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Analysis of Atherosclerosis from Finger Photoplethysmogram (PPG) Signal Using Autoregressive Modelling

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Abstract - This project deals with atherosclerosis detection from Photoplethysmogram. Atherosclerosis is a disease in which plaque builds up inside your arteries. Arteries are blood vessels that carry oxygen-rich blood to heart and other parts of the body. Plaque is made up of fat, cholesterol, calcium, and other substances found in the blood. Over time, plaque hardens and narrows the arteries. This limits the flow of oxygen-rich blood to the organs and other parts of the body. By using the photoplethysmogram technique the peripheral artery characteristics are recorded from the fingertip and the waveform is analyzed using the MATLAB software. The obtained signal is filtered and downsampled to remove the DC components and to increase the accuracy for processing. Signal processing technique is used to derive the pressure waveform from the PPG waveform using the Burgs algorithm. This proposed method is very useful for detecting the atherosclerosis at an early stage.
Keywords - Atherosclerosis, Finger PPG, Signal Processing Autoregressive modelling, Pole tracking*Corresponding

I. INTRODUCTION

Signal processing helps us to understand and predict the characteristics of the signal. PPG signals are obtained from the fingertip using the clip-type LED sensor. Earlier methods are used to extract and classify the respiratory signal from the PPG signal based on the signal processing.

Atherosclerosis affects the major group of people in the world, In India 18,106,200 peoples were affected in the year of 2014. When 50% of the arteries get damaged, atherosclerosis will be diagnosed. It does not show any symptoms and cause stroke, myocardial infarction and damage the whole organ function. PPG signals are characterized using AR modeling technique to predict the chances of atherosclerosis. Most of the signal processing technique did not focus on the detection of atherosclerosis from the PPG signal. This leads to work on PPG signal analysis for the detection of atherosclerosis using MATLAB.

A. Atherosclerosis

Fig 1 shows the plaque builds up inside your arteries. Arteries are blood vessels that carry oxygen-rich blood to your heart and other parts of the body. Plaque is made up of fat, cholesterol, calcium, and other substances found in the blood. Over time, plaque hardens and narrows the arteries. This limits the flow of oxygen-rich blood to the organs and other parts of the body. Atherosclerosis is a disease of the arteries characterized by the deposition of fatty material on their inner walls. Atherosclerosis begins with damage to the endothelium caused by high blood pressure, smoking, or high cholesterol that damage leads to the formation of plaque. [14]

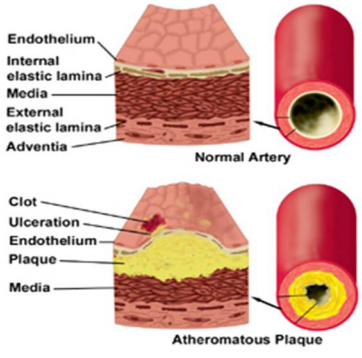

Fig. 1 Atherosclerosis plaque deposition
(Courtesy: http://intlcirc.ahajournals.org)

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B. High Blood Pressure and Atherosclerosis

When the heart beats, it pushes blood through the arteries in your entire body. Higher blood pressures mean that with each beat, arteries throughout the body swell and stretch more than they would normally. This stretching can injure the endothelium, the delicate lining of all arteries, causing arteries to become stiffer over time as shown in Fig 1. (9)(Susanna Mak et al, 2012). Plaque is dangerous. Although it often grows without symptoms for years, plaque can suddenly rupture, forming a blood clot that blocks the artery. The result can be a heart attack or stroke.

C. Photoplethysmogram (PPG)

A photoplethysmogram (PPG) is an optically obtained plethysmogram, a volumetric measurement of an organ. A PPG is often obtained by using a pulse oximeter which illuminates the skin and measures changes in light absorption. A conventional pulse oximeter monitors the perfusion of blood to the dermis and subcutaneous tissue of the skin. With each cardiac cycle the heart pumps blood to the periphery. Even though this pressure pulse is somewhat damped by the time it reaches the skin, it is enough to distend the arteries and arterioles in the subcutaneous tissue. If the pulse oximeter is attached without compressing the skin, a pressure pulse can also be seen from the venous plexus, as a small secondary peak. The change in volume caused by the pressure pulse is detected by illuminating the skin with the light from a light-emitting diode (LED) and then measuring the amount of light either transmitted or reflected to a photodiode. Each cardiac cycle appears as a peak, as seen in the figure. Because blood flow to the skin can be modulated by multiple other physiological systems, the PPG can also be used to monitor breathing, hypovolemia, and other circulatory conditions. Additionally, the shape of the PPG waveform differs from subject to subject, and varies with the location and manner in which the pulse oximeter is attached. (13)(Natascha J. Cuper)

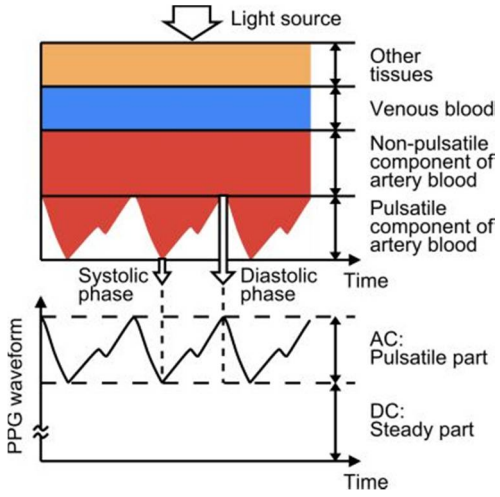

Fig. 2 Obtaining PPG Waveform
Courtesy: http://www.mdpi.com/2079-9292/3/2/282

II. PROBLEM DEFINITION

Atherosclerosis affects the major group of people in the world. When 50% of the arteries get damaged, atherosclerosis will be diagnosed. It does not show any symptoms and cause stroke, myocardial infarction and damage the whole organ function. PPG signals are characterized using AR modeling technique to predict the chances of atherosclerosis. Most of the signal processing technique did not focus on the detection of atherosclerosis from the PPG signal. Using the proposed model the PPG signals are analyzed using the AR model by detecting the pressure changes at the peripheral arteries. The signals are filtered using the windowing techniques for the detection of peaks of the signal.

III. MATERIALS AND METHODOLOGY

PPG signals are recorded using the clip-type LED sensor and the obtained waveform is analyzed and processed using MATLAB

A. Autoregressive Model

The autoregressive model specifies that the output variable depends linearly on its own previous values and on a stochastic term, thus the model is in the form of a stochastic difference equation. The notation indicates an autoregressive model of order *p*. The AR

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(*p*) model is defined as

$$X_{t=C+} \sum_{i=1}^{p} \varphi_i X_{t-i} + \varepsilon_t$$

The power spectral density of an AR (*p*) process with noise

Variance, Var (Z_t) = σ_z^2 is

$$S(f) = \frac{\sigma_z^2}{|1 - \sum_{k=1}^{p} \varphi_k \ e^{-2\pi i k f}|^2}$$

AR (0)

For white noise (AR (0))

$$S(f) = \sigma_z^2$$

AR (1)

For AR (1)

$$S(f) = \frac{\sigma_Z^2}{|1 - \varphi_1 e^{-2\pi i f}|^2} = \frac{\sigma_Z^2}{1 + \varphi_1^2 - 2\varphi_1 \cos 2\pi f}$$

If φ_1 >1there is a single spectral peak at f=0, often referred to as red noise. As φ_1 becomes nearer 1, there is stronger power at low frequencies, i.e. larger time lags. This is then a low-pass filter, when applied to full spectrum light, everything except for the red light will be filtered.

If φ_1< 0 there is a minimum at f=0, often referred to as blue noise. This similarly acts as a high-pass filter; everything except for blue light will be filtered

B. Parametric Estimation Method

Parametric methods can yield higher resolutions than nonparametric methods in cases when the signal length is short. These methods use a different approach to spectral estimation; instead of trying to estimate the PSD directly from the data, they model the data as the output of a linear system driven by white noise, and then attempt to estimate the parameters of that linear system. The most commonly used linear system model is the all-pole model, a filter with all of its zeroes at the origin in the z-plane. The output of such a filter for white noise input is an autoregressive (AR) process. For this reason, these methods are sometimes referred to as AR methods of spectral estimation. The AR methods tend to adequately describe spectra of data that is "peaky," that is, data whose PSD is large at certain frequencies. The data in many practical applications (such as speech) tends to have peaky spectra; so, that AR models are often useful.

C. Burg Method

Does not apply window to data

Minimizes the forward and backward prediction errors in the least squares sense, with the AR coefficients constrained to satisfy the L-D recursion

High resolution for short data records

Always produces a stable model

Peak locations highly dependent on initial phase

May suffer spectral line-splitting for sinusoids in noise, or when order is very large

Frequency bias for estimates of sinusoids in noise

D. Methodology

The data are collected from different age groups of selected 15 subjects (9 female, 6 male). PPG signal and Blood Pressure value were obtained from the subjects for the prediction of dominant pole. PPG waveform is recorded as 3 minute sections such as During

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Rest, during exercise and after exercise. Out of which 10 subjects data were used for analysis (5 female, 5 male). The reference pressure ranges of the subjects were examined visually, and ten sections containing relatively constant pressure ranges and reasonable agreement between the reference measurements were identified. For each section, a series of reference pressure ranges were calculated using the windowing method. The AR method is applied to 60-second sections of the photoplethysmogram, to increase the stability of the AR model, and reduce the influence of dc poles, the signal is first detrended. A digital low-pass filter is then applied to the signal to attenuate frequencies corresponding to the heart rate. The filter is designed using low filter. The filtered signal is downsampled to increase the range of angles that to improve the accuracy of the AR model. The results are analyzed with AR Burg method to obtain the coefficients of the signal. The corresponding roots are plotted in Z domain.

IV. RESULT

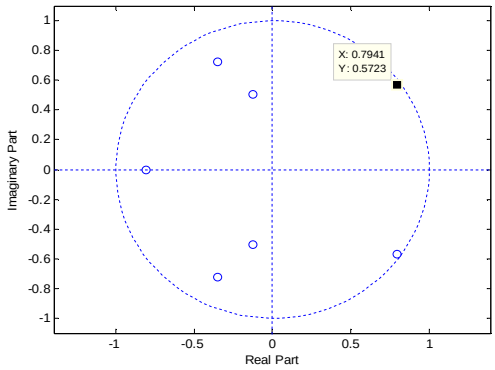

Fig. 3 Pole Plot

V. DISCUSSION

Figure 3 shows the Pole plot of AR poles for a 30-second window from one of the sections. The dominant pole, with magnitude closest to the unit circle, is identified as the pressure pole. For this pole the pressure range is 135/80mmHg. The reference pressure for this window is 130/80 mmHg.

VI. CONCLUSION

These results indicate that AR modeling could be used to diagnose the atherosclerosis from photoplethysmogram. This would allow automated, noninvasive and highly accurate diagnosis of atherosclerosis using a modified pulse oximeter. This would greatly improve the routine measurement of these vital signs in busy clinical settings and permit better informed decisions.

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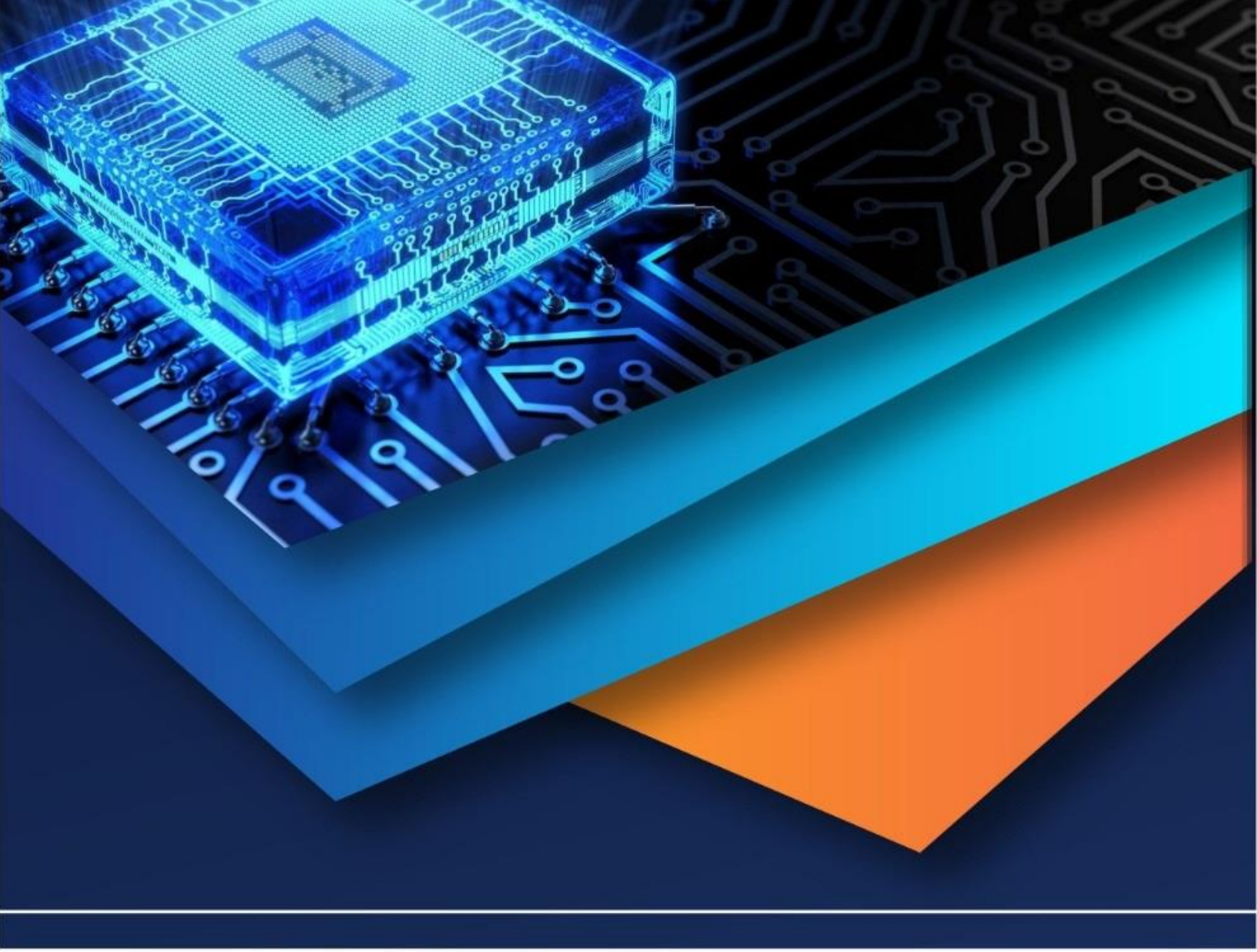

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