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Design and Fabrication of Heart Rate and Oxygen Saturation Measurement Device using LED-LED Configuration and to Study Correlation of PPG Signal Amplitude with Breathing Rate

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Abstract- **we present an approach for non-invasive signal acquisition in healthcare applications, specifically aiming the measurement of oxygen saturation (SpO2) and heart rate (HR) using photoplethysmography (PPG). Our proposed project emphasis on the design of a circuit that uses light-emitting diodes (LEDs) both as emitters and detectors. Through the use of a Field Programmable Gate Array (FPGA), we are able to effectively control the LEDs. By employing three LEDs, with two serving as emitters and one as a detector, we successfully obtain PPG signal after removing the noise. This work also demonstrates the correlation between PPG signal amplitudes and changes in breathing rate, showing lower amplitudes with decreased oxygen concentration and higher amplitudes with increased breathing rates. This proposed circuit design gives a cost-effective solution with low power consumption, making it highly suitable for practical implementation.**
Index Terms-- **heart rate, light-emitting diode, field programmable gate array, photoplethysmography, oxygen saturation.**

I. INTRODUCTION

This The expansion of non-invasive methods for acquiring physiological signals has transformed medical diagnostics and monitoring [1, 2]. Amongst the various signals acquired, photoplethysmography (PPG) has gained significant attention due to its capability to provide valuable information about oxygen saturation (SpO2) and heart rate (HR) without the need for invasive processes. PPG measures the variations in blood volume in peripheral tissues using light absorption and reflection principles.

The aim of this paper is to propose a circuit design for non-invasive [3] signal acquisition, specifically targeting the measurement of SpO2 and HR using PPG and to establish its comparison with the standard device. Our approach involves the use of light-emitting diodes (LEDs) as both emitters and detectors, giving a compact and cost-effective solution for signal acquisition. By carefully controlling the LEDs using a Field Programmable Gate Array (FPGA), we desire to achieve maximum resolution while minimizing noise and power consumption, as reducing power consumption is also important for a low cost solution [4]. FPGA is previously used in many high-performance sensing applications providing low power and high accuracy solutions [5-10].

The precise measurement of SpO2 and HR plays a vital role in various medical applications, including clinical diagnosis, patient observing, and wearable health devices. SpO2 measurement, in particular, has played a critical role during the COVID-19 pandemic, where the accurate and timely assessment of oxygen levels in patients became crucial for effective management and treatment. Traditionally, these measurements were acquired through invasive methods, such as blood sampling or electrode placement, which were not only a source of discomfort for patients but also increased the risk of infections and other complications. Non-invasive methods, like PPG, have emerged as a favorable alternative, proposing convenience, safety, and continuous observing abilities.

Existing non-invasive PPG-based systems often rely on separate emitter and photodetector units, in which LED is used as transmitter and photodiode is used as receiver. Light based solutions are also used for many other applications providing contact less measurements for displacement sensing [11-16] or signal transmission for health care system [17]. Bikash has used the configuration of LED of 940 nm and photodiode as a detector [18]. The red and near –IR LED, photodiode configuration was to measure the oxygen saturation [19]. Esrat has used two LEDs as transmitter and photodiode as receiver [20]. One led is transmitting visible red light and the second one is transmitting infrared light. This technique has successfully measured the oxygen saturation but there is complexity of distinguishing between red and infrared light as the photodiode. These traditional techniques worked well by using a dedicated photodetector in PPG-based systems. However, this approach requires extra components, resulting in increased complexity and cost. Additionally, integration of the photodetector into the system may create difficulty in terms of circuit design and physical space.

On the other hand, the proposed method of using an LED as a photodiode in reverse bias configuration presents numerous advantages. Firstly, it offers cost-effectiveness, as LEDs are generally more economical compared to traditional photodiodes. This cost advantage can be significant, particularly in large-scale use. In addition to this, using an LED in reverse bias as a photodiode simplifies the circuitry by eliminating the need for a separate photodetector component. This results in a efficient design and easier integration into existing PPG systems. Moreover, the use of an LED as a photodiode influences its inherent properties and existing presence in PPG systems as an emitter. This integration leads to improved availability of components. Also, precise control over LED parameters, such as intensity and timing, enabled by a Field Programmable Gate Array (FPGA), allows for optimization of signal quality and measurement accuracy.

In this paper, we have presented the detailed design and implementation of our circuit, emphasizing its key features and advantages. We conducted experimental evaluations to assess the performance of the proposed system, comparing it with the use of a standard medical device (nonin medical's model 7500 pulse oximeter) to validate the working of our proposed work. The results establish the effectiveness of our approach in accurately measuring SpO2 and HR, while maintaining a low-cost and low-power consumption profile.

The remainder of this paper is organized as follows: Section 2 the methodology and design. Section 3 describes experimental results Finally; Section 3 is the conclusion of the paper. Methodology

A. Signal Acquisition:

In the proposed work, a LED-LED configuration is used for signal acquisition. Two LEDs are employed, one as an emitter and the other as a receiver. The LED1 emitter emits light into the finger, and the receiver LED2 working in reverse bias captures the reflected light. The block diagram in Fig. 1 shows the acquisition setup of the PPG signal and estimation of heart rate and SpO2.

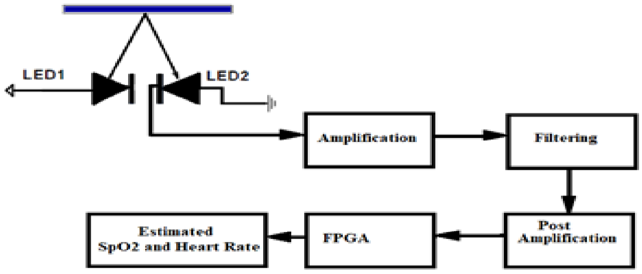

Fig. 1. Block Diagram of the Proposed Device for estimation of SpO2 and HR

B. Amplification:

After the PPG signal is acquired, it is fed into the amplification circuit to enhance the signal strength. For this purpose two operational amplifier are used in inverting mode to amplify the signal as shown in the Fig. The amplification stage is designed to ensure that the acquired PPG signal is correctly scaled for further processing.

C. Filtering:

Following amplification, the PPG signal is passed through a band pass filter. The band pass filter selectively allows a specific frequency range, typically centered on the heart rate frequency, to pass through while reducing noise and unwanted frequencies. The information of the PPG signal lies in the band of (0-8Hz) [21]. The Fig.2 shows the amplification and filtering circuit, in which first two operational amplifiers are used for amplification purpose and the last two acts as band pass filter in the range of (0.5-8Hz). The band pass filter is designed by combination of high and low pass filter. The resistors used in high pass filter were 100kΩ and the value of capacitor used for this purpose is 10μf whereas the resistors used in low pass filter were 150kΩ and the value of capacitor used for this is 0.1μf. This filtering step removes noise and artifacts from the signal, thus enhancing the quality of the PPG signal for estimation of SpO2 and heart rate.

D. Signal Post Amplification:

After the band pass filtering, the cleaned PPG signal is fed into another amplification stage. This additional amplification is required to further enhance the amplitude of the filtered signal, thus making it suitable for subsequent processing i.e estimation of SpO2 and heart rate information.

E. FPGA-Based Signal Processing:

The amplified PPG signal is fed into a Field Programmable Gate Array (FPGA) for further signal processing, to extract the information of SpO2 and heart rate. The FPGA offers flexibility and high-speed processing capabilities, enabling real-time analysis of the PPG signal and efficient computation of SpO2 and heart rate values. To extract SpO2 and heart rate information from the PPG signal, both ratio-based and derivative-based approaches have been used.

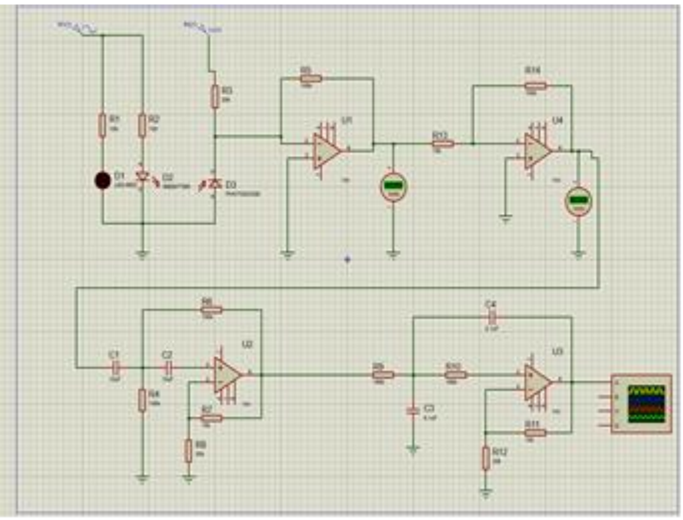

Fig. 2. Schematic Diagram of the amplification and band pass filtering

F. Ratio-Based Approach for SpO2 Estimation:

The ratio-based approach involves calculating the ratio of the pulsatile component (AC component) to the non-pulsatile component (DC component) of the PPG signal. A calibration lookup table is used to convert the ratio into SpO2 values. The ratio from 0.2 to 3.4 ranges is used to estimate the percentage of SpO2.

G. Derivative-Based Method for Heart Rate Estimation:

For heart rate estimation, a derivative-based method has been used. The PPG signal is differentiated w.r.t time to identify the peaks corresponding to each cardiac cycle. The time intervals between these peaks are calculated, and the multiplicative inverse is measured to obtain the heart rate in beats per minute (BPM). Thus, the drastic changes in the PPG signal have allowed the accurate estimation of the acquired PPG signal.

II. RESULTS

To validate the accuracy of the proposed setup, the PPG signal from various subjects were acquired and the heart rate and SpO2 were calculated. In addition to this this study, the effects of breathing rate on oxygen concentration in the blood and its impact on the PPG signal were also studied. The experiment involved the PPG signals acquired from the subjects using proposed device, and after the processing and estimation steps, the results were compared to those obtained using a standard medical device (nonin medical's model 7500 pulse oximeter).

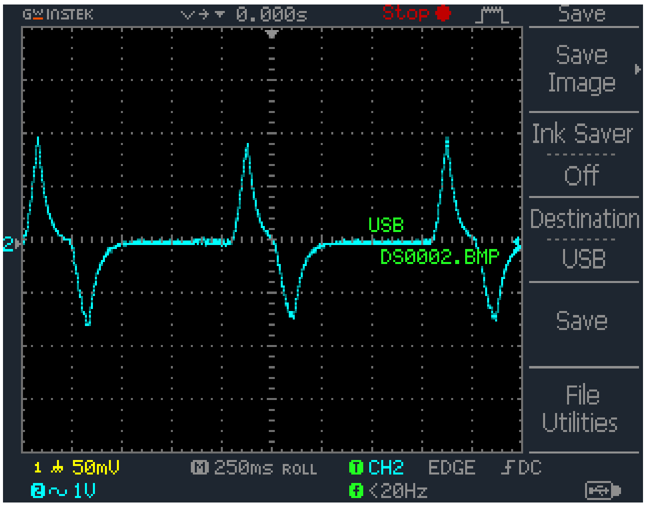

Fig. 3. PPG signal during normal breathing rate.

Firstly, the breathing rate was slowed down; it was observed that the oxygen concentration in the blood decreases. As a result, the absorption of oxygen in the blood was reduced, leading to a lower reflection rate of light during PPG signal acquisition. As a result of which, the signal amplitude was found to be lower as shown in Fig. 4. Secondly, the subjects increased their breathing rate; the oxygen concentration in the blood was increased. This leads to enhanced oxygen absorption in the blood, ultimately resulting in a higher reflection rate of light during PPG signal acquisition. As a result of which, the signal amplitude was found to be higher as shown in the Fig.5. The normal PPG signal is shown in the Fig. 3 so comparison of higher and lower amplitudes can be established with the normal breathing rate.

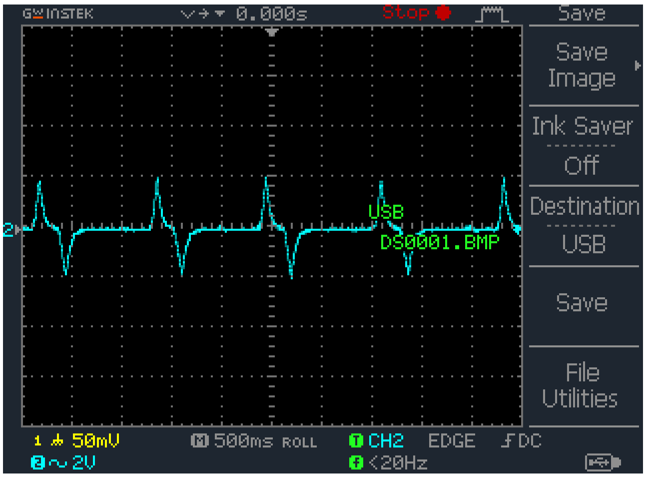

Fig. 4. PPG signal during low breathing rate.

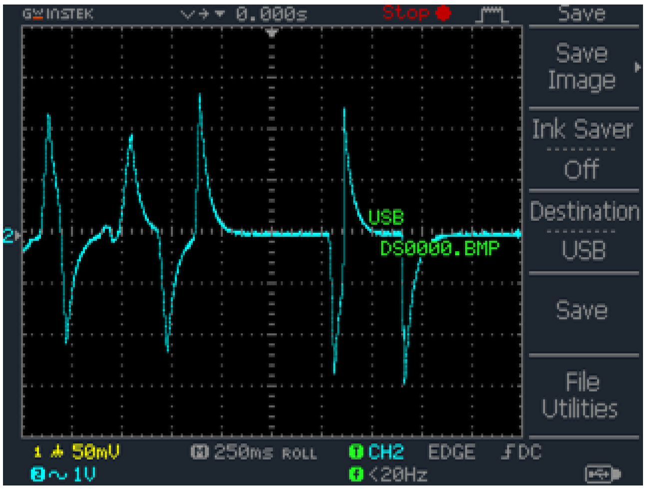

Fig. 5. PPG signal during high breathing rate.

To validate the accuracy of the designed device, the obtained results were compared to the measurements obtained from a standard medical device (nonin medical's model 7500 pulse oximeter) for 15 subjects. The comparison shows that the estimated values of heart rate and SpO2 from the proposed setup and the values recorded from the standard devices are very comparable to each other. The results of SpO2 measurement and its comparison with standard device is shown in the Table I while the results of heart rate and its comparison is shown in the Table II. In case of SpO2 the average error is of 5.3 while in the case of heart rate the average error is 2.93.

Fig. 6. Hardware Implementation of the device

TABLE I: Results of heart rate (HR) measurement using proposed device and its comparison with the standard device

Subjects	**Heart rate measured for designed device**	**Heart rate measured for standard device**	**Error**	**Square of error**
1	69	71	2	4
2	69	72	3	9
3	71	73	2	4
4	67	71	4	16
5	71	73	2	4
6	72	76	4	16
7	69	71	2	4
8	71	74	3	9
9	69	72	3	9
10	66	69	3	9
11	67	71	4	16
12	70	74	4	16
13	73	72	-1	1
14	67	73	6	36
15	69	74	5	25
Average error = 2.9333 **Average Square of error** = 11.6				

TABLE II: Results of SpO2 measurement using proposed device and its comparison with the standard device

Subjects	**Spo2 measured using proposed design**	**Spo2 measured using standard device**	**Error**	**Square of error**
1	92	98	6	36
2	90	96	6	36
3	93	98	5	25
4	94	98	4	16
5	91	95	4	16
6	90	97	7	49
7	92	96	4	16
8	92	96	4	16
9	90	99	9	81
10	92	95	3	9
11	90	97	7	49
12	91	99	8	64
13	94	98	4	16
14	93	97	4	16
15	94	99	5	25
Average of error = 5.33335 **Average of square of error**= 31.33335				

III. CONCLUSION

This paper presents a circuit design for non-invasive signal acquisition of PPG signal to measure oxygen saturation (SpO2) and heart rate (HR). The use of LED-LED configuration, amplification, band pass filtering, and FPGA-based signal processing enables accurate and real-time measurement of SpO2 and HR. This work also demonstrate the relationship of the PPG signal to changes in breathing rate, with decreased oxygen concentration resulting in lower signal amplitudes, and increased breathing rates leading to higher signal amplitudes. The comparison with a standard medical device also confirms the accuracy and reliability of our design. This circuit offers a cost-effective and efficient solution for non-invasive measurement of SpO2 and HR.

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