Using Photoplethysmography Pulse and Radial Pulse to Analyze the Blood Vessel Elasticity

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***Abstract*—In this study, we use the well-known Augmentation Index (AIx) method to verify the newly proposed Accelarated plethysmography (APG) method for blood vessel elasticity derived from PPG pulse. Experiment, including 22 subjects, aged 22~80 years old, reveals that APG method is highly correlated (correlation coefficient = -0.87, p< 0.001) to AIx method, and APG is a feasible method to evaluate the blood vessel elasticity. Besides, the relationship of blood vessel elasticity derived from PPG pulse and radial pulse and respectively using AIx as well as APG method is also verified to be highly correlated. Therefore, the blood vessel elasticity derived from radial artery, which is highly related to aortic elasticity, can also be evaluated from the easily and cheaply acquired PPG pulse.**

***Keywords*—Blood vessel elasticity, Photoplethysmography, Augmentation index, Accelarated plethysmography, Radial pulse, Correlation coefficient.**

1. INTRODUCTION

Cardiovascular disease is the leading cause of mortality in the developed world. Current social changes in eating habits and the increasing economic pressures of life gradually results in the production of many diseases of civilization, such as heart disease, stroke, arteriosclerosis.

CVD(cardiovascular diseases) occurs principally as a result of atherosclerosis, a degenerative condition of the arterial wall. According to statistics of the past two years, there is a clear upward trend of mortality rate of heart and cardiovascular disease compared to the previous year's data. With the trend of an aging population, more and more important issues is includede in this regard.

Many types of physiological signals often reflect the physical situation of the internal environment, and physiological signal becomes an important indicator for disease scoring. The photoplethysmography (PPG) is a non-invasive method to track changes in local blood volume. The PPG waveform can be rapidly acquired by measuring absorption of infrared light across the finger pulp. (The small size and light weight of sensor. Sensor's small size and light weight. The typical optical photoplethysmography (PPG) of the components, including a pair of infrared LED transmitter, receiver and a simple circuit can easily be embedded into many portable or wearable devices.) In addition, the radial pressure waveform indicate much information about blood vessel elasticity. We also want to find the relationship between these two types of signals [1], [2], [3].

2. FRAMEWORK AND METHOD

In this study, the system architecture is shown in Figure 1. Transmission infrared sensor is selected to measured PPG signal. The blood volume waveform can be rapidly acquired by measuring the absorption of infrared light across the finger. Then, we use the high pass filter to remove the baseline drift, low pass filter to remove the high-frequency noise, amplifier for signal amplification, PSoC for signal A/D converter. Finally, Labview under PC enviroment is used for acquiring signal and digital signal processing.

2.1. PHOTOPLETHYSMOGRAPHY

There are two types of infrared sensors, penetrable type and reflective type. We use the 940nm wavelength sensor of penetrable type to detect blood oxygen [4]. Systolic blood pressure and diastolic blood pressure will directly affect the arterial wall vibration and blood volume

change. When Systolic time, the expansion of micro-arterial blood vessels, light through the fingers will have been absorbed by blood and other tissues. At this point the signal becomes smaller. When diastolic time, micro arteries becomes narrow, the larger light signals will pass through your fingers. At this point the signal becomes larger. The optical detection approach is called photoplethysmography (PPG), and the sensor is shown in Fig. 2(a).

Light penetration and sensor detection obey the Beer Lambert's law. Beer Lambert's law describes that increasing the thickness of the main range of media shows the reduced light intensity. Beer Lambert's law is defined by the following formula [5], [6], and shown in Fig. 2(b).

$$I = I_0 \exp^{-\varepsilon(\lambda)cd} \quad (1)$$

$$I_t(\lambda) = I_0(\lambda) \cdot \exp(-\sum_{j=1}^{N} \alpha_j c_j d_j) \quad (2)$$

I_0 is the intensity of penetrant light; $\varepsilon(\lambda)$ is the optical absorption coefficient; c is the substance concentration; d is the light path length; $I_0(\lambda)$ is the incident light, and α is the optical absorption coefficient of medium.

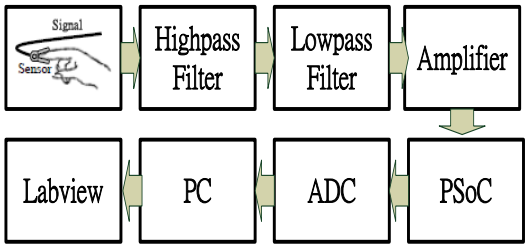
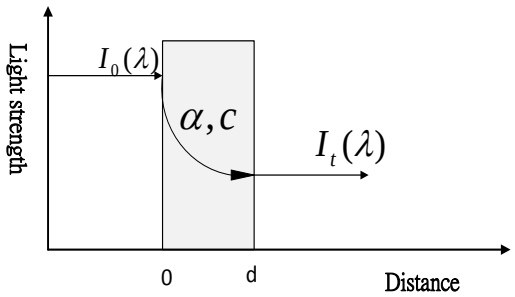


Fig. 1 Flow diagram of the proposed PPG signal acquiring system

(a)



(b)

Fig. 2 (a) PPG sensor and (b) The light intensity curve of Beer Lambert's law

The contraction and relaxation frequency of blood vessel is almost the same as the heart. Using intervals of each peak, the heart rate can be calculated. In addition, the waveform can be captured to approximately evaluate the blood vessel elasticity. After the P wave, the pulse waveform begins to decrease and a wave shoulder occurs resulting from a wave rebound.

2.2. FEATURE OF PPG SIGNAL

The used wavelength of infrared light is about 940nm. PPG signal will be generated to reflect the response of the red blood cells to infrared light [4]. U point: is the starting of pulse. The blood volume causes a maximum amplitude wave when systolic, and it is called Percussion wave (P point). Dicrotic wave (D point) is generated when ventricular is diastolic and the valve is suddenly closed, causing the collision of the blood flow in the vessel wall.

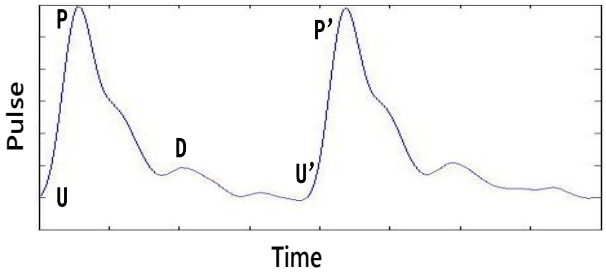


Fig. 3 The feature of PPG signal

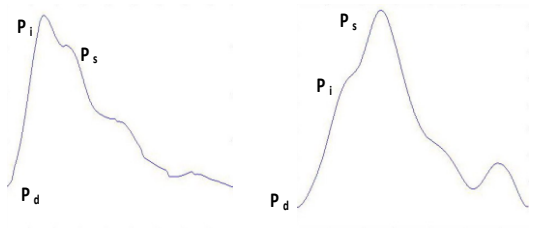
2.3. AUGMENTATION INDEX AND ACCELARATED PLETHYSMOGRAPHY

Augmentation Index (AIx) is a parameter used to calculate the elasticity of artery, and it is the general as well as commonly used in public and hospital equipment methods for cardiovascular evaluation. Feature points used to do the

calculation is defined for two types of PPG signal in Fig. 4(a) and Fig. 4(b). Augmentation Index (AIx) is calculated by the following formula [7].

$$AI_x = \frac{(P_s - P_d)}{(P_i - P_d)} \qquad (3)$$

Pi is a peak systolic pressure, Ps is an inflection point that indicates the beginning upstroke of the reflected pressure wave, and Pd is a minimum diastolic pressure.

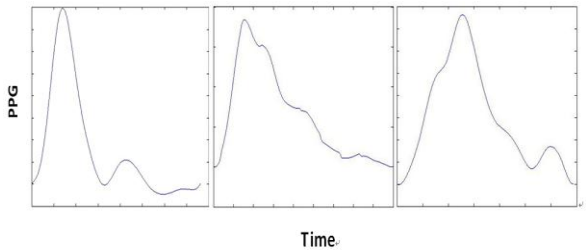


(a) (b)

Fig. 4 Feature points used to do the Augmentation Index (AIx) calculation is defined.

The reflected pressure wave adds to the forward traveling wave by the principle of superposition. As pressure increases in late systole, due to wave reflection, the blood flow decreases during the deceleration phase.

As shown in Figure 5, The Ps point resulting from wave reflectiobn is almost none; thus, the blood vessel elasticity is good. This type of PPG pulse is usually the mostly healthy young people. In Fig. 6, the Ps point is observed, and this type of wave is usually in middle age. Finally, in Fig.7, the Ps point is higher than the Pi point; thus, blood vessels are already in high hardness condition, the elderly were the majority with these kinds of waveforms.



(5) (6) (7)

Fig. 5, 6, 7 From left to right, they are the PPG waveform of 20-year-old, 40-year-old, and 80-year-old subjects.

Accelarated plethysmography(APG) is another parameter recently used to assess the elasticity of blood vessel. This method was proposed by Yukio KATAOKA et al (the Chiba University, Japan) [8]. They use the second derivative of P wave, i.e. the acceleration, to be the accelarated plethysmography(APG). Its definition is in the following,

$$APG = \left| \frac{d^2(Pulse)}{dt^2} \right|_P \qquad (4)$$

In this paper, we want to find the relevance between Augmentation Index (AIx) and Accelarated plethysmography(APG) in order to verify the feasibility of the new developed method, Accelarated plethysmography(APG). If there are correlation to the two methods, we can prove the coexistence of validated prediction of arterial stiffness. In the second part of the experiment, we measure the radial pulse to investigate the correlation of blood vessel elasticity derived by PPG and radial pulse. If correlation exists, then we can derived the blood vessel elasticity by PPG signal, which is easily and conveniently measured. Thus, PPG signal can be widely used in healthcare and telemedicine to provide more information about vessel elasticity. Experiments are done in the following.

3. EXPERIMENT AND RESULTS

In this study, we recruited 22 subjects, between the twenty and eighty years of age, to participate in the verification. The analysis tools we used are Labview and Matlab for Augmentation Indexs (AI) and Accelarated plethysmography (APG) calculations. The experimental result in Fig. 8 shows the significantly negative correlation ($p<0.001$) between APG and age by PPG signal. It successfully describes the normal artery aging. The experimental result in Fig. 9 shows the significantly positive correlation ($p<0.001$) between AIx and age, it also successfully describes the normal artery aging by PPG signal. Fig. 10 indicates that APG method is closely related ($p<0.001$) to AIx method for PPG signal. Fig. 11 reveals that AIx method between PPG pulse and radial pulse is losely related ($p<0.001$). Fig. 12 shows that APG method between PPG pulse and radial pulse is closely related ($p<0.001$).

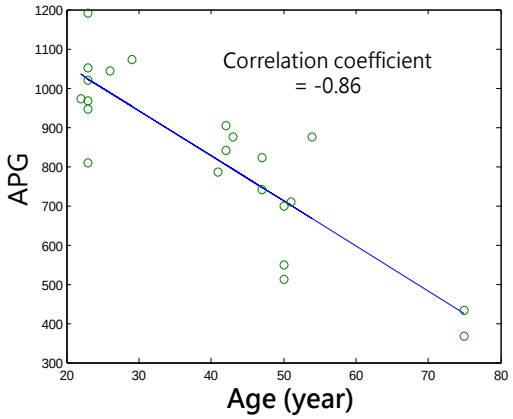


Fig. 8 Relationship between APG and Age for PPG pulse

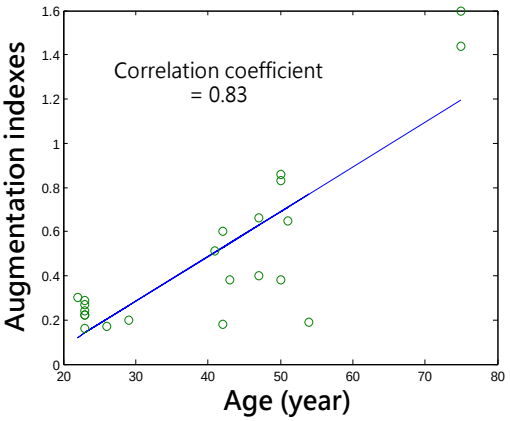


Fig. 9 Relationship between AIx and Age for PPG pulse

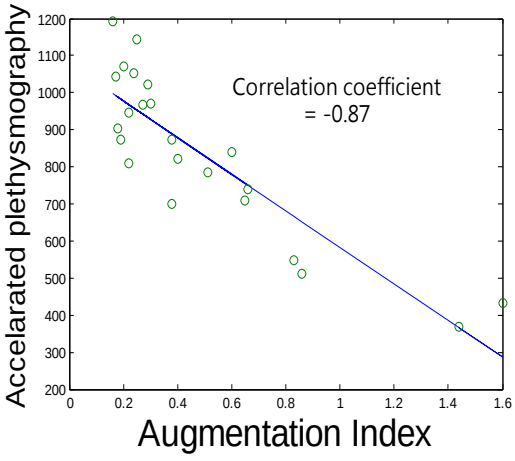


Fig. 10 Relationship between AIx and APG for PPG pulse

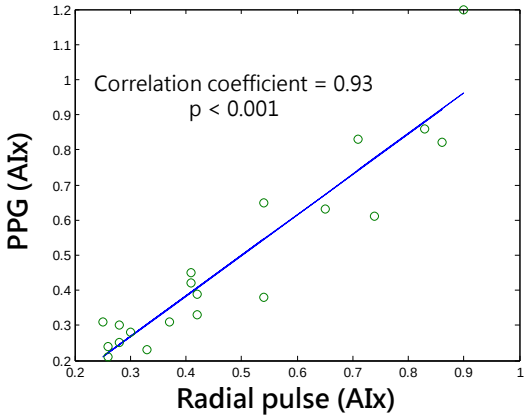


Fig. 11 Relationship between PPG and radial pulse for AIx

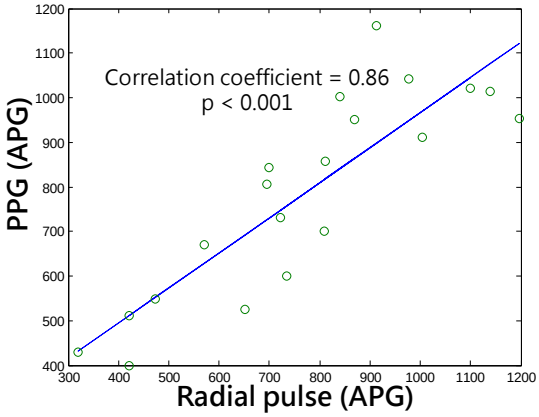


Fig. 12 Relationship between PPG and radial pulse for APG

4. CONCLUSIONS

Firstly, we use the well-known Augmentation Index (AIx) method to verify the newly proposed Accelarated plethysmography (APG) method for blood vessel elasticity derived from PPG pulse. Results (Fig. 10) reveal that APG method is highly correlated to AIx method; thus, APG is a feasible method to evaluate the blood vessel elasticity. Secondly, we investigate the relationship of blood vessel elasticity derived from PPG pulse and radial pulse. Results in Fig. 11 and Fig. 12, respectively using AIx and APG method indicate the high correlation. Therefore, the blood vessel elasticity derived from radial artery, which is highly related to aortic elasticity, can also be evaluated from the easily acquired PPG pulse.

PPG, the blood volume pulse measured using finger signals, is convenient to predict the blood vessel elasticity than the conventional

pressure sensors measurement at the radial artery. Not only simplifies the process of measurement technology and the complexity but also lower the cost. Therefore, we conclude that PPG pulse offers the very exciting property of being suitable for use by health professionals as a screening facility for the assessment of CVD risk.

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