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Smartphone – Based Oximetry Monitoring Device in the Android Platform

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ABSTRACT

The blood oxygen level is considered one of the important vital signs of the body. An oximeter is a non-invasive medical device for determining the oxygen saturation level in the blood and provides information that supports in defining the cardiorespiratory condition of a person. This device is not that accessible to many people considering its price and fixed functionality. With the advent of smart devices like the smart mobile phones, the functionality of an oximeter can be mimicked using the external peripherals and the signal processing capabilities of smartphones. This study aims to address not only the price of commercial pulse oximeters but also the reliability, maintenance, and most importantly, the accessibility of the pulse oximeters to common people similar to portable smartphones. The prototype is a custom-built oximeter with a 3.5mm port audio jack interface to an Android smartphone. The signal processing algorithm gets signals through a light interface touching the human finger, calculate the oxygen saturation levels, and display the values on the screen of the phone. The smartphone-based oximeter was tested with respondents and results show that the prototype is comparable to a commercial oximeter and the obtained measurements are within the set of acceptable limits which do not exceed a 2% deviation on the average. Device accuracy is more than 94% on real-time test and measurement.

Key words : Android, Oximeter, Pulse Signal, Smartphone

1. INTRODUCTION

In modern medical practice, the blood oxygen level is considered as one of the important vital signs of the body [1]. Blood oxygen saturation information should be available to clinicians on a continuous basis instead of every few hours specially in the critical care setting [2]. This need is met through the technology of pulse oximetry.

A pulse oximeter is a non-invasive medical device capable of detecting oxygen saturation of arterial blood and gives information about the cardiorespiratory function of a patient. The principle behind its operation is based on the nature of the hemoglobin, which is a respiratory pigment found in red blood cells [2]. Apparently, the hemoglobin pigment has a different color when it is oxygenated and deoxygenated. A pulse oximeter uses two frequencies of light (red and infrared) to determine the percentage (%) of hemoglobin in the blood that is saturated with oxygen. The percentage is called blood oxygen saturation, or SpO_2. A pulse oximeter also measures and displays the pulse rate at the same time it measures the SpO_2 level [3].

Indirectly, it is also capable of detecting hypoxemia, which is defined as an abnormally-low partial pressure of oxygen in the arterial blood. Though there are other respiratory ailments caused by low oxygen saturation, hypoxemia has a profound negative effect on quality of life. Even nocturnal hypoxemia (i.e., temporary hemoglobin desaturation during sleep) has negative effects on life quality. As such, pulse oximeters are very useful medical equipment especially to people who have a recurring case of Hypoxemia [4]. However, not all people are able to have special detection equipment especially in third world countries where it is not easily accessible to people or if there are pulse oximeters, the people there cannot afford to buy equipment.

Though commercial pulse oximeters nowadays have evolved into smaller probes with sophisticated circuitry that can already display the needed values and its price has decreased considerably in the past decade or so, it is often the case of availability and maintenance. If one of the pulse oximeter's parts is broken or defective, the whole unit needs to be replaced. If only the pulse oximeter can be simplified, or its detecting parts constructed separately and the processing and displaying done separately, then acquiring a piece of equipment such as the pulse oximeter will be easier. With the powerful processing core of smart phones, this could be made possible.

Of all the smart phones, the most popular operating system considered is the Android operating system. The Android platform has quickly captured a significant percentage of the market and now reigns as one of the leading smartphone platforms [5]. With this, it was conceptualized to come-up with a portable oximeter with movable and easily replaceable parts, utilizing the mobile smartphone popularity, fast computing and signal processing capabilities of a smartphone, as well as the flexibility of the Android operating system.

2. METHODOLOGY

The main objective of this study is to design and develop a smartphone-based oximeter using the Android operating system to measure blood oxygen saturation. A pre-processing circuit for amplification and filtering was utilized to smoothen the photodetector output waveform. An interface which measures the voltage levels from the custom-built oximeter was designed with a capability to transfer data to the microphone audio input of a smartphone. A user-interface for displaying the saturation levels based on the SpO_2 values was made and a change in oxygen saturation for a period of three minutes was programmed. It was targeted to produce SpO_2 readings with maximum average of 1 to 2 % deviation or percent error from the commercial pulse oximeter readings. The effect of ambient light to the oximeter's reading was also explored. The prototype was tested to thirty people and a comparison with a commercial finger pulse oximeter was made. The comparison of the commercial pulse oximeter and prototype oximeter should approximately have the same behavior in reading the SpO_2 level.

2.1 Design Prototype

Figure 1 shows the block diagram of the proposed oximeter running in the Android platform. The prototype is a custom-built oximeter with a 3.5mm audio jack interface to an Android smartphone. Signals are processed by a program that continuously reads signals from the oximeter, calculate the oxygen saturation, and displays the values on the screen of the phone. The three wires of the audio jack (left speaker, right speaker, and microphone) are connected distinctly. It is worth noting that the configuration of the 3.5mm jack of the android phone to be tested has the same port configuration: tip - left speaker port, ring 1 - right speaker port, ring 2 - common, sleeve – microphone.

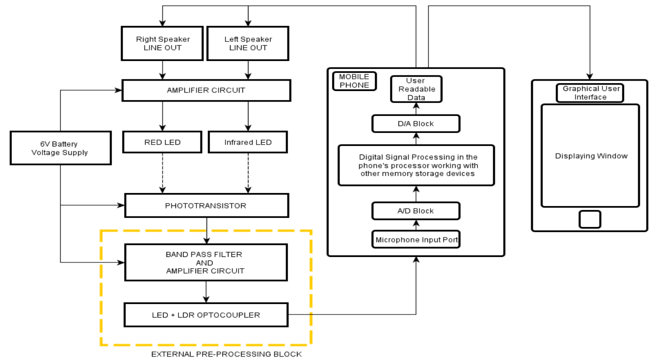

Figure 1: Block Diagram of the Oximeter Prototype Design

The oximeter probe constructed is a transmittance mode type. It is a commonly used type of pulse oximeter probe structure due to its simplicity, signal analysis and convenience of attachment [6].The oximeter probe is constructed using two Light Emitting Diodes (LED), a red LED, with a wavelength of approximately 660nm, and an infrared LED, with a wavelength of approximately 940nm. The LEDs are positioned such that it is pointing towards the photodetector with enough space for a finger to insert in between. The structure of the casing of the oxygen saturation sensor minimizes the ambient light that comes in the sensor.

The switching of red light and infrared light is made based on the fact that the left and right speaker ports control the earphones with small voltages. With enough amplification, both ports should be able to power both LEDs connected to both ports. The audio signal from the headset output, amplified by an op-amp, that is used to control the switching of the LEDs has a switching capability of more than 8 KHz if the time for each LED to turn on or off is 400 microseconds. The earphones have two output speakers, left and right, that are connected to the audio codec of the phone. Instead of being connected to speakers, it will be connected to an external circuit to amplify the signals before connecting it to the red LED and infrared LED. The signal of the customized audio file will perform the alternating manner of the LEDs. Each LED is on for approximately 170us and off for 510us. However, after the researchers' tests, the timing of the LEDs used was thus; 400 microseconds on and 1200 microseconds off. The optimum timing is shown in Figure 2.

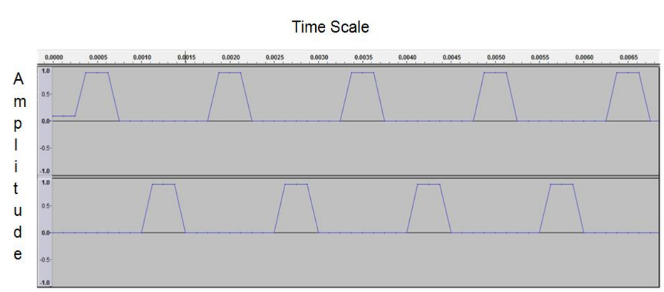

Figure 2: Red LED (top) and Infrared LED (bottom) Timing Sequence

The sensing of the photodiode depends on how much light will pass through the finger of the user. The pulsatile component of the signal from the photodetector is very small compared to the DC component. The pulsatile component is only 1% of the whole signal. The ideal input of this photodetector will be the red light and infrared light. Other color of light cannot be avoided however the unwanted light will be filtered out in the processing of signals. The photodetector used is a phototransistor since the phototransistor is the photodetector used in one of the reference circuits [7][8][9].

The band pass filter passes only the 0.7 – 3 Hz range. The amplifier then amplifies the signal so that the voltage to be converted by the optocoupler. The optocoupler placed before the microphone input acts as a voltage-controlled resistance since the phone microphone input is only able to read resistance. Having the output of the photodetector amplified results to having the highest possible range before it is passed to the microphone port for analog-to-digital conversion. The values obtained from the analog-to-digital conversion are processed through an algorithm that extracts the red LED and infrared LED time multiplexed signals from the original signal and subsequently uses the values from two waveforms to compute for the oxygen saturation or the SpO_2 level of the blood. The computed SpO_2 level is then displayed on the graphical user interface of the phone.

2.2 Pre-processing Circuit

The external circuit that handles both the filtering and amplification of the photodetector output is shown in Figure 3. Since the microphone port was found by the researchers to only respond to changes in resistance, the output of the pre-processing circuit is connected to the LED of the optocoupler and the Light dependent resistor (LDR) is directly connected to the microphone port and common or ground port.

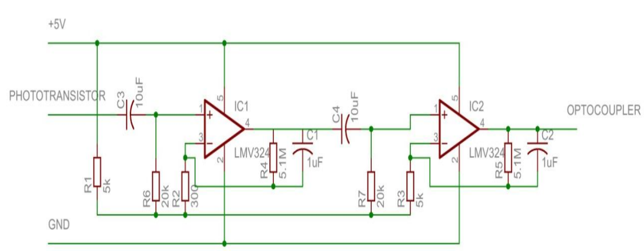

Figure 3: Pre-processing Unit Schematic Diagram

The circuit is composed of a two-stage bandpass filter and amplifier. Both bandpass filters consist of RC high pass filters, C3 and C4 = 10uF and R6 and R7 = 20K ohms which cut-off frequencies below 0.8 Hz, and op amp low pass filters, C1 and C2 = 1uF, which cut-off frequencies above 3 Hz. The first non-inverting op amp configuration has a gain of 17001 and the second non-inverting op amp configuration has a gain of 1021. The output of this pre-processing circuit is connected to the optocoupler. The optocoupler is vital to the acquisition of the photodetector's filtered and amplified output since the multiplexed red and infrared signals are extracted from it. The optocoupler acts both as an isolator and a converter of one form to another. In this case, the voltage output of the pre-processing circuit is converted to light through the LED and then it is received by the LDR which changes its resistance with changes in the intensity of light it receives. The legs of the LDR are connected to the microphone port and common port so the changes in resistance are then received by the analog to digital converter of the phone's processor.

2.3 Signal Processing Algorithm

After the system converts the analog signal to digital signal, the digitized signal will undergo the process of signal processing as shown in Figure 4. The sampling rate at which the microphone input port will record is 8 kHz since this is the rate at which the phone is able to record and obtain samples continuously. After obtaining an exact number of samples of data and converting the raw data which is in signed 16-bit PCM format into normalized values -1 to +1, this data is stored in an array. The array is then passed to a subroutine that samples the raw data at a timing that is the same as the LEDs. To get the red LED level, the raw data is sampled at the same rate that the red LED is turned on, to get the infrared LED, the same raw data is also sampled but at the same rate that the infrared LED is turned on.

$$R = (AC_{RED} / DC_{RED}) / (AC_{IR} / DC_{IR})^{-1} \qquad (1)$$

where

R - ratio of ratios
AC_{RED} – Red LED pulsatile waveform
DC_{RED} – Red LED DC component
AC_{IR} – Infrared LED pulsatile waveform
DR_{IR} – Infrared LED DC component

$$SpO_2 = 10.0002R^3 – 52.887R^2 + 26.871R + 98.283 \qquad (2)$$

where

SpO_2 – blood oxygen saturation

The obtained red and infrared LED are then passed through another subroutine that obtains the Vrms value of the red and infrared LED signals. The V_{DC} value is no longer obtained since the analog-to-digital converter already removes the DC value. The ratio of ratios (1) is then used to compute for the ratio of ratios using the obtained values. The sample calibrated equation (2) will be first used to compute for the oxygen saturation levels.

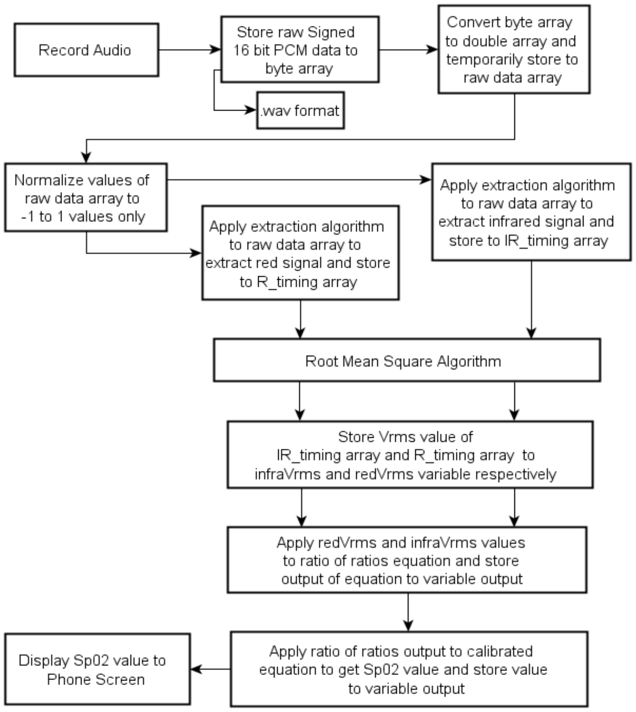

Figure 4: Signal Processing Block Diagram

2.4 Android Graphical User Interface

The program has no menu when the application is opened as shown in Figure 5. The program displays a notification window if the Mobile Oximeter probe is not connected and it displays a separate notification window for saving the input waveform.

After the user answers the notification windows, the start button on the main interface of the program will then be seen as shown in Figure 6. After pressing the button, the program first calibrates the timing of the program before displaying the SpO_2 values, also shown in Figure 6.

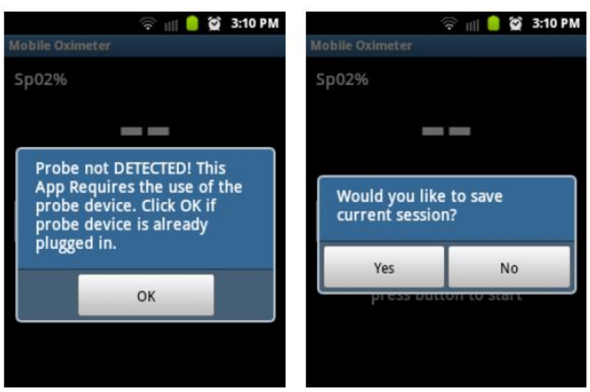

Figure 5: GUI Start Display

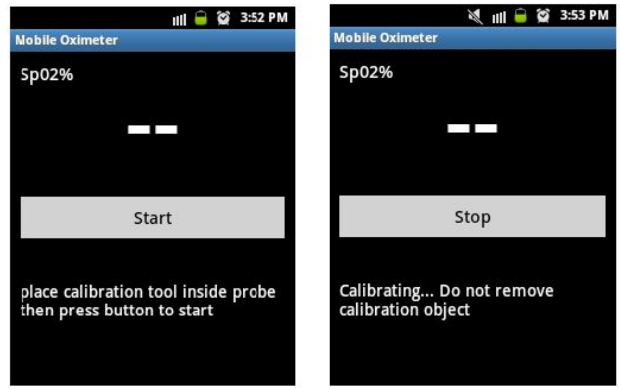

Figure 6: GUI Calibration Display

Figure 7 shows different SpO_2 levels. At levels 99 – 95%, the text is set to green. At levels 94 – 90%, the text is set to yellow with the warning text, "Warning!" At levels 89 – 86%, the text is set to red with the warning text, "Warning! SpO_2 levels low!" At levels 85% and below, the text is set to blue with the text, "FINGER OUT".

3. RESULTS AND DISCUSSION

The hardware and software components of the prototype were made consecutively. The hardware design where the LED amplifier circuit and the pre-processing circuit were built first followed by the software. To have an initial simulation, the software was coded in MATLAB and then converted to an Android code. This also helped in graphing the sampling algorithm of the red and infrared signals on top of the output of the pre-processing circuit and see if the sampling algorithm timing is able to sample the waveform at the right position of the time multiplexed red and infrared signals. The computation of the SpO_2 reading was also tested in the MATLAB program. The current appearance of the finished prototype design is shown in Figure 8.

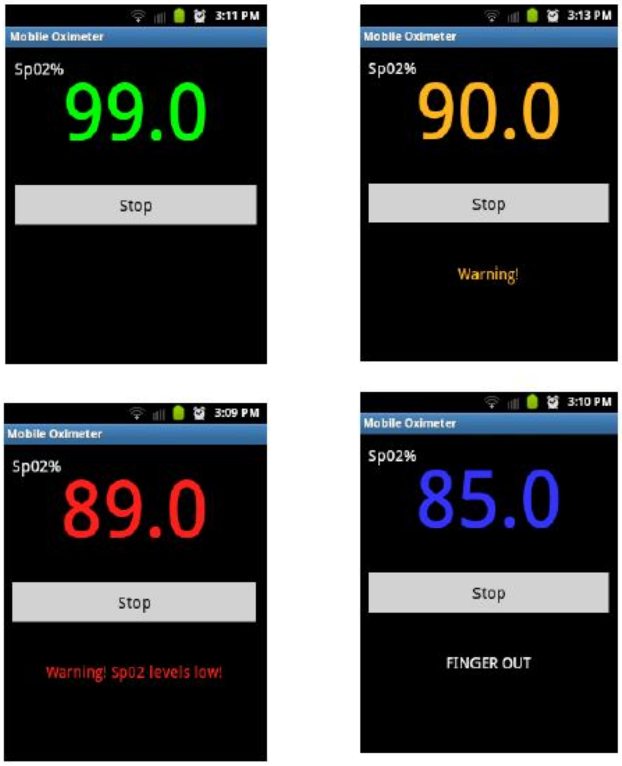

Figure 7: GUI display of Different SpO_2 Levels and Remarks

Figure 8: Design Prototype

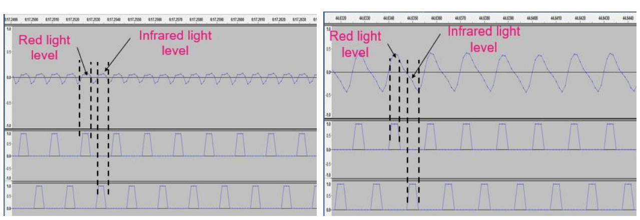

Figure 9: Red LED and IR LED Timing Graphs

The red and infrared LEDs are powered by the Left and Right speaker line from the phone by playing a generated .wav file from Audacity. The timing used was still the 400 µs on and 1200 µs off timing of the LEDs as this was the timing that the photodetector and pre-processing circuit was able to sense and was able to maintain the form of the multiplexed red and infrared timing without clipping or distortion. The red and infrared signals are time division multiplexed signals and should be synchronized carefully as shown in Figure 9. This defines the accurate SpO_2 values readings. It should be such that the waveform to be observed does not have distorted red and infrared light levels to output the precise and accurate $Sp0_2$ values.

The prototype oximeter was tested with least 30 subjects simultaneous with a commercial grade oximeter. The testing was done on a period of 3 days, approximately 10 subjects per day were tested in an air-conditioned room with fluorescent lights on. Test results are shown in Figure 10. The error ranges from a minimum of 0.14% and a maximum of 5.41%. The average percent error obtained from the prototype with respect to the commercial pulse oximeter is 0.24% which within the 1-2% deviation and 99.75% accurate. The maximum SpO_2 reading for both oximeters is 99% and minimum reading for the commercial pulse oximeter is 97% while for the prototype oximeter is 92.7%. Overall, the results show that the Mobile Oximeter device does deviate from the readings, by calculation of the percent error and percent accuracy, it was found that the percent error does not exceed 2% on the average. The overall average percent accuracy obtained is within the expected 1-2% deviation.

The percent accuracy obtained for each subject range from 94.5% up to 99.6% as shown in Figure 11. The noticeable two lowest peaks are because of external shocks experienced by the circuit upon testing. The circuit used was still in a breadboard and is sensitive on being moved or touched by the subjects.

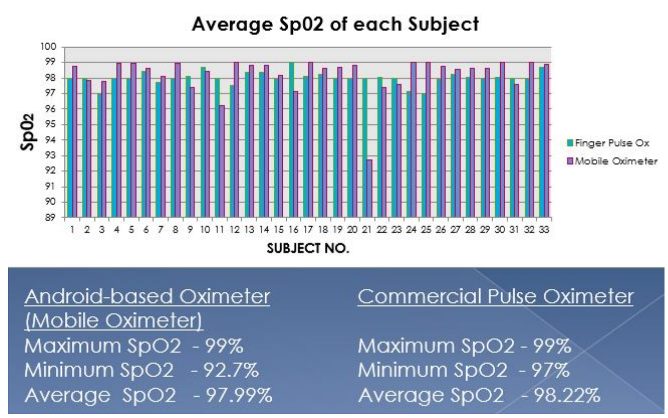

Figure 10: Average $Sp0_2$ Reading of Mobile Oximeter and Commercial Pulse Oximeter

The prototype was also tested considering the effect of ambient light. The overall percent accuracy is 99.09% with a maximum and minimum average percent accuracy of 99.91 % and 98.51%, respectively. Figure 12 shows the average percent accuracy of each subject tested with ambient lighting conditions where it can be observed that only two subjects produce an average accuracy lower that the average percent accuracy.

Comparing the two conditions that the Mobile Oximeter and the finger pulse oximeter were subjected in, in terms of percent accuracy, only have a difference of 0.12%.

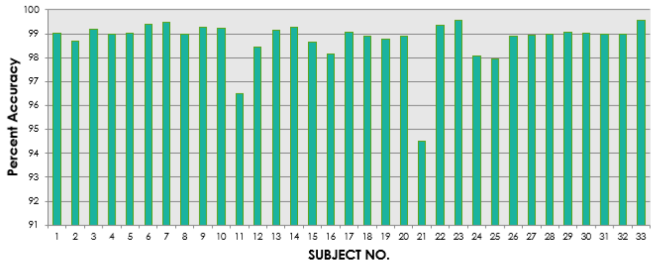

Figure 11: Percent Accuracy per Subject

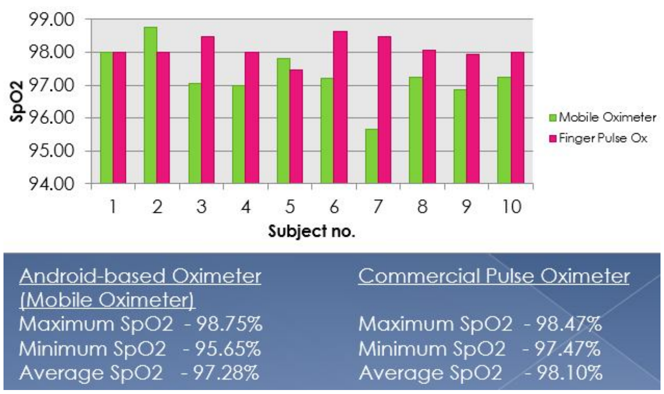

Figure 12: Average Percent Accuracy per Subject Tested Under Ambient Lighting Conditions

4. CONCLUSION

A smartphone-based oximeter was built in the Android platform with its hardware and software components. A pre-processing circuit is important when dealing with noise and amplifying low voltage signals. Without a pre-processing circuit, signals received by the phone are noisy, distorted and timing signals will not be in-sync. Smartphones' audio port could be used as an interface for voltage input and output with which the phone's CPU could be used for signal processing.

The prototype oximeter was able to detect stable SpO_2 readings and small changes in the SpO_2 levels. Based on the results, the expected accuracy was met at 98.8% with 1-2% overall average deviation. of the readings.

Ambient light has no significant effects to the SpO_2 readings. The average percent accuracy obtained was 99.09% and this means that on average, the readings only deviated from expected readings by 0.91%. Hence, it is possible to build an android-based medical device such as an oximeter that can measure oxygen saturation in the blood with accuracy at par with the commercial grade pulse oximeters.

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