Pulse Wave Characteristics Based on Age and Body Mass Index (BMI) During Sitting Posture

Fatemeh Heydari, Malikeh P. Ebrahim, Jean-Michel Redoute, and Mehmet R. Yuce(✉)

Department of Electrical and Computer Systems Engineering, Monash University, Melbourne, Australia
mehmet.yuce@monash.edu

Abstract. Measurement technologies of arterial parameters are mostly based on processing blood pulse wave which is an important representation of cardiac activity. The pulse wave is structured with forward and reflected waves which are affected by individual physiological parameters such as the blood intensity, the elasticity of the aorta, artery elasticity and the reflection location. The pulse wave is also an important parameter in invasive cuff-less blood pressure measurement methods. However, different physiological circumstances can lead to pulse waveforms with different characteristics including the curve factors, amplitude and time landmarks. In this study, the pulse wave signal is obtained by bio-impedance (BImp) via shoulder and photoplethysmography (PPG) from the left ear. Four age groups, as well as three (body mass index) BMI groups, are considered as physiological circumstances and the effect of them on five characteristics factors of the pulse wave, are compared. Overall, the results displayed a significant effect of the aging and BMI on the pulse wave's characteristics.

1 Introduction

Cardiovascular diseases (CVDs) and strokes are the main reasons for death worldwide with causing 15.2 million death in 2016 [1]. There has been an enormous interest in extracting computerized arterial parameters using cardiovascular signals as an initial symptom of the CVDs. These parameters can be utilized to estimate the operative and anatomic variations of the arterial wall. Arterial parameters measurement technologies have been focused on methods that capture a pulse of blood travels from the heart to the other organs (blood pulse wave) which is a significant representation of cardiac activity. The pulse wave can illustrate the heart and arteries activities and peripheral resistance [2,3].

Forward and reflected waves are produced in the pulse wave structure. The forward wave is generated with the start of the blood ejection from heart (systolic phase) and rises until the peak pressure (the crest of forward wave or systolic

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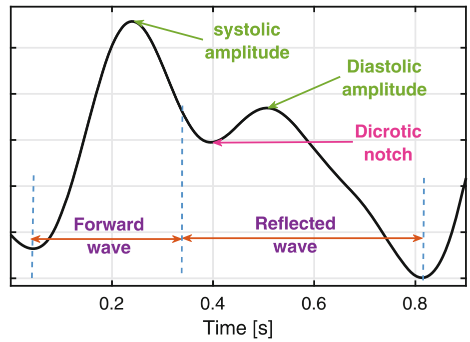

Fig. 1. Forward and reflected waves of pulse waveform.

amplitude). Then, until the ventricular ejection turning point, the pressure waveform starts to drop. At the turning point, the diastolic heart activity begins and the reflected wave is produced. During the reflected wave, the pressure decreases until the dicrotic notch, then with reflected wave passing through the ventricle, the pressure increases to the highest point (diastolic amplitude) of the reflected pressure wave [4]. Then pressure decreases waiting for the next cardiac period (Fig. 1). Forward wave is mostly affected by the blood intensity and the elasticity of the aorta while the reflected wave is associated with the artery elasticity and the reflection location [5,6]. TThis changes the pulse waveform characteristics between different subjects [7].

The pulse wave is also an important parameter in invasive cuff-less blood pressure measurement methods. These methods require different steps of data processing where feature extraction is the most important step and directly changes the results of the blood pressure estimations. To calculate the blood pressure using the pulse wave, first, the signal waveform is recorded from on-body sensors and then, features are extracted by measuring the time difference of the ECG's R-peak and characteristic landmarks on the pulse wave [8]. Since, different physiological circumstances can lead to producing different pulse waveform with different characteristics including the curve factors, amplitude and time landmarks, blood pressure measurement will be affected significantly.

Different types of biotic indicators can be selected as a pulse wave representative such as photoplethysmography (PPG) [9,10], electrical bio-impedance (BImp) [11,12], ballistocardiogram (BCG) [13] and seismocardiogram (SCG) [14,15]. These methods require on-body sensor attachment to neck, ear or arm. In [11,12], pulse wave is extracted from the carotid and subclavian arteries with placing BImp sensors across the shoulder of the patient. In this way, instead of the peripheral arteries, the pulse wave is measured over the central elastic arteries, which reduced the changes caused by vasomotion.

In this study, the pulse wave signal is obtained by both BImp and PPG signals. The BImp is captured using 4-lead sensors placed on the subjects' shoulder and the PPG is recorded from left ear sensor. Signals were collected on human

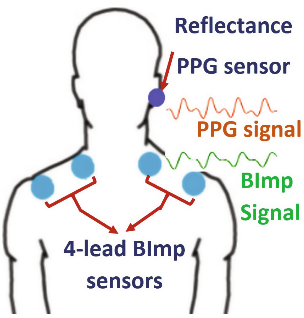

Fig. 2. Sensors placement on the body.

subjects, preliminarily recorded for a blood pressure monitoring project [12], during sitting position for 6 min. Five different characteristics of the pulse wave are extracted for both signals' pulse waveform. Four age groups as well as three (body mass index) BMI groups are considered as physiological circumstances and the effect of them on extracted characteristics are compared.

2 Methods and Implementation

2.1 Subjects and Experimental Details

Subject selected are 52% male, aged 40 ± 15 years, height 168 ± 10 cm and weighted 60 ± 16 kg. Signals were recorded with six minutes sitting position. The placements of the BImp and PPG sensors on body is shown in Fig. 2.

2.2 Signal Processing

The block diagram of signal processing is described in Fig. 3. Both raw sensors' recorded signals (BImp and PPG) are passed through a Chebyshev type II band-pass filter (BPF) modified using Matlab filter design. The heart rate frequency and signals total frequency ranges defined the cutoff frequencies of the filter. To extract the heart rate frequency, the fast Fourier transform (FFT) of the PPG

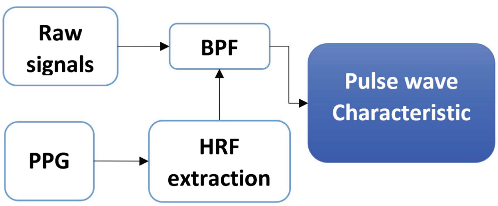

Fig. 3. Signal processing block diagram.

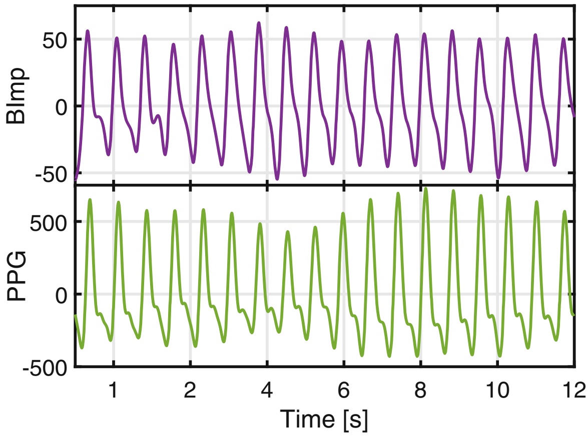

Fig. 4. Filtered BImp and PPG signals samples.

signal is extracted, (the biggest harmonic in the FFT domain of PPG is approximately equal to HRF). This was due to fewer effects of motion and respiration on PPG compared to that of on BImp. A sample of the signal processing output for both BImp and PPG signals is presented in Fig. 4.

2.3 Characteristics Selection

There are various parameters extraction methods that measure amplitude and time information of the pulse wave [16]. In this paper the following characteristics of pulse wave are extracted to be investigated based on age and BMI:

1. *Maximum slope*, the value of the of pulse wave where the first derivative is maximum.
2. *Maximum value (systolic peak)*, the maximum value of the pulse wave.
3. *Augmentation (AI)*, the ratio of the systolic peak to the inflection point which determines the arteries wave reflection.

$$AI = \frac{x}{y}. \tag{1}$$

4. *Crest time*, the time interval between the foot and the systolic peak.
5. *Large Artery Stiffness Index (LASI)*, the time interval between systolic peak and inflection point which indicates the stiffness of the artery.
6. *Inflection Point Area Ratio (IPA)*, the ratio of the S_1, S_2, S_3 and S_4 selected areas under the pulse waveform which indicates the total resistance of the peripheral.

$$IPA = \frac{S_1 + S_2}{S_3 + S_4}. \tag{2}$$

The definition of above characteristics has been illustrated in Fig. 5.

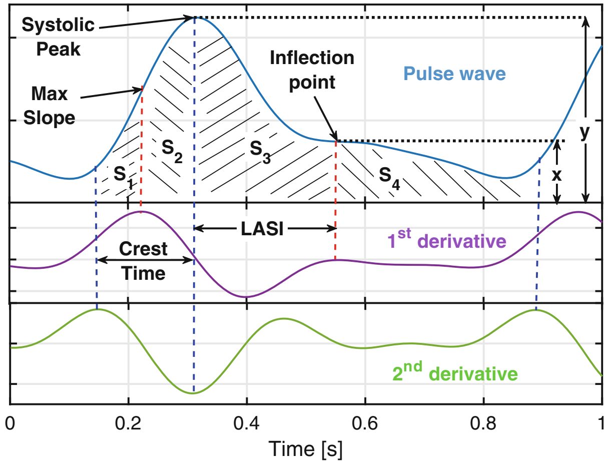

Fig. 5. Pulse waveform characteristic selection.

3 Results and Discussion

To extracted the features, the foot to foot of pulse waves within each recorded signal are extracted. Then, by applying minimum and maximum thresholds, the outlying values are omitted. The results are averaged and final pulse wave is calculated. The characteristics described in Sect. 2.3 are extracted from average pulse wave by using zero-crossing detection of the first and second derivatives. In Fig. 6 samples of all extracted and average pulse waves for both BImp and PPG are presented obtained from three different subjects.

The following four age groups are provided based on the baseline of the subjects:

1: 30 $<$ age $\leq$ 40 2: 41 $<$ age $\leq$ 50 3: 51 $<$ age $\leq$ 60 4: age $\leq$ 60.

The BMI is calculated using the following equation:

$$BMI = \frac{Weight[Kg]}{Height^2[m]}, \tag{3}$$

and based on the distribution of the extracted BMI for subjects, the next three groups are defined:

1: BMI $\leq$ 30 2: 30 $<$ BMI $\leq$ 40 3: BMI $\leq$ 50.

In Fig. 7, the bar charts of the extracted pulse wave (for both BImp and PPG) characteristics based on different age groups is presented. As can be seen, with age increase, the systolic peak, crest time, Max slope and AI values raise while LASI reduces. The IPA values increase from age group 30–40 to 51–60 and then fall in age older than 60. The AI values increasing rate for BImp is almost stable, while for PPG there is a significant rise in age groups over 60. From the figure, it can be seen that, overall aging increases amplitude and timing terms of the pulse wave, while it decreases the stiffness of the artery and peripheral resistance.

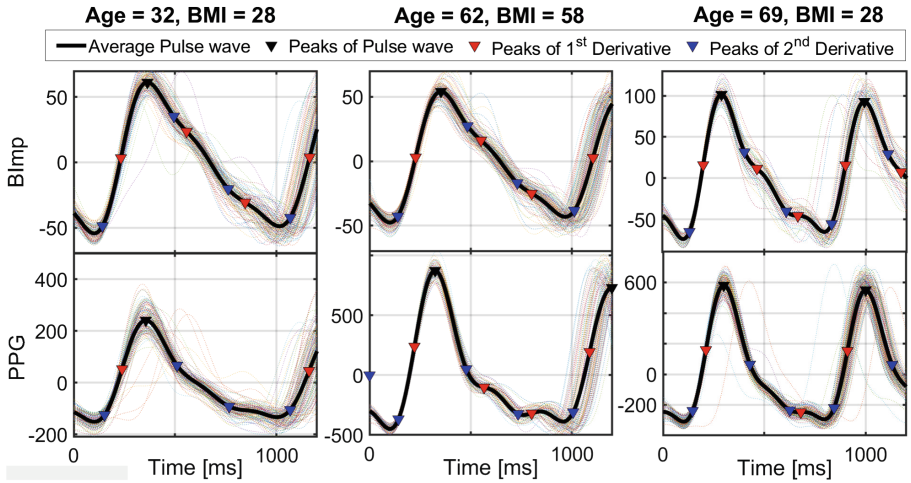

Fig. 6. Samples of extracted average pulse waves of the BImp and PPG for three different subjects: subject1: age = 32, BMI = 28, subject2: age = 62, BMI = 58 and subject3: age 69 and BMI = 28.

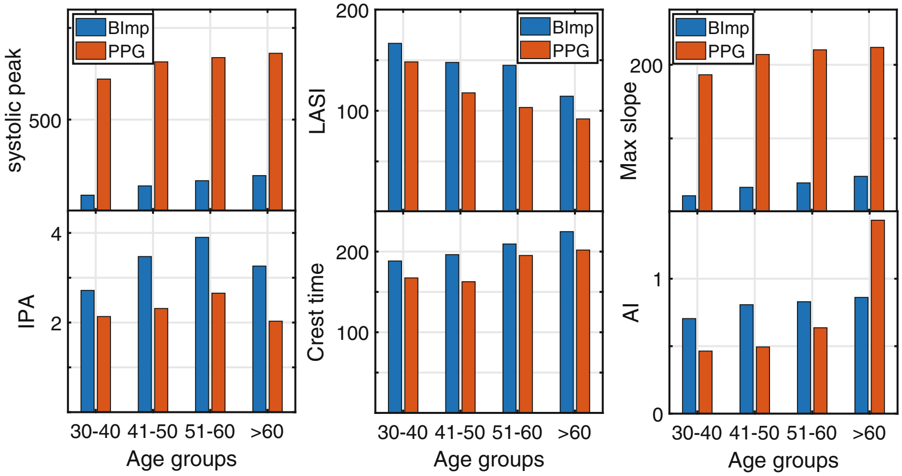

Fig. 7. Pulse wave characteristics based on age groups.

Figure 8, shows the charts of the measured parameters based on BMI groups. The systolic peak, LASI, Max slope, and IPA values reduce due to BMI growth, when in the opposite the crest time and AI increase. There are noteworthy reductions in both systolic peak and max slope values from under 30 to over 30 BMI. The AI increasing and the LASI reduction show that extra weight increases the arteries reflection and decreases its stiffness.

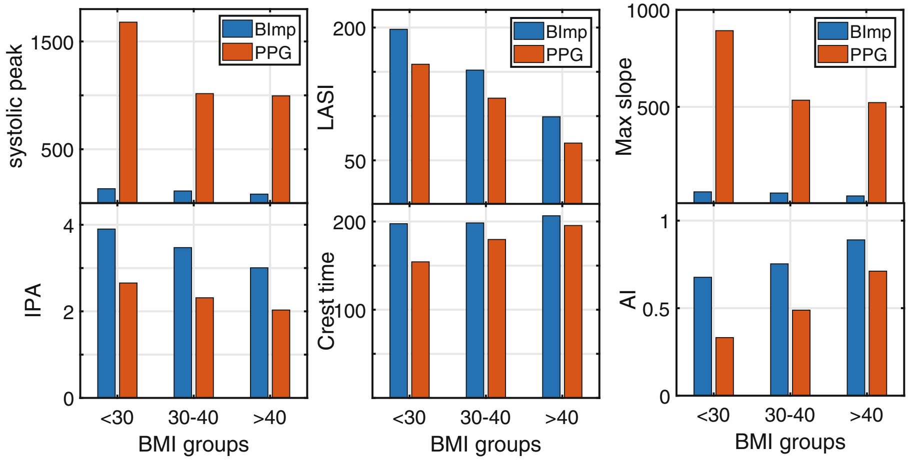

Fig. 8. Pulse wave characteristics based on BMI groups.

4 Conclusion

In this paper, we investigated age and BMI effects on the pulse wave characteristics. Two pulse wave signals from BImp and PPG are analyzed. Data is collected from 43 adult participants in sitting position for the duration of six minutes. We extracted pulse waves from each signal and calculated an average pulse wave for each subject. Five pulse wave characteristics are extracted from average pulse waves and their changes are presented based on four age and three BMI groups. From the obtained results in this paper, the pulse wave information varies due to both age and BMI change. Aging overall increases amplitude and timing terms of the pulse wave and decreases the stiffness of the artery and peripheral resistance and BMI growth increases the arteries reflection and decreases its stiffness. Hence, there is a considerable merit to include age and BMI factors into pulse wave based methods especially blood pressure measurements algorithms. For our future work, we suggest to study data with several conditions and age groups and investigate different physical situations.

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References

1. Top 10 causes of death. Global Health Observatory (GHO) data, World Health Organization, Geneva, 24 May 2018
2. Dutt, D.N., Shruthi, S.: Digital processing of ECG and PPG signals for study of arterial parameters for cardiovascular risk assessment. In: 2015 International Conference on Communications and Signal Processing (ICCSP), pp. 1506–1510, April 2015

3. Saito, M., Matsukawa, M., Asada, T., Watanabe, Y.: Noninvasive assessment of arterial stiffness by pulse wave analysis. IEEE Trans. Ultrason. Ferroelectr. Freq. Control **59**(11), 2411–2419 (2012)
4. Xing-Yun, D., Qing, C., Chao, S.: Study on the extract method of time domain characteristic parameters of pluse wave. In: 2016 IEEE International Conference on Signal and Image Processing (ICSIP), pp. 432–436, August 2016
5. Elgendi, M.: On the analysis of fingertip photoplethysmogram signals. Curr. Cardiol. Rev. **8**(1), 14–25 (2012)
6. Avolio, A.P., Butlin, M., Walsh, A.: Arterial blood pressure measurement and pulse wave analysis their role in enhancing cardiovascular assessment. Physiol. Meas. **31**(1), R1 (2009)
7. Kelly, R., Hayward, C., Avolio, A., O'rourke, M.: Noninvasive determination of age-related changes in the human arterial pulse. Circulation **80**(6), 1652–1659 (1989)
8. Buxi, D., Redouté, J.-M., Yuce, M.R.: A survey on signals and systems in ambulatory blood pressure monitoring using pulse transit time. Physiol. Meas. **36**(3), R1 (2015)
9. Ding, X., Zhang, Y., Liu, J., Dai, W., Tsang, H.K.: Continuous cuffless blood pressure estimation using pulse transit time and photoplethysmogram intensity ratio. IEEE Trans. Biomed. Eng. **63**(5), 964–972 (2016)
10. Tamura, T., Maeda, Y., Sekine, M., Yoshida, M.: Wearable photoplethysmographic sensors-past and present. Electronics **3**(2), 282–302 (2014)
11. Buxi, D., Redouté, J.M., Yuce, M.R.: Blood pressure estimation using pulse transit time from bioimpedance and continuous wave radar. IEEE Trans. Biomed. Eng. **64**(4), 917–927 (2017)
12. Heydari, F., et al.: Continuous cuffless blood pressure measurement using body sensors. In: 2018 IEEE SENSORS, pp. 1–4, October 2018
13. Fierro, G., Silveira, F., Armentano, R.: Central blood pressure monitoring method oriented to wearable devices. Health Technol. **6**(3), 197–204 (2016)
14. Yang, C., Tavassolian, N.: Pulse transit time measurement using seismocardiogram, photoplethysmogram, and acoustic recordings: evaluation and comparison. IEEE J. Biomed. Health Inform. **22**, 733–740 (2017)
15. Verma, A.K., Fazel-Rezai, R., Blaber, A., Tavakolian, K.: Pulse transit time extraction from seismocardiogram and its relationship with pulse pressure. Comput. Cardiol. **42**, 37–40 (2015)
16. Sharma, M., et al.: Cuff-less and continuous blood pressure monitoring: a methodological review. Technologies **5**(2), 21 (2017)