PHOTODETECTOR SIZE CONSIDERATIONS IN THE DESIGN OF A NONINVASIVE REFLECTANCE PULSE OXIMETER FOR TELEMEDICINE APPLICATIONS

C. Pujary, M. Savage, Y. Mendelson
Department of Biomedical Engineering, and Bioengineering Institute
Worcester Polytechnic Institute, Worcester, MA 01609.

Abstract–**Low power management without compromising signal quality is a key requirement in the optimal design of a wearable pulse oximeter. This paper investigates the advantage gained by using a photodetector with a larger active area. Preliminary *in vivo* experiments have demonstrated that by increasing the area of the photodetector it is possible to reduce the overall power requirement of a wireless sensor intended for telemedicine applications.**

Keywords–**pulse oximeter, telemedicine, wearable sensor**

I. INTRODUCTION

Commercially available sensors used in reflectance mode pulse oximeters employ a single photodetector (PD) element typically with an active area of about 12-15mm^2. The light intensity detected by the photodetector in a reflectance pulse oximeter depends on the incident light intensity, absorption by skin, reflection by bones, tissue backscattering and the amount of blood in the vascular bed [1]. Compared to transmittance mode pulse oximetry, reflected photoplethysmograms (PPGs) have generally lower amplitudes.

Low power management without compromising signal quality is a key requirement in optimizing the design of a wearable telesensor. One approach to lowering the power consumption of a wireless pulse oximeter, which is dominated by the current required to drive the LEDs, is to reduce the LED duty cycle [2]. Alternatively, lowering the current supplied to the red and infrared LEDs can also reduce power consumption. However, with reduced current drive, there is a direct impact on the quality of the detected PPGs. Mendelson et al. [3] showed that a concentric array of PDs could be used to increase the amount of backscattered light detected by a reflectance type pulse oximeter sensor. In this paper we investigate the advantages of increasing the PD area and minimizing LED driving currents to optimize the overall power requirement of a reflectance mode pulse oximeter intended for future applications in telemedicine.

II. METHODOLOGY

Experimental setup

To study the effect of different PD areas, we constructed and tested a prototype reflectance sensor employing 6 identical (3mm x 4mm) PDs. The equally spaced PDs were concentrically arranged in a 18mm diameter planar configuration around a pair of red and infrared LEDs. Each PD was individually connected to a central hub. The hub provided an easy way to simulate various PD areas by connecting in parallel multiple PDs to the common summing input of a current-to-voltage converter. Additional circuitry, consisting of amplifiers and band pass filters, were used to produce two different signals (a pulsatile AC component and a non-pulsatile DC component) from each PPG. Analog data streams were digitized at 50Hz for 30s periods by a National Instrument DAQ card installed in a PC running LABVIEW 6.0 software.

In-Vitro Experiments

Dark Tests: To test the background noise level generated by each PD, we performed a series of dark measurements by switching off the LEDs in the sensor and blocking ambient light from reaching the six PDs.

Multiple Photodetectors Tests: Each PD was randomly connected through the hub to determine the spatial uniformity of the illuminating field incident on the PDs. To produce a constant level background illumination, a signal composed of a DC bias voltage modulated by a small 1Hz AC sine wave was generated by a programmable function generator. The signal from the function generator was applied to a separate LED that was used to simulate a typical PPG signal. The external LED was attached to a translucent flat medium serving as an optical diffuser. The surface of the diffuser was positioned at a distance of 30cm away from the planar surface of the sensor.

In-Vivo Experiments

A series of *in vivo* experiments were performed to determine the signal improvement gained by using different PD areas. The prototype sensor was attached to the base of a volunteer's finger and the peak currents supplied to the red and infrared LEDs were adjusted to 3mA and 1.9mA, respectively. As the driving currents were adjusted, the output of each amplifier was monitored to assure that (i) a distinguishable and stable PPG was observed when a single PD was employed, and (ii) maximal PPG signals were produced without causing amplifier saturation when all 6 PDs were connected in parallel through the hub. It is important to note that the final currents selected were significantly lower compared to the typical driving currents employed in commercial pulse oximeters.

III. RESULTS

The Root Mean Square (RMS) values corresponding to the amplitude of the AC components measured from each PD are plotted in Fig. 1. During darkness the average noise

0-7803-7767-2/03/$17.00 ©2003 IEEE

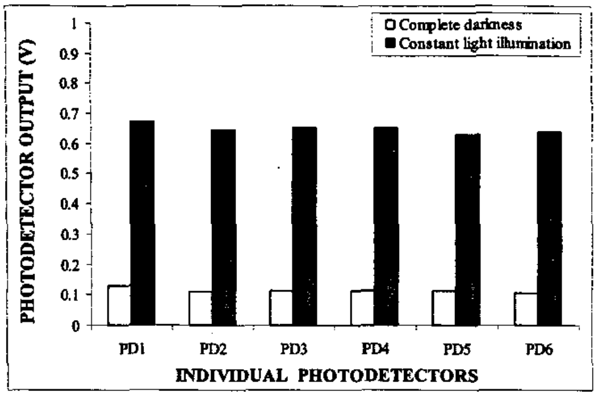

Fig. 1. Individual photodetector performance under complete darkness and a constant light illumination.

generated by the individual PDs was 0.114V. In comparison, the average PPG amplitude measured *in vitro* by the 6 PDs under a spatially uniform illumination field produced by the external LED source was 0.647V.

Fig. 2 shows the signals detected *in vitro* with multiple combinations of PDs using the simulated uniform illumination produced by the external LED. The right-side bars represent the measured RMS values corresponding to different PD areas. For comparison, the left-side bars were computed using the relationship 0.647*n*, where *n* corresponds to the number of PDs connected in parallel. The trend observed provide sufficient evidence of a linear improvement in signal intensity as a function of an increase in the active area of the PDs.

Fig. 3 shows the magnitude of the pulsatile red and infrared PPGs measured *in-vivo* for different PD combinations.

IV. DISCUSSION

Minimizing the current required to drive the LEDs is a critical design consideration in optimizing the power consumption of a wearable pulse oximeter. However, reduced LED driving currents has a direct impact on the incident light intensity produced by the sensor and could lead to deterioration in the quality of the PPGs. Consequently, it could result in unreliable and therefore inaccurate calculation of oxygen saturation.

From the data presented in Fig. 3, it can be observed that the overall increase in the reflected PPG signals achieved *in vivo* when all 6 PDs were connected in parallel is smaller and does not follow the same linear relationship observed *in vitro* as shown in Fig. 2. This deviation was most likely caused by the non-uniform backscattered light distribution emanating from the finger.

V. CONCLUSION

The data presented in this study demonstrate that the driving currents of the LEDs in a reflectance pulse oximeter can be lowered significantly without compromising the quality of the PPGs simply by increasing the overall size of the PD in the sensor. Hence, with reduced LED driving currents, maximizing the backscattered light collected by the sensor and optimized digital switching techniques, a very low power consuming sensor can be developed thereby extending the overall battery life of a pulse oximeter intended for telemedicine applications.

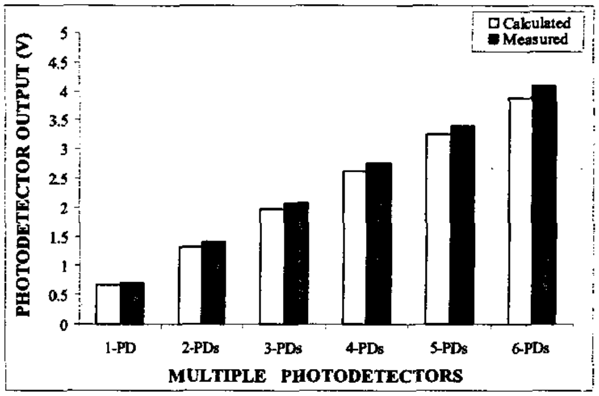

Fig. 2. Signal improvement observed *in-vitro* with multiple photodetectors.

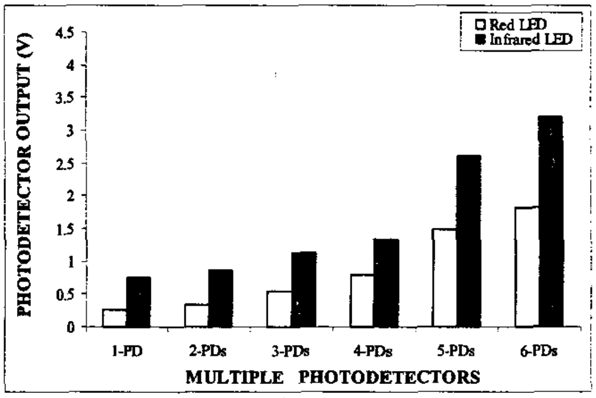

Fig. 3. Signal improvement observed *in vivo* with multiple photodetectors.

ACKNOWLEDGEMENT

This research was supported in part by Department of Defense Cooperative Agreement DAMD17-03-2-0006.

REFERENCES

[1] Y. Mendelson, B. Ochs, "Noninvasive Pulse Oximetry Utilizing Skin Reflectance Photoplethysmography," *IEEE Transactions on Biomedical Engineering*, vol. 35, no. 10, pp. 798-805, Oct. 1988.

[2] S. Rhee, B.H. Yang and H. Asada," The Ring Sensor: A new Ambulatory Wearable Sensor for twenty Four Hour Patient Monitoring," *Proc. of the 20th Annual International Conference of the IEE Engineering in Medicine and Biology Society. Hong Kong*, Oct. 1998.

[3] Y. Mendelson, J.C. Kent, B.L. Yocum and M.J. Birle," Design and Evaluation of new reflectance pulse oximeter sensor," *Medical Instrumentation*, Vol. 22, No. 4, pp. 167-173, Aug. 1988.