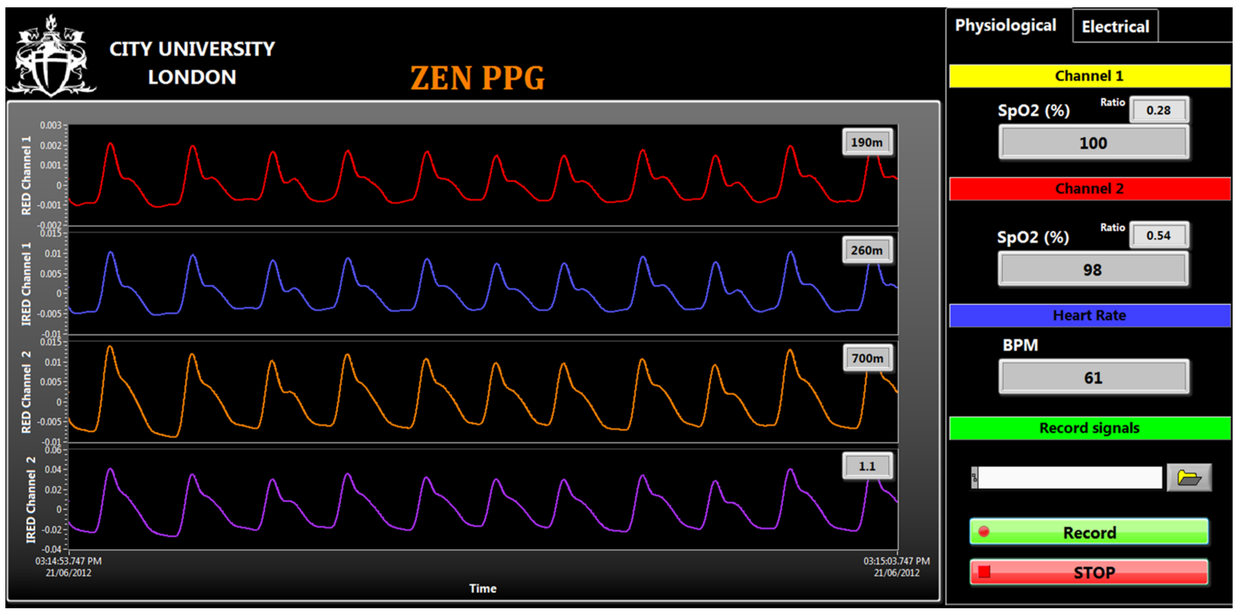

Figure 2: Front Panel VI of real-time PPGs and SpO_2 estimation

Results

The results of the calibration using Channel 1 of the ZenPPG system in conjunction with the Masimo probe were used to derive the following calibration function:

$$SpO2 = -19.49R^2 - 10.47R + 108.9 \quad (1)$$

where R is the 'ratio-of-ratios' determined from the red and infrared AC signals.

Table 1 shows the SpO_2 values obtained from six healthy volunteers using the ZenPPG system and the commercial pulse oximeter. SpO_2 values were calculated from the raw signals obtained from both channels using equation (1). It can be seen that SpO_2 results from the commercial system showed very good agreement with ZenPPG Channel 1 (r^2 = 0.978) and fair agreement with ZenPPG Channel 2 (r^2 = 0.708).

	SpO2 (%)		
Subject #	**Masimo Radical-7**	**ZenPPG Ch.1**	**ZenPPG Ch.2**
1	95	94.76	95.57
2	99	99.61	98.56
3	97	97.84	97.61
4	98	97.84	94.85
5	95	94.19	92.79
6	98	98.56	97.41
Mean	**97.0**	**97.13**	**96.13**

Table 1: SpO_2 values derived from ZenPPG from six healthy volunteers

Discussion

The ZenPPG produces reliable PPG signals, although the accuracy of the reported SpO_2 value is dependent on the calibration function used. Clearly calibration must be performed and a new calibration function generated for each channel and probe combination. The availability of two-wavelength, high signal-to-noise ratio PPG signals makes the system highly suitable for a wide range of physiological investigations. Variations of the PCB modules are under development to provide other physiological measurements such as ECG, blood pressure, temperature etc.

References

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