Biomedical Instrumentation
Project Report

SpO_2 Management System using Fast Fourier Transform (FFT)

Submitted By:
Tirumal Naidu (2017082)
Surya Charan (2017176)

Introduction

Pulse oximetry is a method for monitoring a person's oxygen saturation by collecting the reading of peripheral oxygen saturation (SpO_2). Most commonly, a sensor device is placed on a thin part of the patient's body, usually a fingertip or earlobe. The device passes two wavelengths of light through the body part to a photodetector. It measures the changing absorbance at each of the wavelengths, allowing it to determine the absorbances due to the pulsing arterial blood alone.

Fig 1. Pulse Oximeter

Because of their simplicity of use and the ability to provide continuous and immediate oxygen saturation values, pulse oximeters are of critical importance in emergency medicine.

Pulse oximeters are used to help with the early detection of **COVID-19** infections, which may cause initially unnoticeable low arterial oxygen saturation and hypoxia. Studies of reliability show mixed results, and there’s little guidance on how to choose one. But many doctors are advising patients to get one, making it the go-to gadget of the pandemic.

Problem Statement

Pulse oximetry estimates arterial haemoglobin oxygen saturation ($Sp0_2$) through analysis of light waveforms transmitted through a capillary tissue bed. Usually, we calculate the SpO_2 through the time series analysis of the PPG signal we obtain from the pulse oximeter. In this project, we will measure the SpO_2 through spectral analysis of PPG using Fast Fourier Transform(FFT) in MATLAB.

Motivation

Spectral Analysis is the most efficient methods for SpO2 computation. SpO2 measurement using FFT may provide a low power, low cost, small footprint in portable pulse oximetry applications.

Methodology

SpO2 is simply the ratio of oxygenated haemoglobin concentration co to total haemoglobin concentration c_o+c_d:

$$\mathrm{SpO_2} = \frac{c_o}{c_o + c_d}.$$

When light passes through a material it loses energy as it is absorbed by matter. The attenuation can be described using Beer-Lambart Law:

$$I = I_0 e^{-\varepsilon c \ell}$$

Haemoglobin exists in two difference forms in human blood: oxygenated (HbO_2) and deoxygenated (Hb). Each has different extinction coefficients at different wavelengths.

Using the above law,

$$\begin{aligned}
\varepsilon_{r,o} &= 442 && \mathrm{cm^{-1}\,M^{-1}} && \text{red light (640 nm), } \mathrm{HbO_2}. \\
\varepsilon_{r,d} &= 4345.2 && \mathrm{cm^{-1}\,M^{-1}} && \text{red light (640 nm), Hb.} \\
\varepsilon_{ir,o} &= 1214 && \mathrm{cm^{-1}\,M^{-1}} && \text{infrared light (940 nm), } \mathrm{HbO_2}. \\
\varepsilon_{ir,d} &= 693.44 && \mathrm{cm^{-1}\,M^{-1}} && \text{infrared light (940 nm), Hb.}
\end{aligned}$$

the absorbance of red light and infrared light through one's fingertip can be modeled by the following equation:

$$
\begin{aligned}
I_r(t) &\approx K_r\left[1-\left(\varepsilon_{r,o}\Delta c_o(t)+\varepsilon_{r,d}\Delta c_d(t)\right)\ell'\right],\\
I_{ir}(t) &\approx K_{ir}\left[1-\left(\varepsilon_{ir,o}\Delta c_o(t)+\varepsilon_{ir,d}\Delta c_d(t)\right)\ell'\right].
\end{aligned}
$$

By filtering these signals, the dc (constant over short periods of time) and ac (average value of zero of short periods of time) components may be extracted. Then, the dc-normalized transmission ratio R is calculated. SpO2 is a function of the dc-normalized transmission ratio R.

$$
R=\frac{I_{r,ac}(t)/I_{r,dc}(t)}{I_{ir,ac}(t)/I_{ir,dc}(t)}=\frac{\varepsilon_{r,o}\Delta c_o(t)+\varepsilon_{r,d}\Delta c_d(t)}{\varepsilon_{ir,o}\Delta c_o(t)+\varepsilon_{ir,d}\Delta c_d(t)}.
$$

$$
\mathrm{SpO_2}=\frac{\Delta c_o(t)}{\Delta c_o(t)+\Delta c_d(t)}=\frac{\varepsilon_{r,d}-R\varepsilon_{ir,d}}{R\left(\varepsilon_{ir,o}-\varepsilon_{ir,d}\right)-\left(\varepsilon_{r,o}-\varepsilon_{r,d}\right)}.
$$

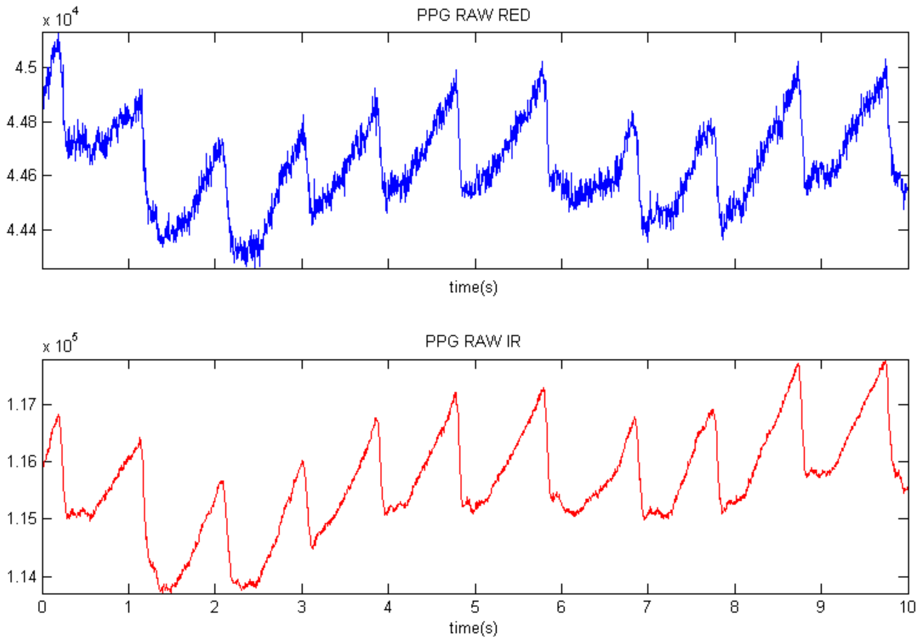

Fig 2. PPG Data (For Red and IR)

Spectral Analysis :

If the spectrum or a sampling of the spectrum of a short frame of signal is obtained, then the values of $I_{r,ac}$ and $I_{ir,ac}$ can be taken as the magnitude of the spectrum at the fundamental frequency of heartbeat. Then, dividing by the respective dc levels (also obtained from the spectra) and taking the ratio yields the overall dc-normalized transmission ratio for that time frame.

This spectral analysis is done by calculating Discrete Fourier transform (DFT) of I_r and I_{ir} using the Fast Fourier Transform (FFT).

The DFT of x[n] at frequency ω_k is given by :

$$X[k] = \sum_{n=0}^{N-1} x[n]\, e^{-j(2\pi k/N)n}, \quad k = 0, 1, ..., N-1.$$

Block Diagram

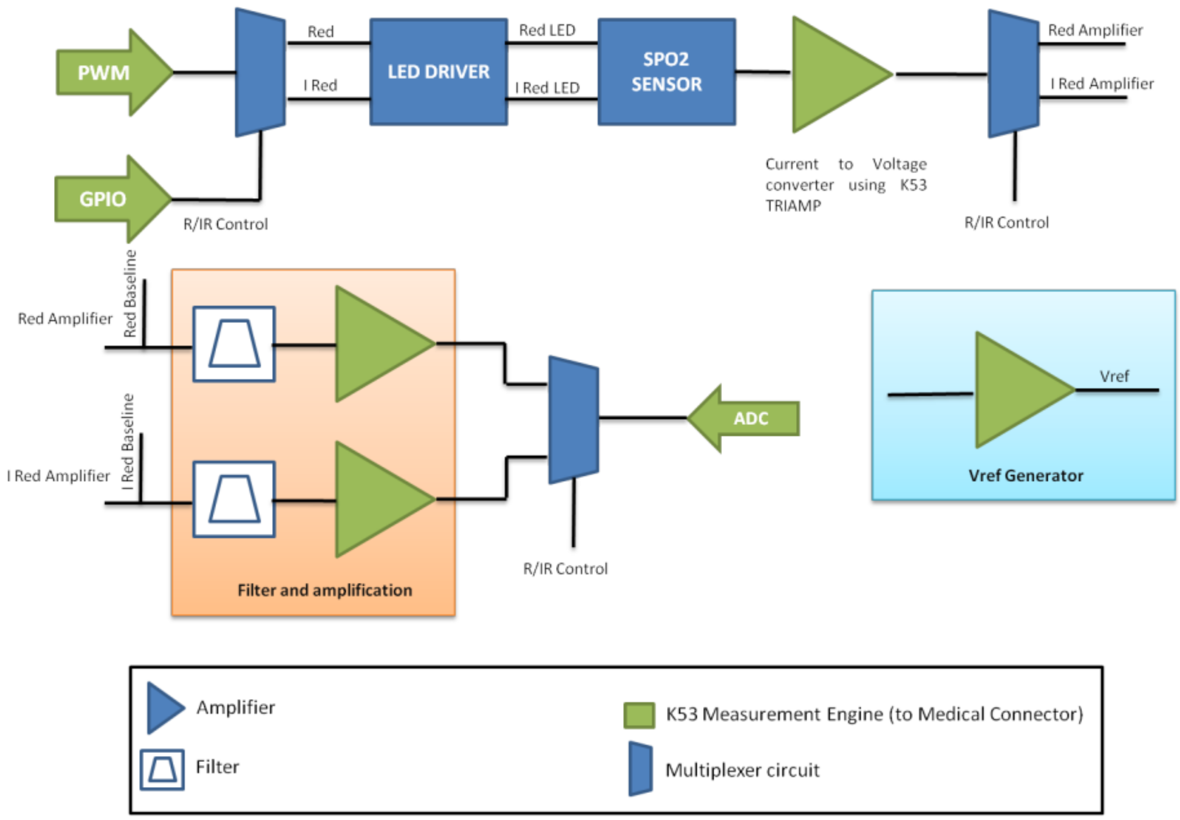

Fig 3. Typical Oximetry Block Diagram

Problem Solution

We process the PPG data of a person by writing a MATLAB program which can implement the FFT and estimate the SpO_2 level and heart rate of the person. If we develop the sensor, we will implement the same algorithm (typically in C++) in a Digital Signal Processor (DSP) of a Embedded processor.

```
%% SpO2 level calculation

%%FFT for RED signal
Y1 = fft(y1,NFFT);


%Find local maximum in RED spectrum
st = 6;

YY=abs(Y1(st:12));
local_max_i=1;
local_max=YY(1);
for i=2:(length(YY)-1)
    if local_max<(YY(i))
        local_max_i=i;
        local_max=YY(i);
    end
end
pk_RED_i=st-1+local_max_i;

%%FFT for IR
Y2 = fft(y2,NFFT);



% Find local maximum in RED spectrum

YY=abs(Y2(st:12));
local_max_i=1;
local_max=YY(1);
for i=2:(length(YY)-1)
    if local_max<(YY(i))
        local_max_i=i;
        local_max=YY(i);
    end
end
pk_IR_i=st-1+local_max_i;

%%SpO2
R_RED = abs(Y1(pk_RED_i)/abs(Y1(1)));
R_IR = abs(Y2(pk_IR_i)/abs(Y2(1)));
R=R_RED/R_IR;
SpO2 = 104 - 28*R

%% END
```

Fig 4. Implementation of SpO_2 measurement in MATLAB

Conclusion

We successfully measured SpO_2 levels and heart rate using Fast Fourier Transform from a PPG data of a patient

References

[1] Christopher Hood, Discrete Fourier Transform Techniques for Pulse Oximetry Signal Processing. OpenStax CNX. Apr 2, 2014

[2] Scharf, John E., and Terry L. Rusch. "Optimization of portable pulse oximetry through Fourier analysis." [1993] Proceedings of the Twelfth Southern Biomedical Engineering Conference. IEEE, 1993.

[3] Scharf E, Athan S, Cain D, "Pulse oximetry through Spectral Analysis", Abstract, Presented at the 12th Southern Biomedical Engineering Conference, Tulane University, April 1993.

[4] Lopez, Santiago, and R. T. A. C. Americas. "Pulse oximeter fundamentals and design." Free scale semiconductor (2012).