Heart Rate Monitor

Project Design Documentation

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1. Introduction

1.1 Purpose

This is the documentation of the hardware and system design for a real time heart rate monitor.

1.2 Scope

This project will input signals from the human body and output them in the form of a comprehensive graph and heart rate number. This will be accomplished using a sensor which will input to an analyzing software.

1.3 Definitions and Acronyms

LV - LabView
DAQ - Data Acquisition
Hb - Hemoglobin (deoxygenated)
HbO2 - Oxygenated Hemoglobin
UI - User Interface

2. System Overview

When the heart pumps blood, the pressure (and therefore volume) of blood in the body's arteries and blood vessels increases or decreases briefly. Using a bright light source on one side of an artery or vessel and a photodetector on the other one can detect the change in volume by measuring a change in light transmitted or absorbed by the blood. As the volume of blood increases the intensity of light that makes it through through the vessel change.

Hemoglobin, the oxygen carrier of blood, has several absorption lines. Some correspond more strongly to deoxygenated (Hb) blood than oxygenated (HbO2). Some of these absorption and transmission peaks are explained intuitively. In the visible spectrum, oxygenated blood (which is red-purple) absorbs green light strongly and transmits red light. Deoxygenated blood (which is blue-purple) absorbs yellow-orange light and transmits blue. Deoxygenated blood also transmit strongly around 700 nm (red light) though not as strongly as HbO2. This is because the body does not fully oxygenate all the hemoglobin.

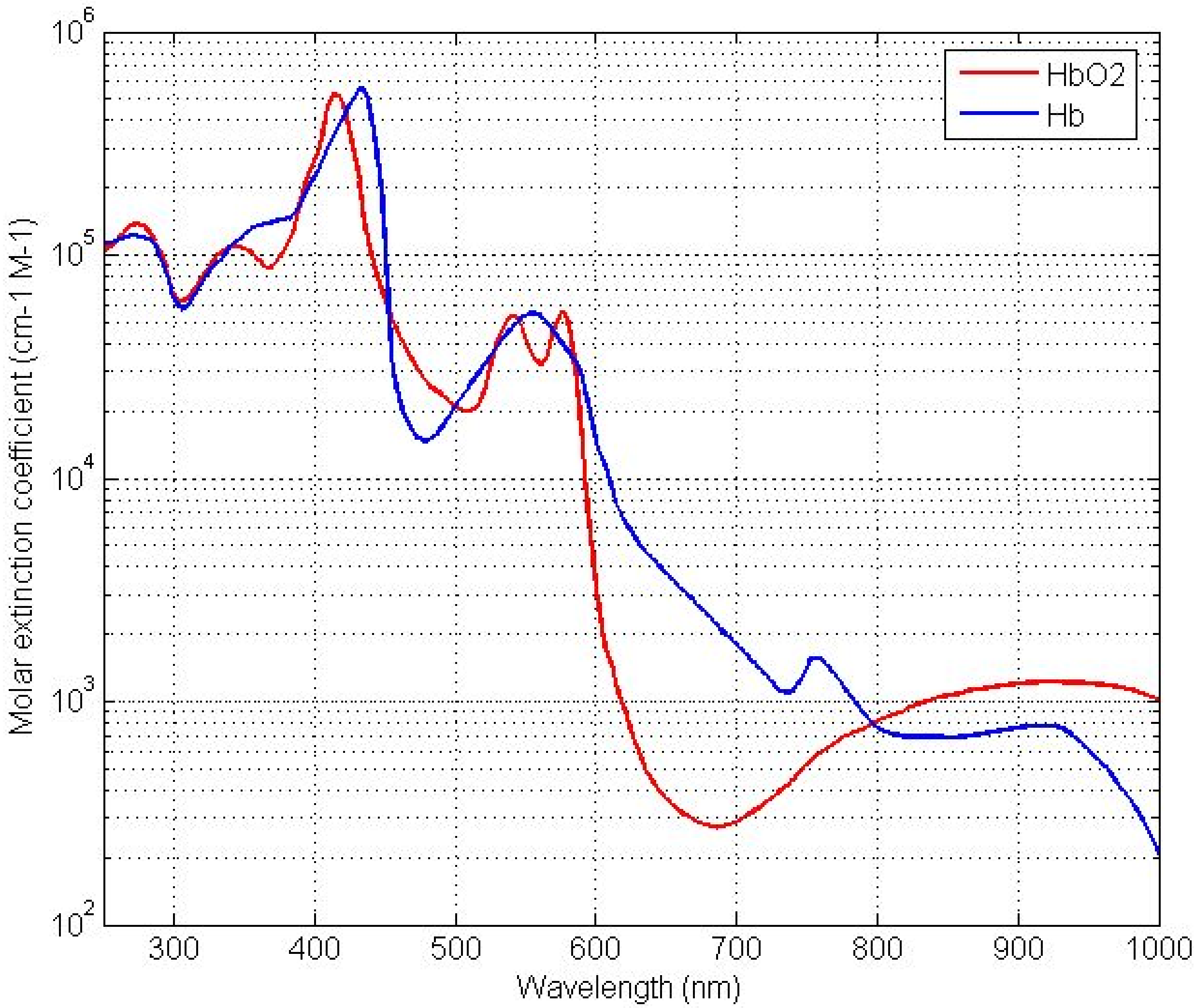

Fig. 1 - The molar extinction coefficient of HbO2 and Hb (by Zhun310 - Own work. Licensed under CC BY-SA 3.0 via Commons.)

The design for this project is to use a red LED and photoresistor on either side of the thumb to detect heart rate. Red light, as discussed previously, is transmitted by both Hb and HbO2. When the volume of blood is increased, the amount of transmitted light is increased.

The signal taken from the photoresistor then be inputted to LabView (LV) using a Data Acquisition (DAQ) device where it will be interpreted, processed, and outputted to the user.

3. System Architecture

3.1 Architectural Design

The software consists of three stages; signal collection, signal process, and signal display. The signal will be collected using a DAQ device. After the data is collected, the frequencies corresponding to a range outside a reasonable heart-rate were filtered and removed and then outputted to a graph for the user.

The data was collected using the circuits shown in fig.2 where the user's finger rests between a 10000 mcd LED and the LPT100 phototransistor.

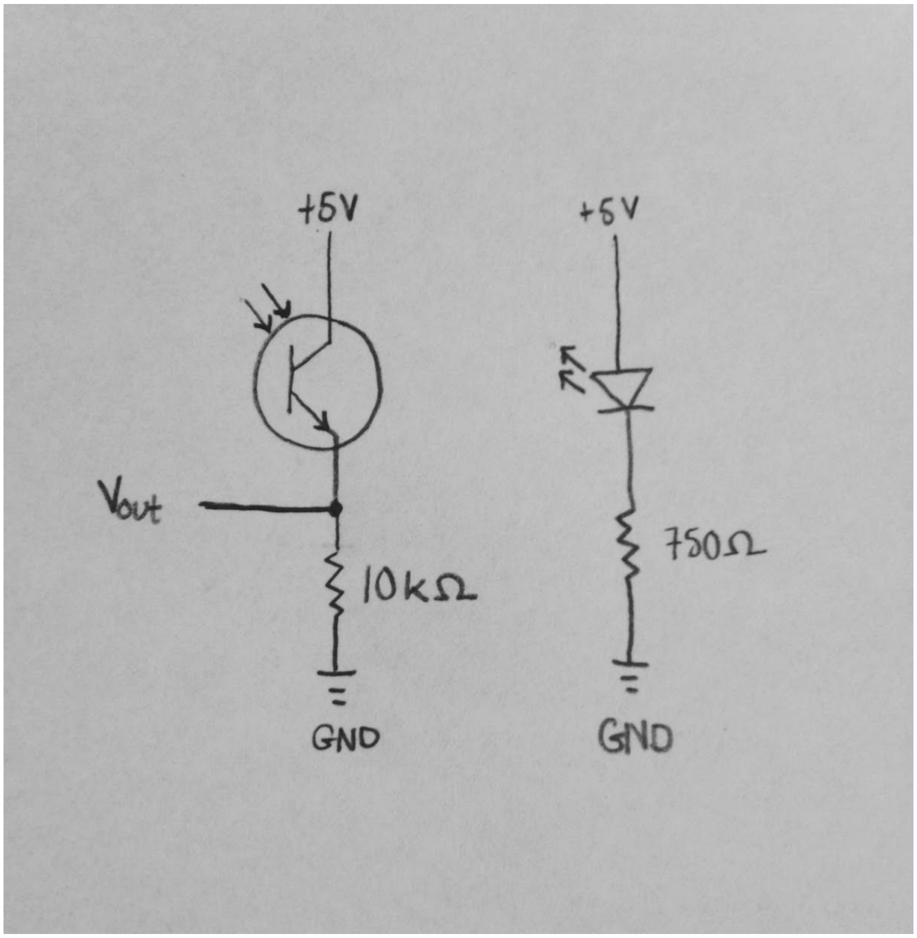

Fig.2 Our circuit setup

The phototransistor circuit was set up as a common collector amplifier which places the resistor between the emitted and ground and leaves the base unconnected. A full discussion of the different phototransistor circuit setups can be found here. A 10K Ohm resistor was used in this circuit in order to operate the phototransistor in switch mode making the circuit turn on and off in response to the light. The output voltage is sent on to the DAQ.

Using sample rate and data collection times defined by the user in the UI, the DAQ inputs the voltage signal produced by the phototransistor into Labview. This signal is output to a graph labeled “Unfiltered Time Plot” in the UI, showing a rough representation of the pulse of the user over the entire time measurement. The signal is then filtered using a Butterworth low-pass filter, which is defined to have a flat frequency response up until the cutoff frequency, which is defined by the user using the software through the Filter VI. We set the cutoff frequency of the filter to be 5 Hz, which corresponds to a heartbeat of 300 beats per minute, which is significantly higher than the normal range of heartbeats of a normal adult human, giving a very conservative maximum limit to our frequency data.

We display this filtered signal on a scale of 10 seconds using the graph “Filtered Time Plot” in the UI in order to display a clean, zoomed in representation of the measured heart beats. The signal is then processed by the “Spectral Measurements” VI, which performs a Fast Fourier Transform on the signal, which converts a set of equally spaced samples of a function with a time or position domain into its frequency domain, providing a data set in respect to the heart beat signal’s frequencies rather than the time of the measurement. This data set is then output in a graph labeled “Frequency Plot” on the UI for frequencies from 0-5 Hz. In order to calculate the heartrate of the user in beats per minute (BPM), we found the peak frequency of the data using the “Array Max & Min Function”, which outputs both the maximum and minimum values of the given array, as well as the index of said maximum and minimum values. The phototransistor and DAQ pick up a large peak amplitude at a frequency of 0 Hz, which corresponds to the 5V signal produced by the Voltage supply for our circuit. To account for this, we extracted the frequency signal from a frequency range of 0.66667 Hz (corresponding to a heart-rate of 40 BPM, which is a conservative lower limit on the heart rate of a human) to a maximum of 5 Hz. We used the Max index output multiplied by the distance between each data sample in the frequency data set (which we labeled “df”) in order to determine the peak frequency in hertz. The “Extract Portion of Signal” VI we used for this purpose shifts the graph by a frequency value of .66667, which we account for by adding .666667 to the peak frequency calculated. To determine the beats per minute from a corresponding frequency, we multiply by a factor of 60, giving us the heart rate of the user in bpm, which we display in the UI.

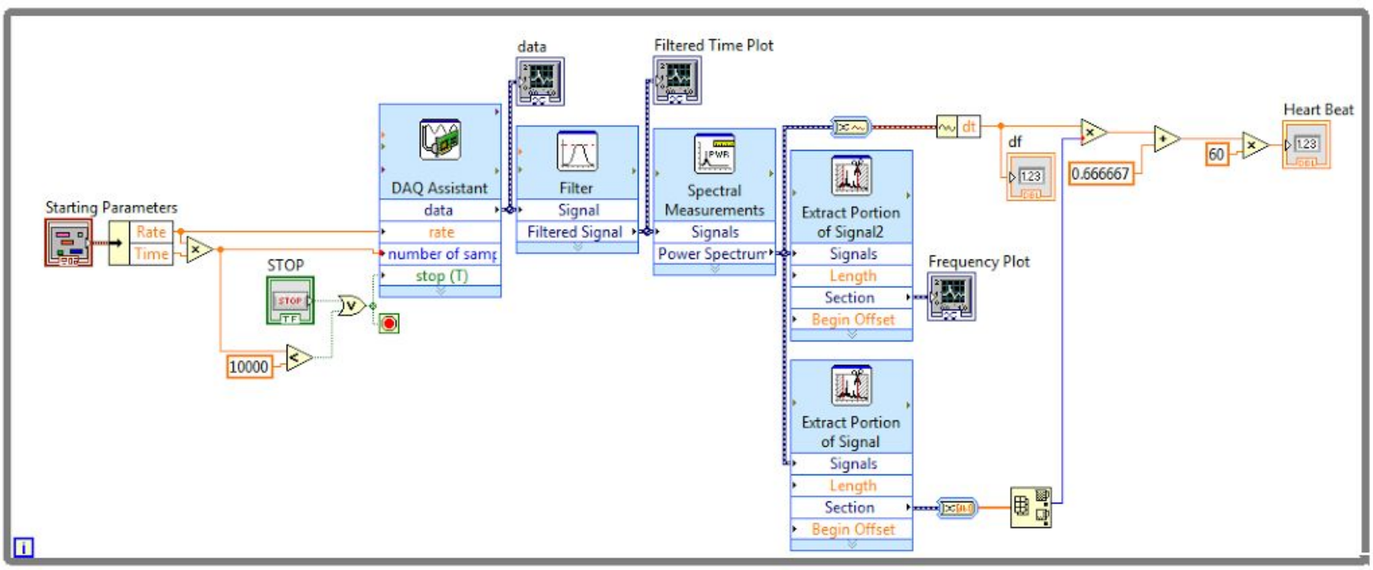

Fig. 3 Signal Processing in LV

3.2 Design Rationale

This is a simple design meant to efficiently and clearly display a heart rate. Other hardware such as an Infrared LED to measure the amount of both oxygenated and deoxygenated blood was rejected due to time constraints.Additionally, the use of an op-amp was considered but removed for simplicity sake due to a lack of any noticeable effect on our pulse signals. A hardware-based low pass filter was rejected in favor of a software based solution due to the easy customization options of the software-based filter.

4. Human Interface Design

4.1 Overview of User Interface

The user will place a finger in between the red LED and the phototransistor. As the signal from the phototransistor is collected and processed they will be able to see the pulses on a graph after each software iteration. Additionally, graphs of both the filtered pulse signal and the frequency data generated from the fourier transform will be displayed. The sample rate and data collection time are both controllable via the user interface (UI).

4.2 Screen Images

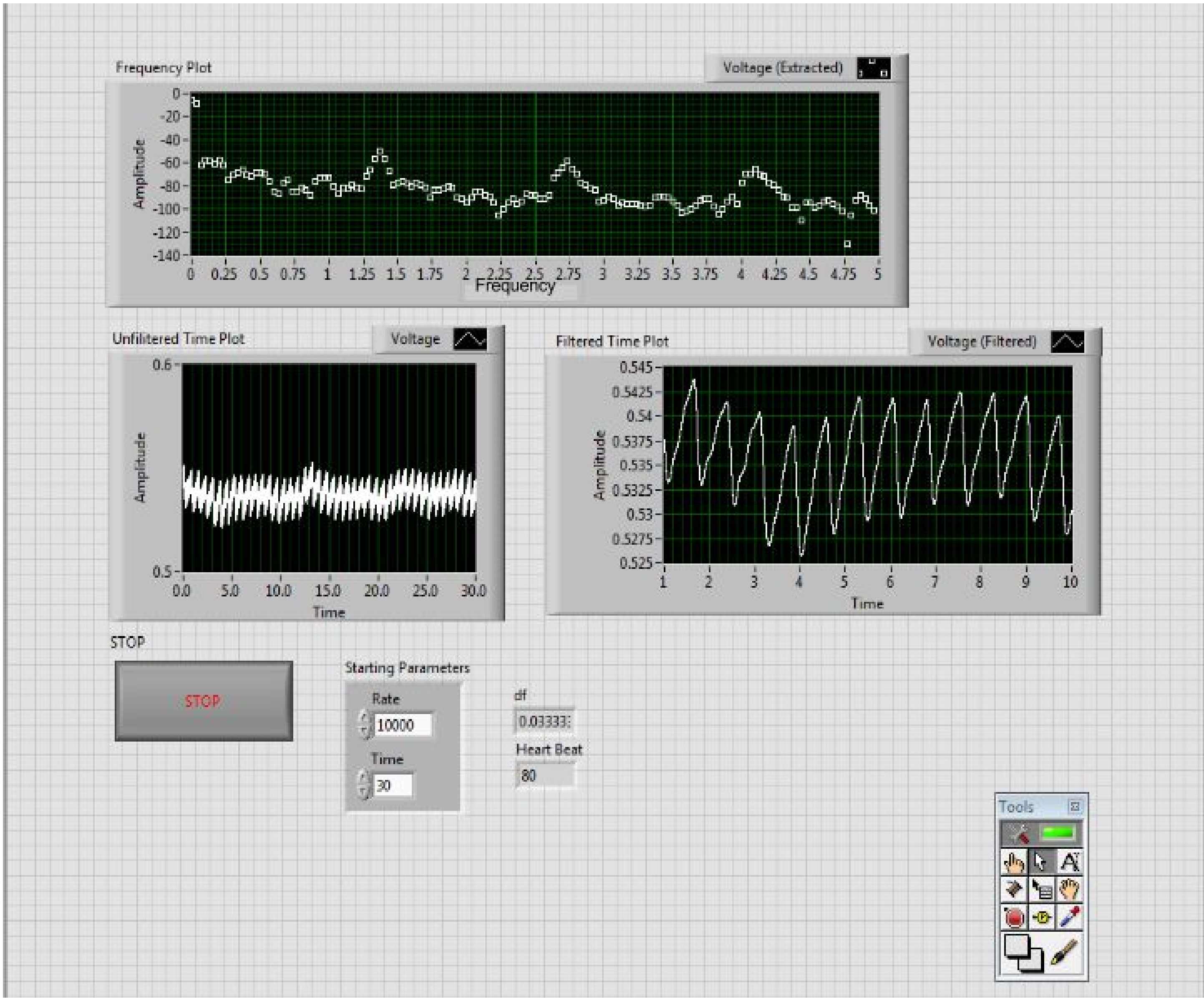

Fig. 4 Front Panel of LV Project

5. Final Notes

5.1 Performance

One thing that was noticed was that measuring the heart rate with smaller fingers was more difficult. This is because the strength of the signal is dependant on the volume of blood passing between the LED and phototransistor. For users with small fingers it is recommended that the palm of the hand is used.

5.2 Possible Adaptation

Since the absorption lines for Hb and HbO2 are not identical a pulse from the oxygenated hemoglobin can be separated from a pulse from the hemoglobin. This is frequently done by using two different colored LEDs each corresponding to strong lines for the Hb and HbO2. Typically a red LED is used to get a signal from the Hb and an infrared LED is used to find the HbO2 signal. Knowing the HbO2 count of an area of the body has many medical applications one of them being the study of perfusion.