Electrocardiogram signal processing method for exact Heart Rate detection in physical activity monitoring system: Wavelet Approach

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Abstract— **Physical Activity Monitoring is a device that can measure the human activity quantity quantitatively through Heart Rate detection in real time. R-Spike detection of ECG is required for this Heart Rate detection. Since Physical Activity Monitoring System is usually used during activity or exercise, however, signal measured in ECG System is contaminated by diverse noises. Diverse noises become the factors of failure in R-Spike detection. Such factors impede the exact HR detection. This paper suggests method to convolute wavelet function and scaling function as the optimum signal disposition method for optimum R-Spike detection. This method was compared with the R-Spike detection method that uses quadratic spline wavelet presented before. To verify performance of signal disposition method suggested in this paper, the ECG of noise stress test database (NSTDB) and MIT-Database were tested in combination. Then, the sensitivity of R-Spike detection rate for noise was also additionally tested by gradually lowering SNR of NSTDB. Then, it was verified through ECG signal that was actually measured in physical activity monitoring.**

Keywords— skin temperature, heart rate variability, aerobic exercise

I. Introduction

Heart Rate is one of the parameters of living body that can show the activity quantity of physical body gradually. As Heart Rate lineally increases with oxygen uptake (VO_2) during exercise, it is used as important parameter of living body during exercise.[1]. Heart rate is measured by using Arterial blood pressure (ABP) and Photoplethysmograph (PPG) or mostly Electrocardiogram (ECG). It is mainly measured by R-Spike detection of ECG in the physical activity monitoring system. (RR interval, namely, the interval between R-Spike and next R-spike is calculated.) Thus, the failure of R-Spike detection makes exact HR detection difficult. R-Spike detection is usually hindered by noises such as Electrode Motion Artifact(EM), Muscle Artifact (MA) and Baseline wandering(BW). Diverse signal disposition methods to remove such diverse noises and detect R-Spike have been introduced in many papers.[2] Among them, wavelet method can locally express the form that includes the diverse patterns which can show signal in time-scale domain and occur in ECG cycle and includes the different frequencies (QRS Complex, T-wave, P-wave). Since noise and artifact that affect ECG can be divided into different frequency and different scale, it can be used as the most powerful ECG signal disposition tool[3]. As the typical wavelet method to dispose ECG signal, there is method to use quadratic spline wavelet. Since quadratic spline wavelet has the property of linear phase and first differential property, the position of R-Spike could be exactly detected by zero-crossing method in dyadic scale [4]. However, quadratic spline wavelet showed abnormal detection in the strong noise that locally appeared. To improve the performance of such abnormal detection, this paper used the Daubechies' orthonormal wavelet. Although orthonormal wavelet generally has linear phase property, it also has nonlinear phase property, thereby perverting ECG[5]. However, this point is not seriously considered in this study, because the objective of physical activity monitoring system is not medical diagnosis, but exact HR detection. The wavelet method suggested in this paper used Daubechies5 wavelet. The calculation is finished by 1 convolution between actual signal and newly formed wavelet function through convolution of Scaling function and Wavelet function.

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II. Wavelet Methods

A. Basic wavelet method

Wavelet transform is basically composed of combination of basic function and signal by the process in formula (1).

$$W(a,b) = \int_{-\infty}^{+\infty} x(t)\psi^*{}_{a,b}(t)dt \qquad (1)$$

Where, x(t) indicates signal, a scale parameter and ψ(t) indicates wavelet. All variables and functions are defined in the area of real number.

$$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}}\psi\left(\frac{t-b}{a}\right) \quad (2)$$

As prototype wavelet, Formula (2) is expanded or reduced by using scale parameter 'a' and wavelet is conveyed by using movement parameter b that indicates the position in the time area. In this paper, wavelet is newly formed through convolution of scale function and wavelet function and the newly formed wavelet is obtained by formula (1).

Multi-resolution Analysis that Mallet's suggested is the most well-known DWT algorithm it is composed of Filter bank with two sub-bands. Original signal is analyzed into two functions Scaling Function and Wavelet Function, by both of which the signal are each analyzed into Approximation and Detail Approximation is again analyzed into High-scale, Low-frequency Component and the Details are analyzed into Low-scale, High-frequency.

The process of returning Detail Coefficient is done as shown in Equation(4) x(t) is broken down by the expansion and movement of prototype function ψ named Mother Wavelet. The signal from basis function projects the Detail Coefficient as shown in Equation(4). Where $D_{a,b}$ is known as the wavelet (or detail) coefficient at scale and location indices (a,b).

$$\psi_{a,b}(t) = 2^{-a/2}\psi(2^{-a}t - b) \quad (3)$$

$$D_{a,b} = \int_{-\infty}^{\infty} x(t)\psi_{a,b}(t)dt \quad (4)$$

Approximation Coefficient can be gained by the projection of the signal from expansion and movement of Scaling function. The scaling function can be convolved with the signal to produce approximation coefficients as shown in Equation(6).

$$\phi_{a,b}(t) = 2^{-a/2}\phi(2^{-a}t - b) \quad (5)$$

$$A_{a,b} = \int_{-\infty}^{\infty} x(t)\phi_{a,b}(t)dt \quad (6)$$

B. Suggest wavelet method

First, scale function and wavelet function were formed by using iteration in the time. Fourier transform m0(w) corresponding to wavelet filter h(k) can be indicated in the form of 2 - π cycle function as follows.

$$m_0(\omega) = \frac{1}{\sqrt{2}}\sum_k h_k \varepsilon^{-j2\pi ft} \quad (7)$$

$$\phi(\omega) = m_0\left(\frac{\omega}{2}\right)\phi\left(\frac{\omega}{2}\right) \quad (8)$$

Further, it is expressed as follows in the Fourier area of scale function and wavelet function.

$$\phi(\omega) = \prod_{1}^{\infty} m\left(\frac{\omega}{2^k}\right) \quad (9)$$

$$\psi(\omega) = m_1\left(\frac{\omega}{2}\right)\prod_{k=2}^{\infty} m_1\left(\frac{\omega}{2^k}\right) \quad (10)$$

The above formula means that scale function can be defined by sequential calculation of filter coefficient. Namely, it is defined as follows as sequential convolution in the time.

$$\varphi^i(n) = \prod_{n=0}^{\infty} \otimes h_k^0(n) \quad (11)$$

$$h_k^0(n) = \begin{cases} \sqrt{2}h_0(m) & \text{if} \\ 0 & \text{otherwise} \end{cases} \quad n = 2^k m0, k \neq 0 \quad (12)$$

In Figure 1, the approximate value of scale function and wavelet function are acquired in k=1~5 by using Daubechie 5 filter coefficient. In the approximate value function, we newly formed function that can optimally detect R-Spike of scale function k=3 and wavelet function k=3 through convolution.

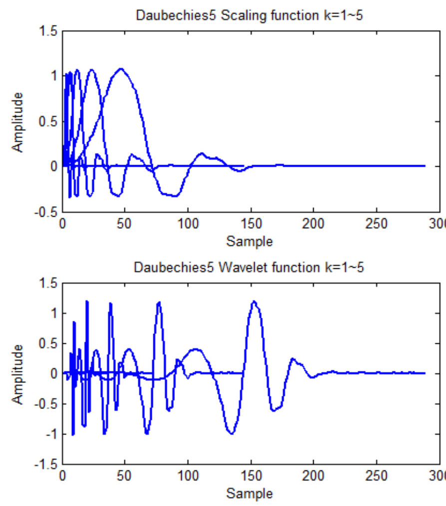

Figure 1. Scale ring function and wavelet function are indicated from k=1 to k=5.

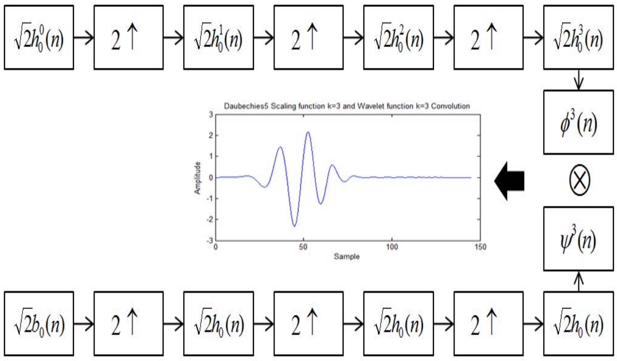

Figure 2. Wavelet that is newly formed after convolution of formation process of scale ring function of k=3 and wavelet function with 2 functions.

As the frequency range of R-Spike is in 10~40Hz, the -3db frequency response of wavelet function that is newly formed in Figure 2 should be in the position similar to that of frequency range of R-Spike. Testing the frequency response of actually designed wavelet, the result was between 11Hz and 45Hz. The wavelet of R-spike detection algorithm used in the paper was converted and negative peak was converted to positive peak through Squaring. Then, Smooth Filtering was done to increase the detection rate of QRS Complex through threshold. Next,R-Spike was detected through threshold method.

III. EXPERIMENTS AND RESULT

TABLE I

R-SPIKE DETECTION SENSITIVITY

SNR(db)		Total	FN	FP	Se (%)	TP (%)
36	QSW	350	0	0	100	100
	CNW	350	0	0	100	100
24	QSW	350	0	0	100	100
	CNW	350	0	0	100	100
18	QSW	350	4	3	98.8	99.1
	CNW	350	0	0	100	100
12	QSW	350	14	8	96.1	97.7
	CNW	350	6	2	98.3	99.4
6	QSW	350	37	15	90.4	95.8
	CNW	350	19	5	94.8	98.5

While NSTDB provides 3 noise data, that is to say, Muscle Artifact(MA), Electrode Motion Artifact(EM) and baseline wander(BW), this experiment used EM and BW noise which mainly appear in the physical activity monitoring system. Since physical activity monitoring system mainly collects data from breast, it is hardly affected by ma noise. Colleting the actual data, ECG was hardly affected by ma noise. We combined and experimented EM and BW noise by gradually lowering SNR in recorder 100 of relatively clean MIT-database. Test result is in Table 1. According to test, the performance of convolution wavelet (CNW) presented in the paper was better than that of Quadratic spline wavelet (QSW).

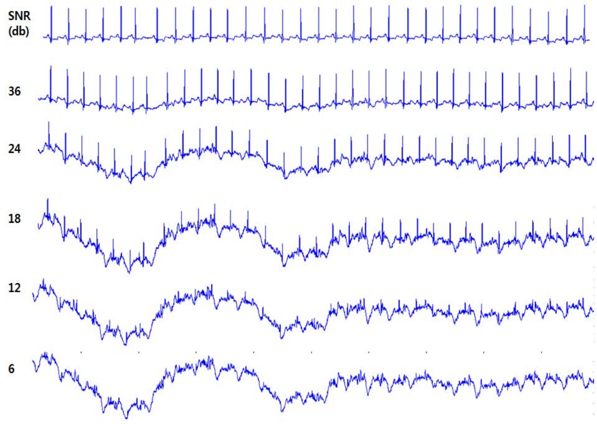

Figure 3. Data made by lowering SNR of data formed by combining 100 Record of MIT-Data Base, EM noise of NSTDB and BW noise.

False Negative(FN) means that actual R-Spike is not detected and False Positive is detected even though it is not R-Spike. Then, sensitivity was calculated through FN and TP. TP is the number of total R-Spike detected by algorithm.

$$S_e(\%) = \frac{TP}{TP + FN} \tag{13}$$

$$+P(\%) = \frac{TP}{TP + PP} \tag{14}$$

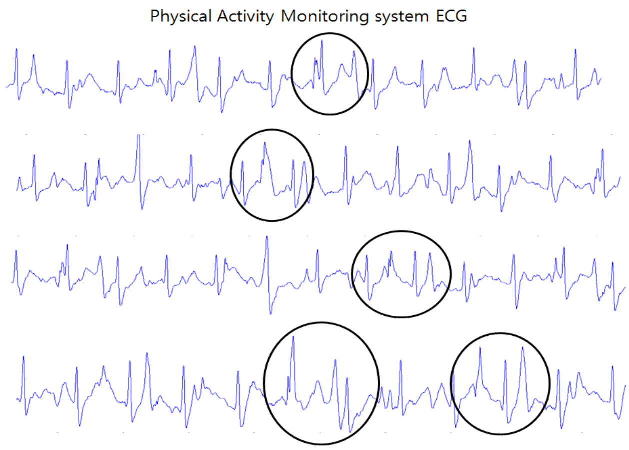

Figure 4. Data collected from portable hardware based on wearable sensor.

As actual movement data, Figure 4 is data collected from portable hardware based on wearable sensor. Sampling. frequency is 500 Hz with 12 bit resolution. The data in the original Figure 4 is noise that locally appears in the actual exercise and the shape of such local noise is similar to that of R-Spike, thereby making R-Spike detection fail. If R-Spike detection fails, heart rate changes more widely, thereby causing false alarm on the system. The original data is the part that makes error when detecting with quadratic spline wavelet. However, detection could be done without error with the algorithm suggested in this paper.

IV. CONCLUSION

This study presented wavelet method that can optimize R-Spike detection in physical activity monitoring system of noisy environment. The wavelet function formed by convolution of scaling function and wavelet function presented in this paper showed performance better than that of quadratic spline wavelet in R-Spike detection of noisy ECG signal rate. Since physical activity monitoring system works in the embedded environment, it should be effective to HR detection in even small calculation quantity. If the result of this study is embodied in the physical activity monitoring system, HR could be embodied more effectively.

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