Final report - GZD pulse oximeter

Introduction

Pulse oximetry is a non-invasive approach for real-time *in vivo* measurement of blood oxygen level and heart rate of a person. In many occasions, blood oxygenation information should be available to clinicians or patients on a continuous basis. For patients under risk of respiratory failure, such as airway obstruction, it is essential to monitor the arterial oxygen saturation in blood, which reflects the efficiency of gas exchange in the lungs. Besides, it is also crucial to monitor both heart rate and oxygenation of patients who are receiving anesthesia so to control the dose. Pulse oximeter, which is an optical device, can be used to detect blood oxygen saturation based on localized volume changes of arterial blood [1].

This report introduces a simple design of pulse oximeter, called GZD pulse oximeter, which consists of a series of electronic components, such as capacitors, integrated chips (ICs) and light emitting diodes (LEDs) that are planted onto a printed circuit board (PCB). A microcontroller device, Arduino is also used to process signals digitally. Coupled with an TFT screen, the resulting device is used for calculating and displaying the measurement results, including photoplethysmogram (PPG) waveform, arterial oxygen saturation and heart rate reading. In the following sections, both hardware and software parts of the design will be introduced in details. After that, a pilot experiment using the GZD pulse oximeter is introduced, and the results will be presented and discussed.

1. Hardware section

The generation of PPG signal revolves around the circuitry on the printed circuit board (PCB) and a 3D-printed probe.

The circuit begins with a master clock, the 555 timer which provides a repetitive signal for the operation of the rest of the circuit. This signal is set to be a square wave pulse with 166 Hz frequency and 50% duty cycle for consideration of desirable dead-time introduction, as well as effective sample-and-hold performance. The timer is linked to a 4017 decade counter, which is capable of generating two LED-driving signals that are fed into a red and infrared LED respectively (figure 2.1). This results in the blinking of LEDs one after another, allowing the photodetector to differentiate the light sources accurately. The frequencies of the two LEDs are 660 Hz (red) and 940 Hz (infrared), such that the distinction between the absorbance of lights by oxyhaemoglobin and deoxyhaemoglobin can be

maximized (figure 2.2). In order to prevent loading effect, two voltage followers are also placed between the counter and the LEDs to isolate each block of circuits.

A silicon photodetector TSL257, chosen for its full coverage of the wavelengths as well as its short rising and falling time, feeds the obtained signal to the sample and hold circuit mentioned above. In order to demultiplex and sample the obtained signal, a 4066 bilateral switch first generates Red/IR capture signals from the clock signal and the Red/IR LED signals that are triggered by the falling edges of clock signals, and then generates the final Red/IR signals with the Red/IR capture signals and the photodetector signal. In order to hold the signal, standard RC circuit with 220uF capacitors are utilized. The specific value can ensure the proper relationship between switch delay time and photodetector falling time, as well as ideal holding performance. Finally, a second-order high pass passive filter (0.8 Hz) and a fourth-order low pass passive filter (10 Hz) are placed sequentially to eliminate motion artifacts, such as respiratory activity, and high frequency noise, including power-line interference respectively. An active amplifier (6X) is also installed to amplify the weak biological signal to a desirable scale so that the analog-to-digital converter (ADC) of Arduino Uno can read the signal.

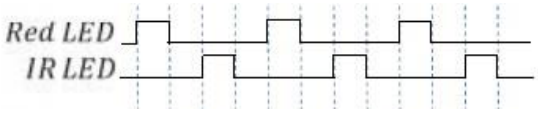

Figure 2.1 (LED driving signals;above)

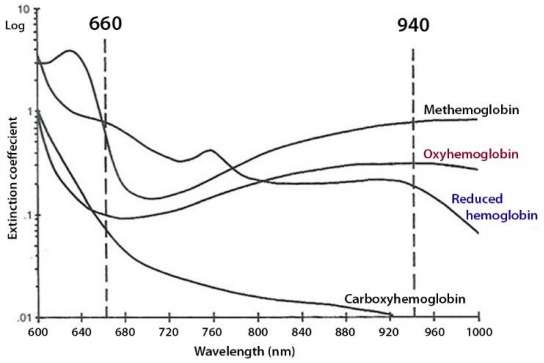

Figure 2.2 (Significant absorption difference of 660Hz and 940Hz by different hemoglobins; right)

The two LEDs and photodetector are fixed into a finger probe such that the light emitted by the LEDs can pass through the subject's finger and be received by the photodetector. The probe is designed using Solidworks and printed with a 3D-printer.

2. Software section

After feeding the filtered analog signal into the digital Arduino device, a digital low-pass filter and a digital high-pass filter is used to eliminate the high-frequency noise induced by the ADC , and to ensure a stable AC signal respectively. The AC signal of IR is then utilised to calculate the heart beat rate. By performing autocorrelation on the IR_AC, a peak-detection algorithm can be used to find the position of the first peak. The heart rate is then

calculated by dividing 1 by the time length between the origin and the first peak. For calculation of the SpO2, a parameter called R_ratio is computed. By conducting an empirical calibration using finger Sims together with a commercial pulse oximeter, a calibrated equation (SpO2 against R_ratio) is obtained. Inputting an R-ratio value gives the SpO2 value.

Apart from the Arduino, a TFT screen is also implemented as an added feature. After calculating the heart rate and SpO2, their values as well as the obtained PPG signal can be displayed on the screen,. After three cycles of waveform display, it will switch to another mode and four waveforms, including the IR_AC, IR_DC, R_AC and R_DC are shown instead. It then changes back into the original mode.

3. Experiment

Hypothesis:

Human reaction time under increased heart rate (RT_IHR) is shorter than that under resting state (RT_RS), i.e. RT_run < RT_rest.

Methodology:

Each volunteer was first asked to sit on a chair and relax for 1 minute to stabilize their heart rate. Next, the heart rate (RT_RS) and SpO2 value were recorded with the GZD pulse oximeter. The subjects were then asked to complete a response test developed by Human Benchmark via a mobile phone. The test displays a red screen initially, and prompts the test subject to press the screen as soon as it turns green. Each volunteer performed the test for 5 times and the average response time was recorded. The volunteers were asked to run for 2 minutes in the second stage of the experiment to increase heart rate [2]. After recording the initial heart rate (RT_IHR) and SpO2 value, the volunteers performed the mentioned test again for 5 times and the average response time was recorded.

35 volunteers have participated in the experiment. Since the sample size is 35, central limit theorem applies and the sampling distribution of the difference between RT_IHR and RT_RS can be assumed to be approximately normal. Therefore, a paired t-test was applied to investigate whether there is a difference between RT_IHR and RT_RS. After that, a post-hoc comparison between the means of the two sets of data was conducted to show the direction of the difference.

Results:

The volunteers' heart rate increased whereas their SpO2 values remained unchanged after running for 2 minutes.

For the paired t-test, the null hypothesis (H_0) is that RT_IHR is the same as RT_RS, i.e. RT_IHR = RT_RS.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	RT_rest - RT_run	.031543	.030662	.005183	.021010	.042076	6.086	34	.000

Table 1. The results of paired t-test.

Since the calculated test statistics (t) is 6.086, which is greater than the critical point for rejection (i.e. 2.032) when $\alpha/2 = 0.025$ and degree of freedom (df) = 34 (Table 1), there is sufficient evidence to reject H_0, at a significance level of 0.05 (Table 1). Therefore, RT_IHR is statistically significantly different from RT_RS, with a p-value being smaller than 0.001.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	RT_rest	.42380	35	.032694	.005526
	RT_run	.39226	35	.036496	.006169

Table 2. The descriptive statistics of the paired samples.

In addition, since the mean of RT_IHR (i.e. 0.39226) is smaller than that of RT_RS (i.e. 0.42380) (Table 2), RT_IHR is statistically significantly smaller than RT_RS.

Discussion:

The p value shows a significant decrease in reaction time after acute exercise, which justifies the rejection of null hypothesis. During exercise, different parts of the body collaborate at numerous levels in order to provide enough nutrients and circulation speed for the sudden change in metabolism as well as to maintain the dynamic stability, known as homeostasis. The peripheral nervous system, particularly the sympathetic nervous system, is activated to maintain the elevated blood pressure and heart rate. The epinephrine, a hormone that binds to beta-2 receptors, is released, prompting vessel dilation and thus peripheral resistance decrease. Blood flows relatively easy throughout the body and brings oxygen and nutrients to organs that have high metabolic needs, thereby allowing better cognitive functioning [3].

However this experiment was performed under several assumptions, one being that the heart rate and spo2 values are the only factors influencing a person's reaction time. This may not be true as reaction time can also be lowered through practice. This could contribute to the shorter measured reaction time after running thus the statistical conclusion.

As the human body responses to environmental or behavioral changes constantly, there could be many unforeseen factors influencing a person's response time, such as the rate of calcium release for muscle contraction, release of glucose for higher energy needs or even changes in body temperature. While the testing environment was kept as stable as possible, there may be certain internal factors of the human body that are yet to be accounted for.

It is therefore suggested that other means which do not interfere with the body's internal equilibrium dramatically should be used instead to increase heart rate. Such methods include drinking coffee or other drinks with caffeine. Independent tests such as the investigation of how consuming large amount of glucose affects reaction time should also be performed to reduce the number of uncertainties.

Conclusion:

This experiment concludes that the GZD oximeter works well and an increasing heart rate has a positive effect on increasing reaction time. This brings an insight as to how warm up exercise and stretching is crucial for sports or work that require high level of attention and cognitive functions such as machinery control and long journey driving. This experiment can be used as a preliminary test to the understanding of the relationship between brain functions and heart beat rate.

5. Reference

1. Pole, Y. (2002, December). Evolution of the pulse oximeter. In *International Congress Series* (Vol. 1242, pp. 137-144). Elsevier.
2. Anderson P, Landers G & Wallman K (2014). Effect of warm-up on intermittent sprint performance. Res Sports Med. 22.1, 88-99 DOI 10.1080/15438627.2013.852091.
3. Cahill, L., & Alkire, M. T. (2003). Epinephrine enhancement of human memory consolidation: interaction with arousal at encoding. *Neurobiology of learning and memory*, *79*(2), 194-198.