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# MINIMIZING POWER CONSUMPTION OF THE ORGANIC OPTOELECTRONIC PULSE METER

ファハド, エス, エー, エルサムナ

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Name : Fahed S. A. Elsamnah

氏　　名　：（ファハド エス エー エルサムナ）

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# 論 文 内 容 の 要 旨

# Thesis Summary

A pulse oximetry sensor has become essential to medical electronics and wearable health monitoring devices. It is a noninvasive, inexpensive, convenient and safe device for monitoring a person's health and avoiding any potential illness. The pulse oximeter is used to determine physiological parameters such as heart rate (bpm) and peripheral oxygen saturation ($SpO_2$) of patients at all times based on the photoplethysmogram (PPG) method. PPG signal is an essential bio-signal that can be used for detecting several heart diseases. It has become fundamental to wearable health monitoring devices. There are various kinds of commercial pulse-meter and pulse oximeter devices available on the market. However, there are still some issues in these kinds of pulse-meters which need to be improved in some performances such as the power consumption and the flexibility of the device.

This research project aims to fabricate organic light-emitting diode (OLED) and organic photodiode (OPD) biosensors, minimize the power consumption of the organic optoelectronic pulse meter sensor, develop the driver circuit of the pulse meter, improves the PPG bio-signal quality and proposes a reliable pulse-meter instrument that can be used in Vivo physiological monitoring. It also implements Bluetooth low energy (BLE) for sending the PPG waveform wirelessly to a mobile phone or a PC host. The thesis consists of six chapters organized as follows:

Chapter 1 begins by giving a brief overview of the study, motivation and problem statement, objectives of the research and followed by the research methodology.

Chapter 2 comprises literature review and related works, where the previous works on pulse oximeter systems, PPG principle, reflective type, transmissive type, organic optoelectronic, driving circuits, and digital filters are discussed in detail.

Chapter 3 discusses the results of the optical simulation that leads to the best design structure in terms of power consumption and signal quality. Following that, the proposed design structure of the organic optoelectronic pulse meter and the characteristics of the device performance are presented.

Chapter 4 discusses the system design developed for the proposed organic pulse meter. The driver circuit and its stages were explained thoroughly. It also illustrates the approach of measuring the SNR, the algorithm for measuring the heart rates, the data traffic of the BLE and designing the digital filter that applied to the system.

Chapter 5 contains the results of the proposed system's performance and accuracy. It compares the

proposed design structures and discusses the results of the obtained PPG signal from several parts of the body along with comparing the PPG signal that acquired wirelessly via BLE.

Chapter 6 presents the outcomes of the work presented in this dissertation. Thesis contribution to the current state of knowledge, recommendations, and future work are also presented.

Two approaches can be used to obtain a PPG signal from a biosensor pulse meter: reflection and transmission. The reflection method was adopted in this research because of the freedom of use. The device could be easily worn or attached to different parts of the human body. The transmission method involves tissue transillumination and requires that a light source and a detector be placed opposite each other. Consequently, the transmission method could only be used on external body parts such as fingertips, toes, and ear lobes.

The thesis addressed the significance of designing an effective OLED and OPD structure to improve pulse meter sensors in terms of power consumption and signal quality. Designing an OLED that emits a high amount of light is not necessary to produce a high-quality PPG signal; instead, it will consume more power. On the other hand, designing an effective OLED and OPD structure guided by optical simulation led to the best result in terms of power consumption and signal quality. That assumption was verified by comparing three different pulse meter design structures. One device had a circle-shaped OLED in the center of the device and was surrounded by a ring-shaped OPD, while the second device had the opposite structure. The third device had a bigger OLED area and a shorter distance gap between the OLED and the OPD. The devices were simulated optically where the simulator traced one million rays in each device. The simulation results showed the irradiance on the OPD area, where the maximum estimated irradiances were $3.7 \times 10^{-10}$ W/mm$^2$, $2 \times 10^{-9}$ W/mm$^2$ and $9.8 \times 10^{-10}$ W/mm$^2$ as a total received power of 0.42%, 0.1%, and 0.55% for Device-A, Device-B and Device-C, respectively.

The gap distance between the OLED and the OPD showed a top priority while designing an organic pulse meter along with the OLED's area and OPD's area. For the OLED's area, if we reduced the OLED's area in order to reduce the power consumption, the OLED's lifetime will also be reduced because the current density will be increased on a small area. On the other hand, if the OLED's area increased, then the area in the center of the OLED will be impractical and will not contribute to increasing the reflected light from the human body. For the OPD's area, it should be designed in a way to surround the OLED sufficiently in order to collect more reflected light. However, increasing the OPD's area too much will result in increasing the DC noise. Therefore, the area of the OPD should be consistent with OLED design which can be achieved by optical simulation.

Red OLEDs, 625 nm, and OPDs sensitive at the aforementioned wavelength were fabricated monolithically on glass substrates. The external quantum efficiency (EQE) of the OLED and the OPD were 7% and 37%, respectively. The power consumption and the signal-to-noise ratio (SNR) were evaluated for all devices' PPG signals, which were successfully acquired from a fingertip. Accordingly, the proposed reflectance-based organic pulse meter operated successfully at an ultra-low low power consumption of 8 μW at 18 dB SNR and low power consumption of 0.1 mW at 62 dB.

The proposed organic pulse meter was implemented for wireless monitoring of the PPG signal and successfully presented compatible characteristics. Clear PPG waveforms were obtained from the portable pulse meter via Bluetooth low energy (BLE) at 500 SPS and 8-bit resolution on the receiver PC host. The maximum throughput data rate between the chip and the PC host was 256 kbps at the minimum connection interval of 7.5 ms. The proposed pulse meter showed accurate results of about 1.5% error of the pulse rate (PR) compared to the commercially reference we obtained. Eventually, the proposed organic biosensor reduced the power consumption and improved the capability of the pulse meter for long-term use.