International Journal of Computer Trends and Technology (IJCTT) – volume 4 Issue 5–May 2013

Estimation of Arterial Stiffness by using PPG Signal: A Review

Sanjeev kumar#1, Dr. S.C. Prasanna kumar #2, Dr.B.G. Sudharshan #3

(1) Biomedical Signal Processing and Instrumentation, I.T Dept., RVCE, Bangalore, India
(2) Professor & HOD, I.T Department, R.V. College of Engineering, Bangalore, India
(3) Associate Professor, I.T Department, R.V. College of Engineering, Bangalore, India

Abstract- Arterial stiffness leads to cardiac disorders, the degree of arterial stiffness can be obtained by calculating the augmentation index, arterial stiffness index and reflection index of a pulse wave. Three different algorithms can be used to determine the above indices i.e. finding local and global maxima and minima by slope gradient method, zero-crossing point identification and intersecting tangents. Thus by calculating the augmentation index, arterial stiffness index and reflection index the degree of arterial stiffness can be calculated by which cardiac risk of a patient can be diagnosed. All three indices can determined by implementing an algorithm in MATLAB. In this paper we have discussed various methods to analyse and estimate the arterial stiffness parameters and software tools available for analysis.

***Keywords*— Cardiac risk, PPG, Augmentation index**

I. INTRODUCTION

.The absolute risk of cardiovascular disease in patients with type 1(insulin dependent) diabetes is longer than that in patients with type 2(non insulin dependent) diabetes. Cardiovascular disease occurs principally as a result of atherosclerosis and arteriosclerosis, inflammatory and degenerative conditions of the arterial wall [2]. Therefore it is important to determine the cardiac risk of a patient in advance to prevent premature death. The analysis of peripheral pulse volume helps us to understand arterial pathologies, a major contributor to cardiovascular diseases, which is a common cause of death in modern society. The risk factor for cardiovascular diseases is associated with the increasing stiffness of the arterial wall. Furthermore, arterial stiffness has also been shown to be an useful predictor of all-cause cardiovascular mortality in subjects with end stage renal disease [1]. PPG is a measure of the volume of the blood in vessel. Thus by analysing this peripheral pulse wave we can

area. So, the benefit of this kind is we get a clear signal

3) PPG sensors- In the reflective PPG sensors comprised of an infrared light emitting diode (LED) with a peak wavelength of 940 nm. In the measurement of pulse wave velocity (PWV) ultrasonic sensor, pressure sensor, piezoelectric sensor and infrared sensor are used.

A. GENERAL BLOCK DIAGRAM

predict cardiovascular risk. High pulse pressure is now recognized as an important cardiovascular disease risk factor for myocardial infarction, stroke and development and progression of heart failure, even after adjusting for the affects of other known cardiovascular disease risk factors. Increased arterial wave reflections are associated with the presence and extent of coronary atherosclerosis and patients with cardiovascular mortality.

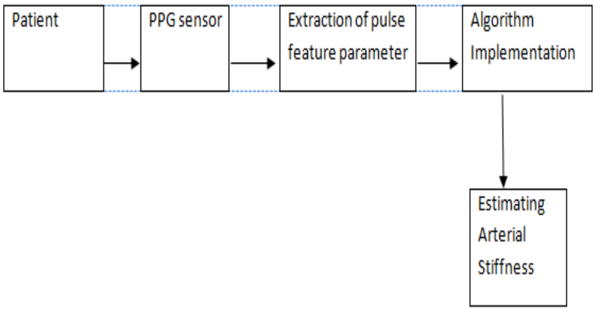
II. OVERVIEW OF PPG SIGNALS

PPG is an instrument mainly used to determine and register variations in blood volume or blood flow in the body which occurs with each heartbeat. Photoplethysmography is an optical measurement technique that can be used to detect blood volume changes in the micro vascular bed of tissue. The basic form of PPG technology requires only a few opto-electronics components: a light source to illuminate the tissue (e.g. skin) and a photo detector to measure the small variation in light intensity associated with changes in perfusion in the catchment volume. PPG is most often employed non invasively and operates at a red or a near infrared wavelength. [3].

III. TYPES OF PHOTOPLETHYSMOGRAPHY

1) Reflectance PPG- These types detect the reflected light at the tissue levels. The amount of reflected light is very small in comparison to the transmitted type. Hence, weak signals are detected on the PPG. The light here cannot be transmitted.

2) Transmission PPG- Here the detector is positioned opposite to the emitter’s side. So, the benefit of this kind is we get a clear signal.



PPG signals are taken from individual's persons using biokit at a sample rate of 1000 samples/seconds. The frequency response for PPG it is .05-10Hz. It is obtained by using reflection finger PPG sensor, these signals are amplified using a PPG amplifier and are interfaced with the PC using DAQ (NI USB-6009), the NI USB-6009 is a USB based data acquisition (DAQ) and control device with analog input and digital input and output.

Algorithm: To detect the peaks in the PPG signal, find the local maxima and minima as well global maxima and minima by using slope gradient methods:

B. DIFFERENT TYPES OF APPROACHES

From the previous literatures existing technology AS can be broadly classified into six categories

1) Oscillometric method and pulse wave velocity(PWV) methods:

The inner pressure signal of cuff on the upper arm and the pulse wave signal at the tip of finger will be sampled, and the special software can utilize these signals to calculate two accessing parameters and obtain the evaluation conclusion of arterial stiffness. The pressure sensor MPX5050GP is used to measure the inner pressure of cuff which reflects not only the static cuff pressure but also the change of pulse wave. The cuff pressure is a low frequency signal for it is gradually reduced and its cut-off frequency is below 0.5Hz, whereas the frequency range of pulse wave is about 0.6Hz-6.4[4]. The filter circuit is designed to separate these two signal is processed by a low-pass filter (0.5Hz) and a high-pass filter(7Hz), the cuff pressure wave and the pulse wave as shown below. When the cuff pressure is equal to the mean arterial pressure the amplitude of pulse wave reaches the maximum [5]. Therefore, one pulse waveform can be selected respectively whose amplitude is nearest to 80% maximum before and after the cuff pressure reaches the mean arterial pressure

Fig.1. ASI and PWV measurement

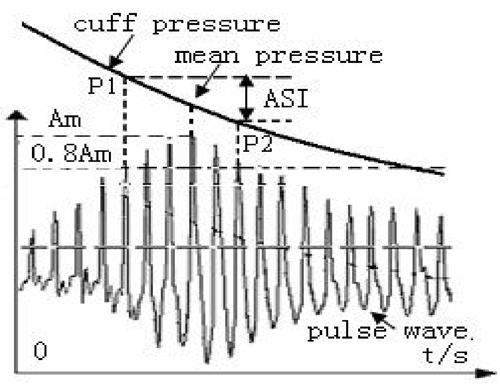


Fig.2. pulse wave and cuff pressure wave

Results:

ASI and IMT: The ASI is significantly correlated with the IMT(r=0.461, p<0.01). The data of all volunteers show the ASI also present increasing trend with augment of the IMT.

ASI and Blood pressure: The ASI is significantly correlated with PP and SBP(r=.464, and r<.0.622, p<0.01), but DBP is not a significant influencing factor factor for ASI.

ASI and Age: The ASI is correlation with the age(r=0.461, p<0.01), and the ASI slowly increases with increment of age.

2) pulse wave velocity:

The proposed device is based on a double-headed sensor probe and allows the assessment of PWV in one single location, providing important information on local arterial hemodynamic. Local stiffness (PWV) is an accurate marker of the degree of atherosclerosis and it is generally measured over carotid artery [6]. To assess PWV in the carotid artery is to decrease the distance between the two measurement sites, thus providing information on local hemodynamic. PWV is then simply calculated as the linear ratio between distance d, and the time delay between the two acquired pressure waves, Δt.

The most important element of the proposed instrument is based on a double-headed sensor probe (DP). The DP consists of two circular-shaped piezoelectric (PZ) sensors (MURATA 7BB-12-9 sounder, 12mm diameter), placed 23 mm apart and mounted on a trip double layer printed circuit board (PCB). The probe's mechanical interface consists of two mushroom-shaped PVC pieces, located in the centre of the PZ discs. These elements are responsible for transmitting the distension imparted to tissues by the pressure waveform, to each PZ sensor [7]. A longitudinal pressure wave is generated by a 700µm stroke actuator (Physik Instrumente, P-287), driven by a high-voltage linear amplifier (Physik Instrument E-508), and launched into a 200 cm silicon rubber tube, (Lindemann, 8 mm inner diameter, 0.5 mm wall thickness), filled with water.

Algorithm: For time delay estimation, three main algorithms were used a) maximum of cross correlation;

Periods	Young's modulus[MPa]		
	A	B	C
EJ (ejection)	0.75	0.64	1.03
RE (rapid ejection)	0.92	1.04	1.26
SE (slow ejection)	0.33	0.78	0.91
SE' (slower ejection)	0.11	0.22	0.64
DE (dicrotic elevation)	1.70	0.34	3.19
ME (middle ejection)	1.25	1.16	2.46
RL (relaxation period)	1.11	3.63	1.92
Inner radius r_0 [mm]	6.7	7.9	6.3
Wall thickness h_0 [mm]	0.8	0.7	0.7
Systolic pressure [kPa]	15.0	15.7	14.2
Diastolic pressure[kPa]	8.4	9.2	9.2

b) maximum amplitude detection and c) Zero-crossing point identification

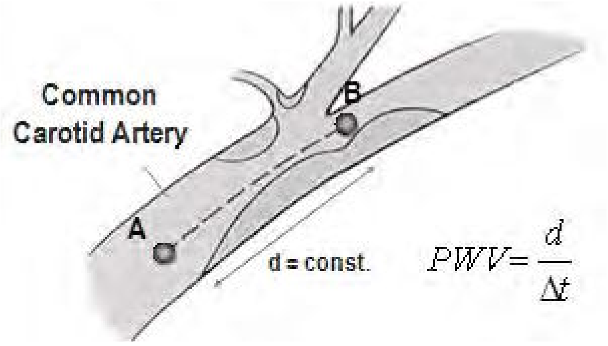


Fig.3. Local pulse wave velocity

Results:

An innovative double piezoelectric sensor probe is developed for single-point hemodynamic measurement on short (arterial) segments. This probe is successfully characterized in a dedicated test

3) Pulse Pressure Velocity measurement- A wearable sensor:

Pulse pressure velocity measurements (PPV) may be a source of useful information on artery state. A 2007 guideline of the European Society of Hypertension recommends assessing arterial stiffness in patient with arterial hypertension, by measuring the PPV, Mechanical changes in the cardiovascular tree involved in the blood ejection have been measured at the thorax level and on the wrist using impedance techniques, in combination with a one channel electrocardiographic signal. Different approaches for PWV measurement may be applied [8], [9]. While in most of them the pulse pressure is measure at two distant points separated by a known distance, and the propagation delay between the two signals is estimated. This time delay is determined between two "corresponding" points on the pressure wave.

The pressure wave or its function has been measure at the thorax and wrist using two different sensors, both being based on the impedance technique. The thorax sensor is described elsewhere [10]. The electronic circuit of the wrist sensor, which consists of a current source, built around two operational amplifiers that deliver a current of 0.1mA at 20 kHz.

The high output impedance of the current source

Ensures a constant current for changes of load impedance up to 10kΩ. These specifications have been realised by means of an active feedback design.

Results: It can be assumed that pulse velocity is larger than 5m/s for the considered arteries (starting from the ascending aorta and finishing at the ulnar or the radial arteries).

4) Evaluation of Elastic Property of the Arterial Wall using ultrasound:

The elastic modulus of the arterial wall depends upon the arterial inner pressure because of the hysteresis property between the inner pressure and the strain of the artery. Therefore, we obtain the change in the young's modulus in measure in each short period. From the resultant PWV in each short period. The hysteresis property of the arterial wall is estimated. The small change in thickness of the arterial wall in one cardiac cycle is obtained by

measuring the small velocity signals on intima and adventitia of the arterial wall [11].

Results: Young's modulus obtained from the PWVs for various periods for 3 healthy subjects (A), (B), and (C) are given in above table.

5) Double Probe Based in piezoelectric sensors for local pulse wave velocity assessment:

The principle of PWV measurement involves determination of the pulse transit time between the signals acquired simultaneously by both piezoelectric placed 23 mm apart in the same probe. Two circularly-shaped piezoelectric sensors(MURATAR 7BB-12-9 Sounder, 12 mm diameter are placed 23 mm apart and mounted on a triple double layer printed circuit board (PCB), the signal conditioning electronics is based on a voltage follower amplifier which is set to a gain of approximately 2, for each piezoelectric[12]. The approach used for IR determination was to build a set-up capable of exiting the double probe with a Dirac like pulse. Due to complexity of generating a pure Dirac impulse, a most effective technique was used, based on a chirp signal that sweeps linearly the range of frequencies. The spectra of piezoelectric output (Y(jw)) were computed, and correspondent transfer function was inferred, where H(jw)=FFT(IR) is the system's transfer function resulting from the fourier transform of IR. Through the inverse fast fourier transform (IFFT), this frequency response was transformed back to the time domain, resulting in the typical IR of the piezoelectric sensor. This procedure was applied to both sensors.

$$X(jw) = Y(jw)/H(jw)$$

Algorithm: Different time delay algorithms are used based on the identification of reference point of the pressure waveform. Algorithm such as intersecting tangents, maximum upstroke of the first derivative zero crossing the second derivative and 10% of the pulse pressure are used for time delay estimation.

6) Non-invasive Assessment of Arterial stiffness: Elastic expansion coefficient of blood vessel (named as ETK) denotes the degree of arterial elastic expansion during systolic ejection, usually used to calculate other cardiovascular parameters as the intermediate variable. The system works as follows. In measuring, the cuff is set in the human upper arm close to elbow joint. A microcontroller controls the air pump to inflate the cuff, collecting the pressure signals through the pressure sensor and setting the maximum of inflation. When the pressure in the cuff reaches the predetermined value, the microcontroller controls the air pump to stop inflating the cuff. At the moment the blood vessel of the brachial artery is suppressed so as to stop pulse. When the pressure in the cuff drops below the systolic pressure of brachial artery, brachial artery began to pulsate, and the pulsations continuously strengthened with the cuff pressure decreasing. The pressure in the cuff and the pulse signal of brachial artery are converted to voltage signal by the pressure sensor, and the voltage signal is amplified and filtered, thus, you can get one cuff pressure signal and one pulse wave signal with appropriate amplitude, which are converted into digital converter.

Results:

Correlation analysis is done between the arterial stiffness obtained from the three detection methods and the parameters obtained from the clinical echocardiographic instrument, and the correlation coefficient R denotes the degree of correlation.

Software tools to analyse the Arterial stiffness parameters:

There are various software tools to analyse the arterial stiffness parameters namely MATLAB, LABVIEW and SciLAB etc.,

CLINICAL RELEVANCE: By analysing PPG signal, stiffness of the aorta and the brachial artery can be estimated.

REFERENCES:

[1] Dae-Geun jang, Umar Farooq, seung-Hun park, choong-won Goh, and Minsoo Hahn "A knowledge –Based Approach to arterial Stiffness Estimation Using Digital Volume Pulse" IEEE Transaction s On Biomedical Circuits And Systems,Vol .6 No. 4, August 2012.

[2] S.R.Aity N Angirata-jaimes S.C Millasseau and P.J chowienczyk "predicting digital volume pulse from waveform from" IEEE Trans. Biomed. Eng. Vol. 54, No. !2 .pp . 2268-2275,2007.

[3] Physio. Meas. 28 (2007).R1-R39 doi:10.1088/0967-3334/28/3/R01 IOP PUBLISHING

[4] J.C.T.B. Moraes. M. Cerulli, P.S. Ng, "Development of a new ocsillometric blood pressure measurement system", Computers in Cardiology 1999, 26-29 Sept. 1999 Pages: 467-470.

[5] J.C.T.B.Moraes, M. Cerulli, P.S.Ng, "A strategy for determination of systolic, mean and diastolic blood pressure from oscillometric pulse profiles", Competers in Cardiology 2000, 24-27 Sept. 2000 Pages:211-214

[6] J. Meinders, L.Korner, P.Brands and A. Hoeks, "Assessment of local pulse wave velocity in arteries using 2D distension waveforms." Ultrason. Imaging, vol. 23, pp.199-215,2001

[7] H. Pereira, T. Lopes, V.Almedeida, E.Borges, E.Figueiras, J. Basilio, J. C.Cardoso, J. Malaquias, and C. Correia, "Characterization of a double probe for local pulse wave velocity assessment," ph Ysiol Meas., vol.31, pp.697-714,2010

[8] M.W. Rajzer, W. Wojciechowska, M. Klocek, I. Palka, M. Brzozowska-Kiszka, and K Kawecka-Jaszcz, "Copmarision of aortic pulse wave velocity measured by three techniques Complior, ShygmoCor, Arteriograph,", Journal of Hypertension, 28, pp. 2001-2009, 2008.

[9] A.P.G Hoeks. P J Brands, JM Willigers, and R S Reneman Non-invasive measurement of mechanical properties of arteries in health and disease, proceeding of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine 213: 195-202, 1999

[11] J Wtorek, A. Bujnowski, M. Lewandowska, J. Ruminski, M.Kaczmarek simultaneous monitoring of heart performance and respiration activity, proceedings of the 3rd IEEE Conference on Human System Interactions (HIS), Rzeszow, Poland, 2010, pp, 661-665

[12] H.Hasegawa, H. Kanai, N. Chubachi, and Y.Koiwa: "Noninvasive Evaluation of Poisson's ratio of arterial wall using ultrasound," Electronics letters, vol. 33, No. 4, pp. 340-342, 1997.