Analysis Spectrum of ECG Signal and QRS Detection during Running on Treadmill

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Abstract. The heart is an important organ in our metabolism in which it controls circulatory and oxygen. The heart exercise is needed one of them using the treadmill to prevent health. To analysis, it using electrocardiograph (ECG) to investigating and diagnosing anomalies of the heart. In this paper, we would like to analysis ECG signals during running on the treadmill with kinds of speeds. There are two analysis ECG signals i.e. QRS detection and power spectrum density (PSD). The result of PSD showed that subject 3 has highly for all subject and the result of QRS detection using pan Tomkins algorithm that a percentage of failed detection is an approaching to 0 % for all subject.

1. Introduction
The heart is primarily organ in humans, it pumps circulatory, supply oxygen and nutrients to body tissues. Many people were deaths caused by heart disease in which it suddenly attack us. We never know when it occurs to us however we can to prevent it such as sports or physical exercise. One of the tools to analyze the heart is Electrocardiograph (ECG). In general, ECG is applied to investigating and diagnosing anomalies of the heart based on electrical activity. The electrical conduction of the heart is generated by two main of the cell: cardiomyocytes in which it provides electrical potentials when contraction and cells particularized in the production and conduction of the action potentials.

The characteristic of ECG signal as shown in Fig. 1, which there are three elements in the ECG waveform i.e. isoelectric line, segments, and intervals. Isoelectric describes as the horizontal line during no electrical activity, Segments is defined as the time duration of the isoelectric among waves, and Intervals is the term for the time among in around the same segments [1].

![Figure 1. The characteristic of ECG waves [1].](image-url)
In this paper, we would like to analyze ECG signal when the subjects using a treadmill with various speed to identify anomaly and quality of the heart. The researchers of ECG fields and cardiologist were proposed several methods and experiments to heart rate exercise such as physical activity consisted of two hours per week, daily swimming routine, fitness and others training then the whole is compared to heart rate each of them [2-3]. The ECG signal recorded by the device on wireless during running on the treadmill and the data will process using wavelet transform (WT) algorithms to removing artifact and it provides to analyze in the frequency domain and finally, we detect a QRS peak of ECG signal using pan Tomkins algorithm.

2. Material and Method

2.1. Data Acquisition

The five subject were recorded ECG signal with the mean of age from 25 - 28 years, each of them given instruction to running on treadmill to one minutes for one kinds of experiments in which there are five various based on treadmill speed (m/s): 0, 1.5, 3.0, 4.5, and 6.0. The device used has specification are frequency sampling (FS) 1000 Hz/s, wireless based, 1-lead (1-positive, 1-negative, 1-reference) and Bipolar differential measurement. The position of placement sensor and the experimental setup is given in Fig. 2.

2.2. Preprocessing

The scheme of signal processing to removing noise and artifact during the experiment as shown in figure 3, which is the signal acquisition was described foregoing. In addition, there is three part of preprocessing i.e. detrending data, windowing, and finite impulse response (FIR) filter. The detrending data described to remove the baseline data by eliminating the trend of ECG data in which to calculate it follows:

\[
\text{Level}_{\text{trending}} = \left[ \frac{\log_2 2T}{\log_2 N} \right]
\]

where \( t \) is the time duration of sampling and \( N \) is the number of sampling. The windowing reduces the amplitude of the discontinuities in data and The FIR filter generally used to operate on discrete-time signals and occurs weighted of the data in which it describes as

\[
y[n] = \sum_{k=0}^{M} b_k x[n - k]
\]

where \( M \) is finite [4].
2.3. Wavelet Transform

Wavelet Transform (WT) commonly used to signal processing for several application such as EEG and ECG, which it provides to analyze the signal in time domain, signal decomposition and signal compression. In mathematics, WT describe as

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

where \((\psi_{a,b})\) as wavelet function and \(a, b \in \mathbb{R}, a > 0\), and \(\mathbb{R}\) is the wavelet space \([5,6]\). Furthermore, WT has several of properties are can be represented on multiple resolution scales called Discrete wavelet transform (DWT). In particular, DWT used to analyze various signals to obtain good resolutions by decomposing them. Moreover, it can yield approximation \((a)\) and detail coefficient \((d)\), DWT decomposition can be defined as

$$a_{i} = x(k) * \psi_{i,j}(k),$$
$$d_{i} = x(k) * \phi_{i,j}(k),$$

where \(a_{i}(l), d_{i}(l)\) is the approximation and detail coefficient and \(i\) is the resolution \([7,8]\). In figure 4 describe as scheme of DWT in which the filter bank implementation of wavelet transform for three-level wavelet decomposition.

2.4. QRS Detection using Pan Tompkins’ algorithm

There are many kinds method for QRS detection or beat per minutes (BPM) calculation such as Pan Thompkins’ algorithm, Savitsky-Golay algorithm, and the simplest algorithm is applying three processing: linear high-pass filter, non-linear low-pass filter, and the decision making \([9-10]\).

Pan Tompkins developed by J. Pan and W. J. Tompkins in which they were built an algorithm for detection of the QRS on ECG signal in real time. In general, the scheme of the algorithm is given in figure 5. First is an integer coefficient bandpass filter composed of cascaded low-pass and high-pass filters, Its function is noise rejection. The signal was filtered next is a filter that approximates a derivative in which five-point with the transfer function (Eq. 6), the amplitude response (Eq. 7), and the difference equation (Eq. 8).

$$H(z) = \frac{1}{8T} (z^{-2} - 2z^{-1} + 2z^{1} + z^{2})$$
$$|H(wT)| = \frac{1}{4T} [\sin(2\omega T) + 2 \sin(\omega T)]$$

Figure 3. Schematic of ECG signal processing

Figure 4. The properties of wavelet decomposition.
\[
\begin{align*}
y(nT) &= (1/nT)[(-x(nT - 2T) - 2x(nT - T) \\
&+ 2x(nT + T) + x(nT + 2T)]
\end{align*}
\tag{8}
\]

the results from derivation, do square process using mathematical operation \( y(nT) = [x(nT)]^2 \), the signal moves into a moving-window integrator. Finally, Adaptive thresholds then separate the locations of the QRS complexes [11].

![Figure 5. The block diagram of pan thomkins algorithm](image)

3. Results and Discussions

The raw signal was recorded as shown in figure 6 based on each of speed on the treadmill, their signal was included noise caused by error transmission device through wireless and artifact caused by hand or any body movement to disturb when ECG sensing. So, required to remove them and obtained the real ECG signal. To implementation, do signal processing. First, pre-processing step i.e. detrending data, windowing, and FIR filter and last, used discrete wavelet transform to analyze the signal in approximation and coefficient then using FFT to get power spectrum density (PSD) for the complete subject as shown in figure 7 in which for subject 3 has PSD highly than another subject.

![Figure 6. The raw data ECG signal from subject 1.](image)

![Figure 7. Power Spectral Density](image)
The results of QRS detection using pan Tompkins algorithm is given in table 1 in which it powerful to detects them, Moreover, a percentage of failed detection is an approaching to 0 % for all subject. The total peak calculated manually peak by peak in ECG signal and this table showed an increasing speed of treadmill it's so difficult to detect them but overall, this algorithm can detect it.

| Speed (m/s) | Subject | Total Peak | QRS Detection | Failed detection (%) | Speed (m/s) | Subject | QRS Peak | QRS Detection | Failed detection (%) |
|-------------|---------|------------|----------------|-----------------------|-------------|---------|----------|----------------|-----------------------|
| 0           | 1       | 83         | 83             | 0                     | 4,5         | 1       | 128      | 128           | 0                     |
|             | 2       | 87         | 87             | 0                     |             | 2       | 129      | 131           | 0.02                  |
|             | 3       | 97         | 97             | 0                     |             | 3       | 136      | 136           | 0                     |
|             | 4       | 135        | 135            | 0                     |             | 4       | 147      | 147           | 0                     |
|             | 5       | 80         | 80             | 0                     |             | 5       | 118      | 122           | 0.03                  |
| 1,5         | 1       | 99         | 101            | 0.02                  | 6           | 1       | 136      | 134           | 0.02                  |
|             | 2       | 111        | 111            | 0                     |             | 2       | 138      | 137           | 0.01                  |
|             | 3       | 111        | 111            | 0                     |             | 3       | 159      | 158           | 0.01                  |
|             | 4       | 135        | 135            | 0                     |             | 4       | 168      | 168           | 0                     |
|             | 5       | 95         | 97             | 0.02                  |             | 5       | 131      | 131           | 0                     |
| 3           | 1       | 110        | 110            | 0                     |             |         |          |               |                       |
|             | 2       | 115        | 115            | 0                     |             |         |          |               |                       |
|             | 3       | 125        | 125            | 0                     |             |         |          |               |                       |
|             | 4       | 133        | 133            | 0                     |             |         |          |               |                       |
|             | 5       | 133        | 133            | 0                     |             |         |          |               |                       |

4. Conclusions
In this paper, we would like to analyze ECG signal during running on the treadmill with power spectrum density and QRS detection using pan Tompkins. There is five subject for the participant in this experiment. The raw data was recorded that increasing peak for each of speeds on the treadmill as shown figures foregoing. The result of PSD shown that subject 3 has highly PSD than another subject. In
addition, QRS detection using pan Tomkins shown that a percentage of failed detection is an approaching to 0 % for all subject.

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References
[1] Gacek A 2011 ECG signal processing, classification and interpretation: a comprehensive framework of computational intelligence ed Pedrycz W (Berlin: Springer Science & Business Media).
[2] Furlan R, Piazza S, Dell’Orto S, Gentile E, Cerutti S, Pagani M and Malliani A 1993 Early and late effects of exercise and athletic training on neural mechanisms controlling heart rate Cardiovasc. Res. vol 27 pp 482-8.
[3] Aubert AE, Seps B and Beckers F 2003 Heart rate variability in Athletes Sports Med 33(12) pp 889-919.
[4] Kumar KS, Yazdanpanah B and Raju GS 2014 Performance Comparison of Windowing Techniques for ECG Signal Enhancement Int. J. Eng. Res. 3(12) pp 753-6.
[5] A. Prochazka, J. Kukal, and O. Vysata. “Wavelet transform use for feature extraction and EEG signal segments classification.” In Proc. IEEE ISCCSP, pp. 719-722, Malta, 2008. Prochazka A, Kukal J and Vysata O 2008 Wavelet transform use for feature extraction and EEG signal segments classification Proc. IEEE ISCCSP pp 719-22.
[6] Murugappan M, Nagarajan R and Yaacob S 2010 Combining spatial filtering and wavelet transform for classifying human emotions using EEG signals J. Med. Biol. Eng. 31(1) pp 45-51.
[7] Subasi A 2007 EEG signal classification using wavelet feature extraction and a mixture of expert model Expert Syst. Appl. 32 pp 1084-93.
[8] Ciupe A M and Roman NM 2015 Study of ECG signal processing using wavelet transforms Proc. IEEE ATEE pp 27-30.
[9] Das S and Chakraborty M 2012 QRS detection algorithm using savitzky-golay filter Int. J. Signal Image Process. vol 03.
[10] Chen HC and Chen SW 2013 A moving average based filtering system with its application to real time QRS detection Proc. IEEE Comput. Cardiology.
[11] Pan J and Tompkins WJ 1985 A real-time QRS detection algorithm Proc. IEEE. Trans. Biomed. Eng. vol BME-32.