Measurement of Arterial Pulse Wave at the Temple Using PZT Piezo Sensor

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Abstract: Generally, arterial pulse waves are measured at the radial arterial of wrist or carotid arterial of neck using a sensor such as pressure sensor, piezoelectric sensor or optic sensor. But in this paper, arterial pulse wave is measured at the temple using PZT piezo sensor which is attached on the temple in form of a hair-band. Arterial Pulse waves are generally measured when a reagent is in a static state. But in this paper, we implemented the arterial pulse wave measurement system, as a previous stage of the arterial pulse wave measurement system for running at outdoors or on a running machine, that measures arterial pulse waves at the temple, which is the least moving part when running. Thorough the continuous study, if the motion artifact when running is possible to be removed, the system will be able to perform monitoring of running men's states and especially emergency signals such as serious pulse waves of an old and feeble persons and handicapped persons.

Keywords: Arterial Pulse, Piezo, Temple, Feature Point, Wavelet

1. INTRODUCTION

Arterial pulse waves, show physical characteristics of a heart, mean reports of pulse and pressure changes when blood, spouted from a heart, flows to a whole body.
Generally arterial pulse is measured at the radial arterial of the wrist or at the carotid arterial of the neck.[1] And pressure sensor, piezoelectric sensor and optic sensor is used for the measurement. In this paper, we acquired the arterial pulse wave data at the temple using PZT piezo sensor, usually it is called a buzzer, which is attached on the temple in form of a hair-band. After acquisition the data, we set the period of the arterial pulse using the wavelet transform and recognized the characteristics.

2. FEATURE POINT OF ARTERIAL PULSE

Fig. 1 shows the general shape of the arterial pulse wave. The arterial pulse wave which has this period is called the normal catacrotic wave. This wave is shown from a young and healthy person.[2]
Blood vessels make pulsation when an atrium beats, then blood current is generated. Arterial pulse wave rapidly rise by the contraction of the left ventricle from the sinoateria node. The impact by this contraction makes the P wave (Percussion wave).
Continuously, blood which is driven into the aorta presses the wall of the aorta and then the T wave (Tidal wave) is generated as the blood in the aorta is refracted.

Fig. 1 The general shape of radial pulse.

After the systole, the valve of the aorta is closed. This point is same as the incisura(dicrotic notch). Subsequently, blood of the aorta rapidly flows backward to the direction of the ventricle by the difference between the inner pressure of the ventricle and the aorta. But, the blood flows to the aorta again by the elasticity of the valve and the myocardium because the valve of the aorta is closed. This vibration situation of blood makes the D wave (dicrotic wave).

3. MEASUREMENT OF ARTERIAL PULSE

3.1. Characteristics of PZT piezo sensor

There are some kinds of piezo sensor such as a PZT(Lead zirconate Titannate), PVDF(Polyvinylidenefluoride), copolymer and etc.[3] In this paper, a PZT sensor was used because it is admirable in both cost and sensitivity. Generally, voltage is generated when pressure is applied to a piezo sensor, and the voltage generates distortion. The principle of voltage generation when pressure is applied to a piezo sensor is as follows. The pressure that applied to a piezo sensor is expressed in the ratio of the sum of forces that piezo sensor gets from all directions to the whole size of the sensor. So, we can see that voltage is directly proportional to the force that applied to a piezo sensor. And also, the force is only for vertical direction because sensor's thickness is much thinner than its size. Therefore the voltage V_P is as following formula (1), if we set vertical pressure is $X_{Vertical}$, sensor's thickness is t and piezo constant to the vertical direction is $g_{Vertical}$.

$$V_P = g_{Vertical} \times X_{Vertical} \times t \qquad (1)$$

3.2. Composition of measuring instrument

The measuring instrument of arterial pulse is made up of sensor part, drift removing circuit, filter part, ADC, PC interface part. Expression of the arterial pulse wave and data acquisition is processed in PC. Following fig. 2 shows the composition of the measuring instrument of arterial pulse wave.

AD converter for the acquisition of the arterial pulse wave is 12bit resolution converter. And its sampling frequency is 300Hz.

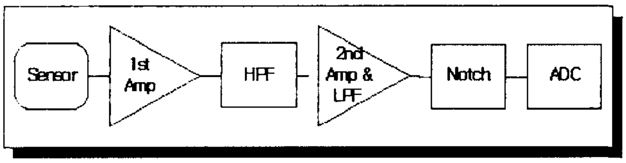

Fig. 2 The composition of the measuring instrument of arterial pulse wave.

4. EXPERIMENT & RESULT

Generally arterial pulse waves are measured at the radial arterial of the wrist or at the carotid arterial. But in this paper, the arterial pulse wave is measured using the measuring instrument which is attached on the temple in form of a hair-band. Fig. 3 shows measuring the arterial pulse wave at the temple.

Fig. 3. Measuring arterial pulse at the temple.

The flowchart of the algorithm for feature point detection after acquisition of the measured arterial pulse wave, by PC, is as following fig. 4. Preprocessing is processed after input of signal, then the period of the arterial pulse wave is computed, and then the detection is performed step by step.

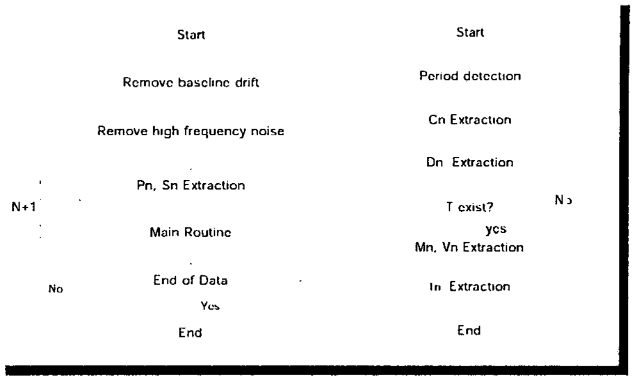

Fig. 4. The flowchart of characteristic point detector.

4.1. The preprocessing of arterial pulse

Usually various types of noise can be mixed in the arterial pulse wave as measuring environment or condition. Among the noise, the chief things are such as the high frequency noise caused by external electro magnetic wave interference and baseline drift caused by breathing or body movement. [5]

In this paper, we used the Daubechies Wavelet(db4) for the preprocessing of the arterial pulse signal. Frequency bandwidth according to the level of the wavelet transform is shown in the table 1.[6]

Table 1 Frequency bandwidth according to the level

Level	A	Frequency	D	Frequency
1	cA_1	0 Hz ~ 150 Hz	cD_1	150 Hz ~ 300 Hz
2	cA_2	0 Hz ~ 75 Hz	cD_2	75 Hz ~ 150 Hz
3	cA_3	0 Hz ~ 38 Hz	cD_3	38 Hz ~ 75 Hz
4	cA_4	0 Hz ~ 19 Hz	cD_4	19 Hz ~ 38 Hz
5	cA_5	0 Hz ~ 9 Hz	cD_5	9 Hz ~ 19 Hz
6	cA_6	0 Hz ~ 5 Hz	cD_6	5 Hz ~ 9 Hz
7	cA_7	0 Hz ~ 2 Hz	cD_7	2 Hz ~ 5 Hz
8	cA_8	0 Hz ~ 1 Hz	cD_8	1 Hz ~ 2 Hz

4.1.1. The removal of baseline drift

The obtained coefficient (A8; 0~1.2Hz) of the last low frequency bandwidth is adjusted to the original signal S. As subtracting it from the S, the noise by the baseline drift is removed.

$$S' = S - cA_8 \qquad (2)$$

The fig.4-(a) shows the original shape of the arterial pulse wave that its baseline is drifted by movement of the reagent. The signal shape that baseline drift is removed is in the fig.4-(b).

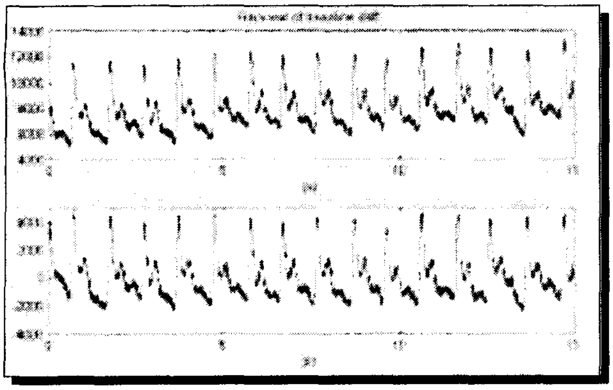

Fig. 4-(a). The original signal shape of arterial pulse.
Fig. 4-(b). The signal shape that baseline drift is removed.

4.1.2. The removal of high frequency noise

To remove high frequency noise, cD1 signal in the high frequency component (cD1 : 150~300Hz) of the first level was set to 0, and high frequency component (cD2 : 75~150Hz) of the second level was set as the following formula (3).

$$cD_2 = \begin{cases} cD_2 - Max\_cD_1, if \quad cD_2 > Max\_cD_1 \\ cD_2 - Min\_cD_1, if \quad cD_2 > Min\_cD_1 \\ 0, \quad otherwize \end{cases} \quad (3)$$

Following fig. 5-(a) shows the arterial pulse signal that includes high frequency noise, and the signal that high frequency noise is removed is shown in the fig. 5-(b).

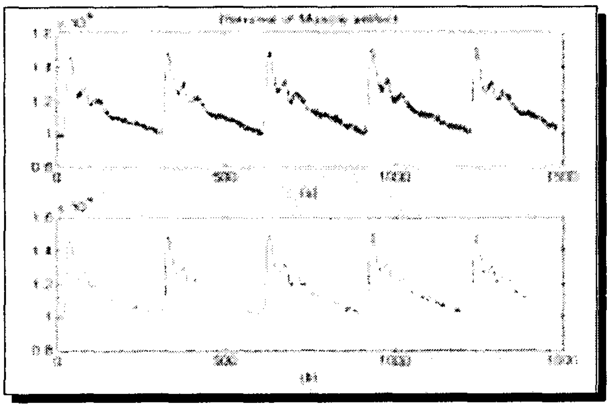

Fig. 5-(a). The original signal of arterial pulse.
Fig. 5-(b). The signal that high frequency noise is removed.

4.2. The recognition of characteristic point

4.2.1. The extraction of S point and P wave

To extract S point and P wave of the arterial pulse signal, we used not the Daubechies Wavelet(db4) transform used for noise removing but the Harr wavelet transform because its computation process is simple, discrete and it is proper to set up the domain for the recognition of feature point.
In this paper, the arterial pulse signal was converted to the three level by the Harr wavelet transform. and among the converted signal, the cD3 signal (38~75Hz) is used to detect the S point and P wave.
The P wave is the highest part in the arterial pulse wave and it appears well in the cD3 signal of the wavelet transform. The fig. 9 shows the comparison between the noise removed arterial pulse signal and the cD3 signal.

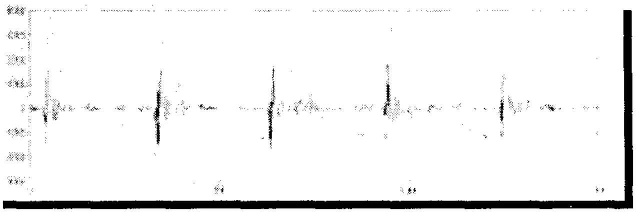

Fig. 6. Arterial Pulse and cD_3 signal.

After computing the maximum and minimum value of the cD3 signal, the difference of them, cDdistance is normalized to cDnormal. and the formula (4) is applied to the normalized value, cDnormal, then the reference point P(i) is determined for detecting S point and P wave.

$$cD_{distance} = cD_3(i+1) - cD_3(i) \quad (4)$$

$$ref \quad P(i) = \begin{cases} 1, \quad if \quad cD_{normal} \geq threshold \\ 0, \quad else \end{cases} \quad (5)$$

The reference point P(i) computed by the formula (4) is placed between minimum points of S point and maximum point of P wave. Therefore the peak of P wave is obtained by searching, in the right direction of the arterial pulse progressing, between two continuous reference points and S point is obtained by searching in the opposite direction.

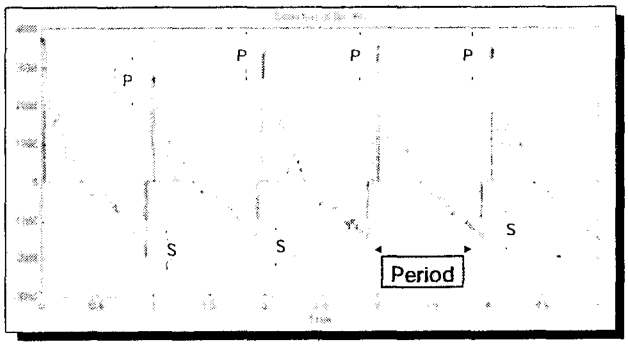

Fig. 7. The extraction of S point and P wave.

4.3.2. The extraction of C point , D wave and P wave

C point is computed by the difference of changing amount between the original signal and differential signal of the arterial pulse. cDPD is defined as the difference of the signal cD3 that the arterial pulse is converted to level 3 by wavelet and cD3_differential that the differential arterial pulse is converted to level 3. The reference point C(i) is obtained by the formula (7).

$$cD_{PD} = cD_3 - cD_{3\_differential} \quad (6)$$

$$ref \quad C(i) = Max[cD_{PD}(i+1) - cD_{PD}(i)] \quad (7)$$

And the C point that satisfies following two conditions ((1) the minimum value in around values. (2) the differential arterial pulse value is 0.) is detected as searching both left and right sides of the reference point C(i).
The following fig. 8 shows C point (Incisura) that is recognized through wavelet transform after the period computing process of the preprocessed arterial pulse wave.

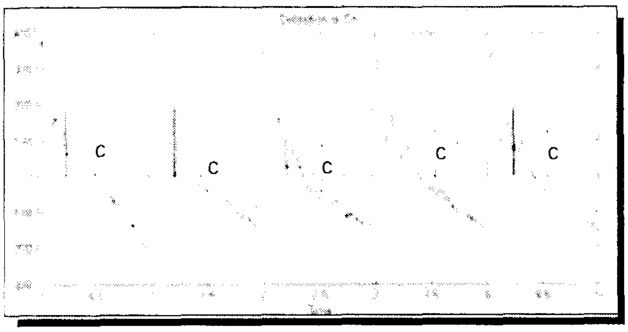

Fig. 8. The extraction of C point.

The peak of the D wave is detected at the first peak, that is the first zero crossing point of the differential arterial pulse, through searching to the right direction from the C point.
In case of the T wave, its location is exact if there is a peak but it is not exact if no peak. The T wave is detected using the zero crossing points of the second differential arterial pulse S" after decision of the existence of the T wave and the D wave.[4]
The fig. 9. shows the result of the detected D wave and T wave when the C point, the S point and the P wave were set as the standard.

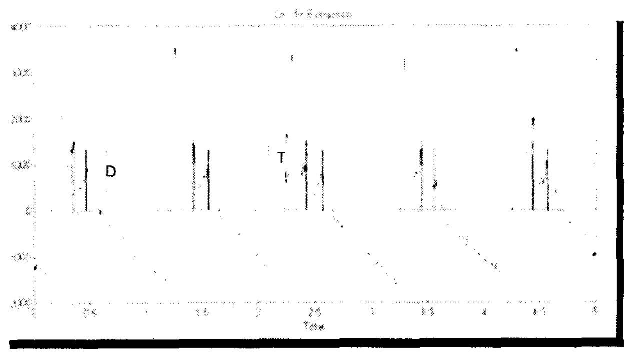

Fig. 9. The extraction of D wave and T wave.

4.4. The result of recognition

In this paper, reagents for measuring of the arterial pulse wave are ten males those are in their twentieth and healthy. 5,000 signal samples are acquired for each reagent. The rate of recognition is estimated by comparison the number of actual period of acquired signal with the number of characteristic point that is acquired by the program using the proposed algorithm.
As shown the following table 2, the rate of recognition is estimated about 96.55% in case of the S point and the P wave, 94.25% in case of the C point and the D point and 89.65% in case of the T wave.

Table 2 Recognition rate of characteristic point

Person	Period	S	P	C	D	T
1	19	18	18	18	18	17
2	15	15	15	15	15	15
3	15	15	15	14	14	14
4	18	18	18	18	18	18
5	17	17	17	17	17	16
6	25	22	22	21	21	17
7	12	11	11	10	10	9
8	19	19	19	19	19	19
9	19	19	19	19	19	19
10	15	14	14	13	13	12
Recognition	174	168	168	164	164	156
Rate		96.55%	96.55%	94.25%	94.25%	89.65%

5. CONCLUSION

In this paper, the arterial pulse wave is measured at the temple using piezo sensor. To recognize the feature point and preprocess the arterial pulse wave, we applied a new algorithm using wavelet transform. That is, preprocessing was performed to detect the feature point easily as removing high frequency and baseline drift noise included in the arterial pulse wave. To recognize main feature points (the S point, the P wave, the C point, the D and T wave) in the arterial pulse, we applied the wavelet transform.
Generally the arterial pulse wave is measured when a reagent is in a static state. But in this paper, the arterial pulse wave is measured at the temple because it is the least moving part when running at outdoors or on a running machine. If we can remove the motion artifact when running through further study, it is seems that health condition of running people, especially emergency signal like a rapid change of heart beat of the aged or the handicapped, can be monitored.

6. REFERENCE

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