Application of PPG Signal Processing to Patients undergoing Angioplasty Procedure

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Abstract— *Cardiovascular diseases are disorders of the heart and its blood vessels and include coronary heart disease and other such conditions. Photoplethysmography (PPG) signals provide rich amount of information for the health diagnosis and it is effective for analyzing cardiovascular diseases. In this paper, we show the efficiency of the angioplasty procedure by recording the PPG signals from the patients suffering from myocardial infarction before and after the procedure. To quantify changes taking place in PPG signals we apply signal processing techniques. One of the techniques is to find the energy ratio of the PPG signal before and after angioplasty. From the energy ratio, we can observe clear changes in the PPG signal before and after angioplasty. Another technique used is the Poincare Plot Analysis. Here we first find the Poincare plot of the PPG signal before and after angioplasty. Then we calculate the standard deviations and area under the ellipse of the Poincare plot. These parameters show that clear differences in the PPG signal before and after angioplasty. The results obtained from the above two techniques indicates the changes brought about by angioplasty procedure.*

Keywords— **Angioplasty. Cardiovascular Disease, Energy Ratio, Myocardial Infarction, Photoplethysmography, Poincare Plot Analysis.**

1 INTRODUCTION

Cardiovascular diseases (CVDs) include coronary artery diseases (CAD) such as angina pectoris and myocardial infarction (MI). The PPG signals are useful index of the conditions of a living body, and potentially form an excellent basis for a diagnostic technique. PPG signal is easy to acquire because the sensor is placed at the fingertip [1]. MI, commonly known as a heart attack, occurs when blood flow decreases or stops to a part of the heart, causing damage to the heart muscle [2]. Atherosclerosis is a condition where the arteries become narrowed and hardened due to a buildup of plaque in the arterial wall. It is also known as arteriosclerotic vascular disease. It is usually treated by a non-surgical procedure called angioplasty. The angioplasty procedure is done after performing angiogram [3]. PPG is a non-invasive technique that measures relative blood volume changes in the blood vessels close to the skin. Its system consists of two LEDs Red (660nm) and Infrared (IR-940nm) sources and a photo detector. The sensor system monitors the changes in light intensity associated with the changes in blood perfusion to the tissue bed that in turn provides information on cardiovascular monitoring system design [4]. Fig.1 shows a typical PPG signal. The appearance of the PPG signal is commonly divided into two phases – Anacrotic phase and Catacrotic phase. Anacrotic phase is the rising edge of signal and Catacrotic phase is falling edge of the signal. The dicrotic notch is usually seen in the catacrotic phase of healthy compliant arteries. The first phase is primarily concerned with systole and the second phase is associated with diastole and wave reflections from the periphery

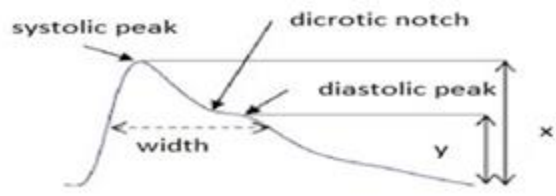

Fig 1: Typical PPG signal

PPG sensor can be placed at any extremities such as forehead, earlobe, fingertip, nasal septum etc. The principle involved in PPG is that the optical light travelling through the tissue is absorbed by different substances such as bone, pigments, arterial and venous blood and skin. Oxyhaemoglobin allows the red light and de-oxyhaemoglobin allows the infrared light. PPG technology is a promising approach for individual cardiovascular monitoring systems design [5].PPG is blood volume measurement method which detects volume changes caused by vessel pressure which can be by the light illuminated from photodiode.

Several authors have studied the application of signal processing techniques to PPG signals with particular reference to angioplasty. Mohamed Elgendi et.al [6] emphasizes the potential information embedded in the PPG signals and also discusses various features of the PPG signals. PPG is a promising technique for early screening of various atherosclerotic pathologies and could be helpful for they have discussed the different types of artifacts added to PPG signal, characteristic features of PPG waveform, and existing indices to evaluate for diagnoses. Chun T. Lee and Ling [7] talk about the analysis of the wrist pulses by calculating two parameters, Pulse Spectral Graph (PSG) and Energy Ratio(ER). The PSGs were plotted from the pulses that were taken from the wrist. Energy ratio (ER) is defined as the ratio of the energy of PSG below 10 Hz to that above 10 Hz. We have extended this technique to

PPG signals to assess the efficiency of angioplasty procedure. Kumar et.al [8] have analyzed the features of ECG using Poincare plot analysis. An electrocardiogram (ECG) provides information about individual cardiac health. Aside from directly analyzing the ECG signals, researchers and doctors also extract other indirect measurements from the ECG signals and one of the most popular measurements is HRV, which show the variation between consecutive heartbeats. HRV measurements analyze how the RR intervals of an ECG signal, change over time The Poincare plot is a representation of a time series into phase space where the values of each pair of successive elements of the time series define a point in the plot. We plot the Poincare plot for the PPG signals to show the efficiency of angioplasty procedure.

2 METHODOLOGY

We acquire the PPG signals by placing the sensor in the finger tip. The PPG signal is recorded before and after angioplasty. The analog PPG signal is converted into digital form using Arduino microcontroller. The data from the Arduino microcontroller is sent to computer or laptop using software called PLX-DAQ. The PLX-DAQ software converts the serial data of the microcontroller to excel data.

The data obtained from the PLX-DAQ software is used in MATLAB. We use nonlinear techniques in MATLAB to analyze the collected PPG data. Finally the results obtained are compared.

2.1 Energy Ratio

We analyze the recorded PPG signal from the patients suffering from myocardial infarction before and after angioplasty. To calculate Energy Ratio, we will find the Power Spectral Density (PSD) plot of the recorded PPG signal. The power spectral density plot is usually plotted using FFT and Welch method. We divide the PSD plot into 5 bands and calculate the energy of each band, i.e.,

E1 1 to 10Hz

E2 11 to 20Hz

E3 21 to 30Hz

E4 31 to 40Hz

E5 41 to 50Hz

The Energy Ratio is calculated using the formula

$$ER = \frac{Energy\ below\ 10Hz}{Energy\ above\ 10Hz} = \frac{E1}{E2+E3+E4+E5}$$

We want to find ER and then observe the changes in the PPG signal before and after angioplasty.

2.2 Poincare Plot Analysis

Poincare Plot Analysis is done to evaluate the dynamics of PPG signals. It provides both quantitative and qualitative analysis of the signal. It is basically a scatter graph plotted by x(n) and x(n+1) where x(n) is the recorded PPG signal. We calculate Standard Deviation (SD1, SD2) and Area under Ellipse of the Poincare plot for the recorded PPG signals before and after angioplasty. The Standard Deviation1 (SD1) gives the width of the ellipse, Standard Deviation2 (SD2) gives the length of the ellipse and area under the ellipse is the amount of area covered by the ellipse. It is calculated by the product of SD1 and SD2.

3 RESULTS AND DISCUSSION

We have recorded the PPG signal, before and after angioplasty from 10 patients suffering from Myocardial Infarction. Fig.2 shows the PPG signal before and after angioplasty. We quantity the changes in the PPG signal using energy ratio technique and Poincare plot analysis.

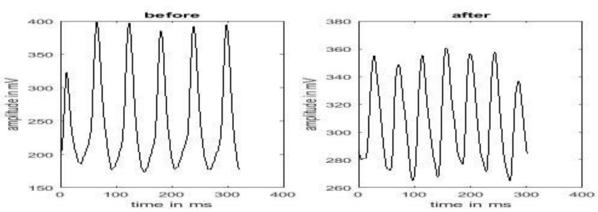

Fig.2: PPG signal before and after angioplasty

3.1 Energy Ratio

Fig.3 shows the Power Spectral Density (PSD) plot of the recorded PPG signal before and after angioplasty. The PSD plot shows the change in power spectrum density w.r.t frequency of the PPG signal. The PSD plot gives the variation of the signal at different frequencies. The PSD plot helps us in calculating the Energy Ratio of the recorded signal. From Fig.3, we observe that high frequency component is more in PSD plot before angioplasty than after angioplasty.

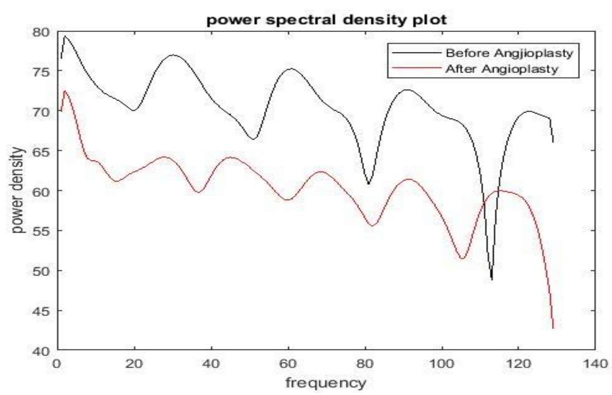

Fig.3: Power Spectral Density Plot before and after angioplasty

The Table 1 shows the energy ratio of the recorded PPG signal before and after angioplasty. From the table, we can infer that the Energy Ratio of the recorded PPG signal after angioplasty is greater than before angioplasty.

We observe that there is considerable percentage change in the Energy Ratio before and after angioplasty. This indicates that there is an improvement, after angioplasty procedure.

Table-1: Energy ratio before and after angioplasty

SUBJECT	ENERGY RATIO			
	BEFORE ANGIOP - LASTY	AFTER ANGIOP -LASTY	DIFFE - RENCE	PERCENT-AGE OF DIFFERE-NCE (%)
SUBJECT 1	0.3500	0.4963	0.1463	41.80
SUBJECT 2	0.3998	0.4661	0.0663	16.59
SUBJECT 3	0.3634	0.5085	0.1451	39.92
SUBJECT 4	0.4661	0.7154	0.2493	53.48
SUBJECT 5	0.3382	0.7154	0.3772	111.53
SUBJECT 6	0.3605	0.3998	0.0393	10.90
SUBJECT 7	0.4638	0.5852	0.1214	26.18
SUBJECT 8	0.3735	0.5852	0.2117	56.68
SUBJECT 9	0.3607	0.3900	0.0293	8.12
SUBJECT 10	0.3648	0.4618	0.0970	26.58

3.1 Poincare Plot Analysis

Another technique to analyze and quantify changes in the recorded PPG signal is Poincare plot analysis. The Poincare plot analysis is a nonlinear method used to assess the dynamics of PPG signals geometrically.

It is one of the scatter graph plotted between x(n) and x(n+1), where x(n) is the recorded PPG signal. We have found the Poincare plot of the PPG signals recorded from the patients suffering from myocardial infarction before and after angioplasty.

Fig.4 shows the Poincare plot of the recorded PPG signals before and after angioplasty.

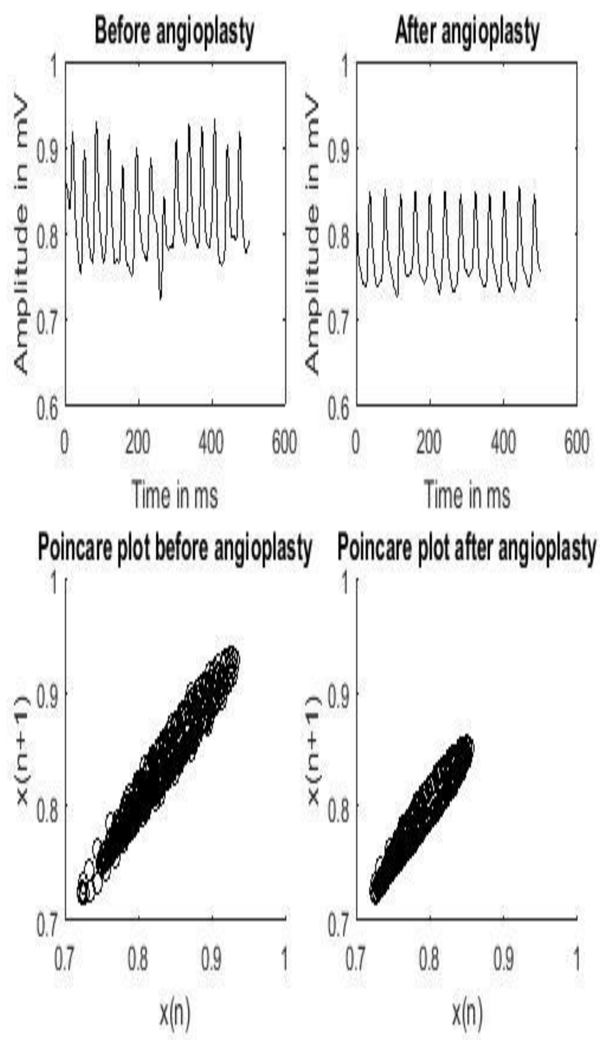

Fig.4: Poincare plot for before and after angioplasty

From the Fig.4, we can see that there are clear changes in the PPG signal before and after angioplasty, but to quantify the change in the signal we use Poincare plot analysis. In the Fig.4, the left side plot is before angioplasty PPG signal and its Poincare plot and the right side plot is after angioplasty PPG signal and its Poincare plot. From Fig.4, we can also observe that there is a clear change in the Poincare plot before and after angioplasty. From the Poincare plot we calculate the standard deviations (SD1, SD2) and area under the curve. The Table.2 gives the standard deviations and the area under the curve before and after angioplasty. From the table we can observe that there is a clear change in the PPG signal before and after angioplasty. We can also see that the SD1, SD2 and area under the ellipse will be greater in PPG signal before angioplasty than after angioplasty.

Table-2: SD1, SD2 and area under the ellipse from the Poincare plot before and after angioplasty

Subject	SD1		SD2		Area Under Ellipse	
	before angio - plasty	after angio - plasty	before angio - plasty	after angio - plasty	before angio - plasty	after angio - plasty
Subject 1	0.045	0.008	0.309	0.161	0.0436	0.0038
Subject 2	0.035	0.006	0.381	0.012	0.0419	0.0002
Subject 3	0.020	0.010	0.147	0.091	0.0092	0.0023
Subject 4	0.010	0.008	0.188	0.091	0.0059	0.0022
Subject 5	0.035	0.008	0.471	0.263	0.0518	0.0165
Subject 6	0.013	0.008	0.170	0.071	0.0066	0.0005
Subject 7	0.025	0.008	0.294	0.086	0.0230	0.0020
Subject 8	0.020	0.010	0.197	0.172	0.0123	0.0054
Subject 9	0.030	0.015	0.272	0.258	0.0256	0.0122
Subject 10	0.013	0.008	0.185	0.118	0.0073	0.0028

CONCLUSIONS

The PPG signal has been recorded from 12 patients suffering from Myocardial Infarction before and after angioplasty. The analog PPG signal has been converted into digital form using Arduino microcontroller and the data from the Arduino microcontroller is sent to computer or laptop using software called PLX-DAQ and then used in MATLAB.

We have used signal processing techniques in MATLAB to analyze the collected PPG data. The Power Spectrum Density (PSD) has been first obtained and then using Energy Ratio technique, we analyze the recorded PPG signals of the cardiac patients. We have found that the Energy Ratio of PPG signal shows a considerable change before and after angioplasty. Another technique used is to find parameters for Poincare plot. From the standard deviation and the area under the curve we can observe clear changes in the recorded PPG signal before and after angioplasty. This work has demonstrated the positive effect of angioplasty through the measurement of easily accessible PPG signals.

We have demonstrated here the use of PPG signals in determining the efficiency of angioplasty procedure. The work can be extended by recording wrist pulse signals instead of PPG signals and then applying a similar procedure.

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BIOGRAPHIES

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