International Journal of Applied Engineering Research (IJAER)

Print ISSN 0973-4562
Online ISSN 1087--1090

Aims and Scope: The International Journal of Applied Engineering Research (IJAER) is an international research journal, which publishes top-level work from all areas of Engineering Research and their application including Mechanical, Civil, Electrical, Computer Science and IT, Chemical, Electronics, Mathematics, Environmental, Education Geological etc. Researchers in all technology and engineering fields are encouraged to contribute articles based on recent research. Journal publishes research articles and reviews within the whole field of Engineering Research, and it will continue to provide information on the latest trends and developments in this ever-expanding subject.

Audience: Mechanical, computer, aeronautical, chemical, civil, electronics, mathematic, geology, electrical.

Submission: Authors are requested to submit their papers electronically to IJAEReditor@gmail.com

INDEXING: SCOPUS, EBSCOhost, GOOGLE Scholar, JournalSeek, J-Gate etc.

CHECKING LISTING OF IJAER ON SCOPUS

Please visit SCOPUS website at http://www.elsevier.com/online-tools/scopus download excel file of journals list and search by Title or our company name "Research India Publication" you will find our five journals are indexed in SCOPUS list. IJAER is also listed in SCOPUS.

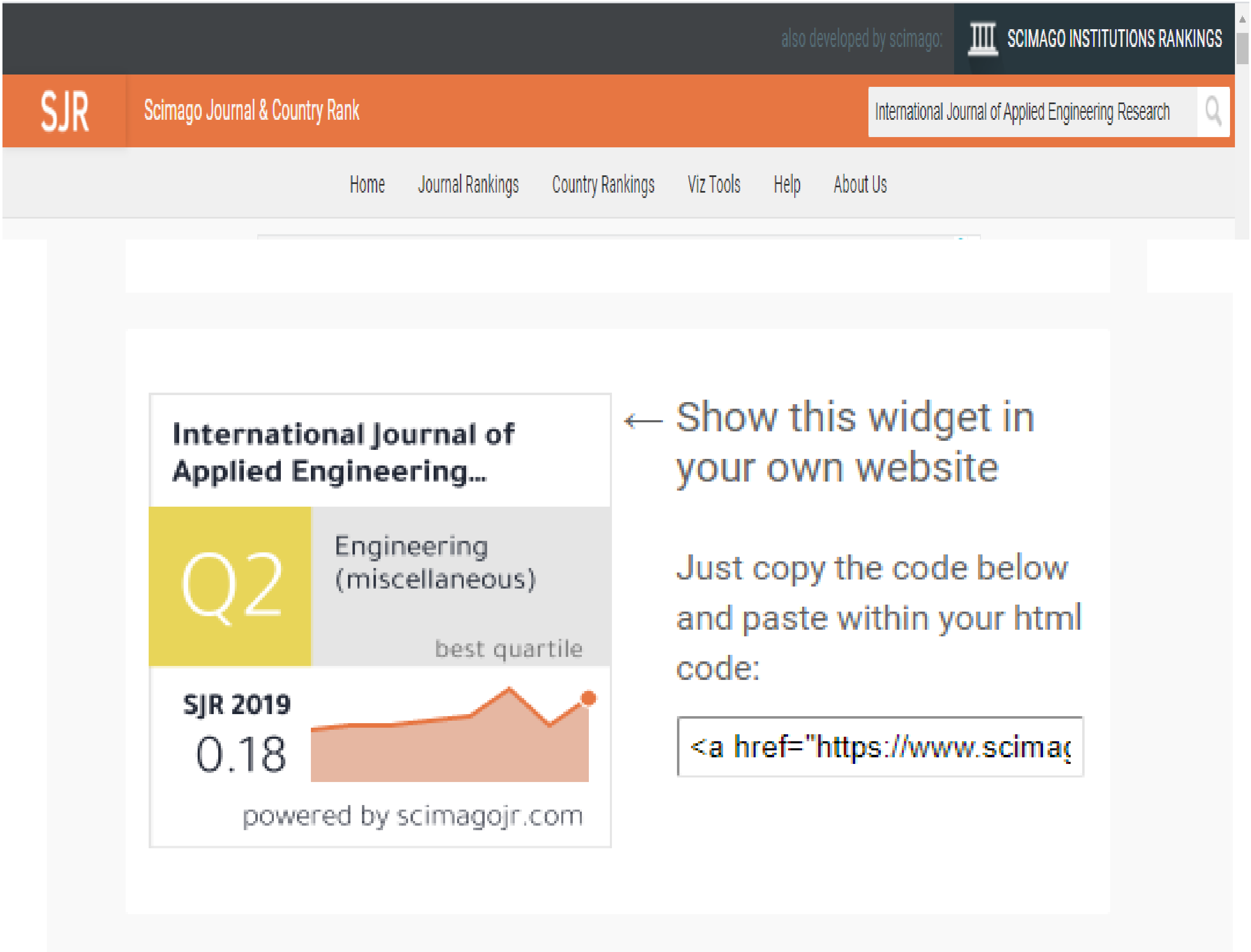
Publication Date and Frequency: Twenty Four issues per year.

Annual Subscription Price:
Library/Institutional: Print : US$1160.00 Online Only: US$1140.00
Print + Online : US$1200.00
Individual/Personnel: Print US$580.00
Inside India: Rs.5500.00

International Journal of Applied Engineering Research (IJAER)

Volume 9, Number 22 (2014)

CONTENTS


also developed by scimago:
SCIMAGO INSTITUTIONS RANKINGS
SJR
Scimago Journal & Country Rank
International Journal of Applied Engineering Research
Home
Journal Rankings
Country Rankings
Viz Tools
Help
About Us
International Journal of Applied Engineering...
Q2
Engineering (miscellaneous)
best quartile
SJR 2019
0.18
powered by scimagojr.com
← Show this widget in your own website
Just copy the code below and paste within your html code:
<a href="https://www.scimag

International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 9, Number 22 (2014) pp. 15353-15360

http://www.ripublication.com

T-wave identification in ECG Signal using Symmetric Distance Coefficient

Nemuel Daniel Pah

Department of Electrical Engineering, Faculty of Engineering, University of Surabaya, Jl. Raya Kalirungkut, Surabaya, Indonesia.
E-mail: nemuelpah@staff.ubaya.ac.id

Abstract

Symmetric Distance Coefficient (SDC) is a parameter developed by the author to measure similarity between wavelet function and transient in a signal. It is based on a fact that wavelet coefficients of a transient that has similar shape and similar time support to a wavelet function are always symmetric. The parameter measures similarity by measuring the degree of symmetry in wavelet coefficients. The parameter and the measurement procedures are very useful in identifying the existence of specific shape transients in a signal. Since SDC measures the degree of symmetry in gradual level, it can identify transients in a signal that are contaminated by noises or interferences. This paper reports experiment procedures and results in identifying T-wave in ECG signals based on SDC. The results suggested that the parameter identified T-wave with an accuracy level of 90% to 100%.

Keywords: Electrocardiogram (ECG), T-wave, Transient, Symmetric distance, Wavelet transform.

Introduction

Electrocardiogram (ECG) signal is the recording of electrical activity of the heart over time [1]. An ECG signal is characterized by some components, called the P, QRS, and T-wave [1]. The shape, duration, and amplitude of each wave, as well as the relative time distances between waves contain significant information about the condition of the subject's heart. The P-wave represents the atrial depolarization. QRS wave is related to depolarization of ventricles, and the T-wave is related to repolarization of ventricles. Therefore, the detection of the waves is a significant step in automatic ECG analysis.

Numerous methods have been developed to detect waves in ECG [2, 3]. The detection of P and T-waves are more challenging compared to the detection of QRS wave, due to their weak amplitude and shape variation. Therefore, the detection of QRS-wave location is often being used as a starting point to detect P and T-waves. Several approaches have been used in P and T-waves detection. The existing approaches used filtering, pattern recognition, and basis expansion such as Fourier transform, discrete cosine transform and wavelet transform [4, 5, 6].

This paper reports another approach to identify T-wave in ECG signal by using a new parameter, called symmetric distance coefficient (SDC) developed by the author [7]. The parameter, SDC, measures symmetric pattern in wavelet coefficients. The location of symmetric pattern indicates the location of transients with a shape similar to the wavelet function being used. By using a proper wavelet function with a shape similar to T-wave, SDC can be used to detect the existence of transients in ECG signal such as the T-wave. Section 1 introduces the issues related to shape similarity in wavelet transform, while Section 2 describes the mathematical definition of SDC. Section 3 and 4 explain the method and the experiments, conducted to identify T-wave in ECG. The last section concluded the paper.

Shape Similarity in Wavelet Transform

Wavelet transform (WT) of a signal $f \in L^2(R)$ is defined as a correlation between the signal and a wavelet function $\psi_{s,}\sigma$[8, 9]. The wavelet function, $\psi_{s,}\sigma$, is a dilated and translated version of a mother wavelet, ψ, by scale, s, and time-shift, σ.

$$Wf(s,\sigma) = < f, \psi^*_{s,\sigma} > = \int_{-\infty}^{+\infty} f(t) \frac{1}{\sqrt{s}} \psi^* (\frac{t-\sigma}{s}) dt \quad (1)$$

The magnitude of wavelet coefficient, $|Wf(s,\sigma)|$, indicates the strength of correlation between the wavelet function, $\psi_{s,}\sigma$, and transient in the analyzed signal, f, around $t = \sigma$. It indicates how well the properties of wavelet function and the properties of the transient correlate to each other. Some considered wavelet function properties are time and frequency support, regularity, vanishing moment, orthogonality, and symmetry [8, 9]. The properties of wavelet function and transient are always correlated if their shapes are similar.

Shape similarity between a wavelet function and a transient can be observed on the symmetric pattern of wavelet coefficients around the transient's centroid, $t = t_c$[10]. This method is based on the argument that correlation function of two similar shape functions is always symmetric (even-symmetric).

Suppose $f(t)$ is a signal with only one transient at $t = t_c$ that has a shape similar to a wavelet function, $\psi_{s,}\sigma(t)$. The transient is compactly supported within a time support of $[t_c-t_s, t_c+t_s]$. The signal can be expressed as:

$$f(t) = \psi_{s,t_c}(t) = \frac{1}{\sqrt{s}} \psi\left(\frac{t-t_c}{s}\right) \quad (2)$$

The wavelet coefficient at $\sigma = t_c$ calculated using a wavelet function $\psi_{s,}\sigma$ is

$$Wf(s,t_c)=\int_{-\infty}^{+\infty} f(t)\frac{1}{\sqrt{s}}\psi\left(\frac{t-t_c}{s}\right)dt=\int_{-\infty}^{\infty} f(t)f(t)dt \tag{3}$$

The coefficients in the neighborhood of $\sigma = t_c$ are even-symmetric,

$$\int_{-\infty}^{+\infty} f(t)f(t-\tau)dt=\int_{-\infty}^{+\infty} f(t)f(t+\tau)dt \tag{4}$$

because the integration in (3) are for the whole duration of time and *f(t)* is compactly supported.

The above equations prove that wavelet coefficients in the neighborhood of $t=t_c$ are always even symmetric if the wavelet transform is calculated using a wavelet function that is similar in shape to the transient in the analyzed signal. In other words, symmetric pattern in wavelet coefficients around $t = t_c$, indicates the existence of a transient (such as T-wave) at $t = t_c$.

Symmetric Distance Coefficient

It is impossible to find a wavelet function that is similar to any transients in input signal. For example, there is no wavelet function with a shape similar to T-wave in any ECG signal. One can only find a wavelet function that is nearly similar. This wavelet function will produce nearly even-symmetric wavelet coefficients. Symmetric Distance Coefficient (SDC) was developed to measure symmetric pattern in wavelet coefficients in gradual levels. The parameter opens the possibility to measure shape similarity in gradual levels.

SDC is defined as the ratio of energy difference between left and right sides of a function around its center $t = t_c$ to the total energy of the function within the same time support of$t= [t_c-t_s, t_c+t_s]$.

$$SDC(t_c,t_s)=1-\frac{\int_{0}^{t_s}\left(f(t_c-\tau)-f(t_c+\tau)\right)^2 d\tau}{\int_{-t_s}^{t_s} f^2(t_c-\tau)d\tau} \tag{5}$$

The range of *SDC* is [*-1, 1*] with *1* represents even-symmetry, *-1* represents odd-symmetry, and the center point, *0*, represents asymmetry.

SDC is independent to input signal amplification. This property of SDC makes it able to detect the existence of weak and strong transients with the same level of accuracy. This advantage may create problem if the input signal contains unexpected small ripples.

To avoid measuring SDC of unwanted small transients, a threshold level, *th*, is added to the equation to ignore transients with energy less than the threshold level.

$$SDC_{th}(t_c,t_s,th)=\begin{cases} SDC(t_c,t_s) & if \int_{-t_s}^{t_s} f^2(t_c-\tau)d\tau > th \\ 0 & else \end{cases} \tag{6}$$

Figure 1 illustrates SDC of transient with various conditions of symmetry.

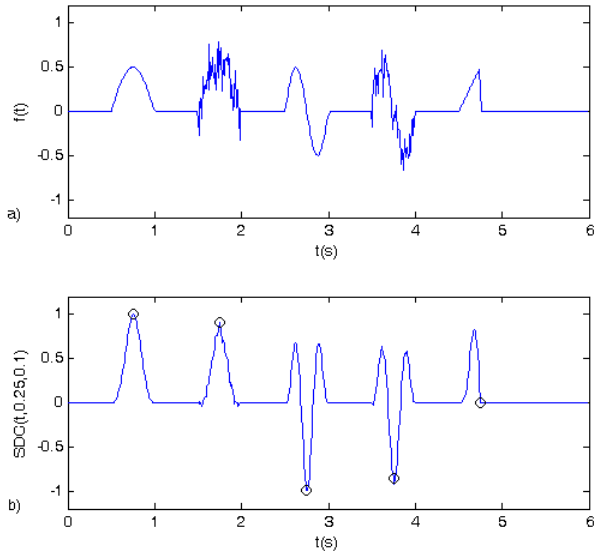


Figure 1. a) A signal with even-symmetric transient at $t=0.75$ s, nearly even-symmetric transient at $t=1.75$ s, odd-symmetric transient at $t=2.75$ s, nearly odd-symmetric transient at $t=3.75$ s, and an asymmetric transient at $t=4.75$ s. b) The $SDC_{th}(t,0.25,0.1)$ of the signal. The SDC of the transients are marked with 'o'.

Transient Identification using SDC

The procedures to identify the existence and time location of specific transient in a signal using SDC are as follows:

1. Select a wavelet function, $\psi_{s,}\sigma$, that has the most similar shape to the interested transient.
2. Apply WT to the signal, $f(t)$, using the selected wavelet function, $\psi_{s,}\sigma$, to the whole time duration of $f(t)$. The output of this process is wavelet coefficients $Wf(s,\sigma)$.
3. Calculate $SDC_{th}(t_c, t_s, th)$ of wavelet coefficient, $Wf(s,\sigma)$. The time support parameter, t_s, should be half of the selected wavelet function's time support or half of the interested transient's time support. Use an appropriate threshold, *th*, to ignore small ripples in wavelet coefficients.
4. Locate local maxima in $SDC_{th}(t_c, t_s, th)$. The local maxima indicate the time location of interested transients. The closer the value of $SDC_{th}(t_c, t_s, th)$ to *1*, the closer the shape of the transient to the selected wavelet function.

Experiment Results and Discussion

The procedures to identify transient using SDC were implemented in identifying the existence and time location of T-wave in ECG signals. The purpose of these experiments was to demonstrate the ability of SDC to identify T-wave. The ECG signal, downloaded from MIT-BIH PhysioBank database record *aami3a.dat* (AAMI-EC13) [11] was used for this experiment. The signal was re-sampled with a sampling rate of *360* Hz.

On the first step, an experiment was conducted to find the most suitable wavelet function for T-wave detection. Wavelet coefficients of the ECG signal were calculated using five wavelet functions (*Db2*,*Db3*, *Db4*, *Gaus2*, and *Mexh*) at scale 1 to 56. The selection of wavelet functions was based on their significant results when being used in the experiments. The SDC calculation was then applied to all wavelet coefficients. The SDC at the location of T-waves were recorded as shown in Fig. 2. The result showed that *Db2* wavelet at scale *28*,*29*, and *30* (shown in Fig. 3) were the most suitable for T-waves.

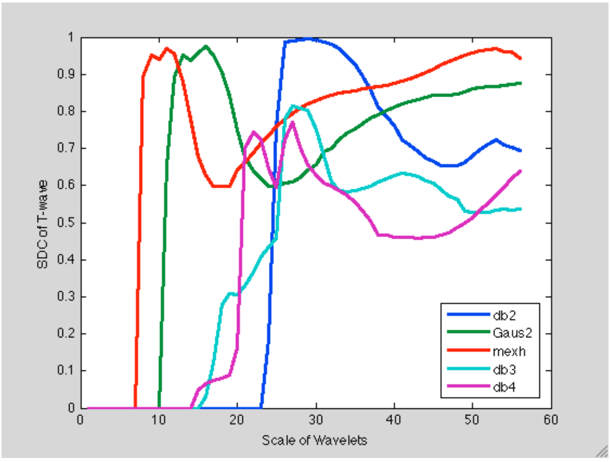


Figure 2. The *SDC* of T-waves calculated on wavelet coefficients using *Db2*,*Db3*, *Db4*, *Gaus2*, and *Mexh* at scale *1* to *56*. *Db2* at scale *28*, *29*, *30* gave the highest SDC.

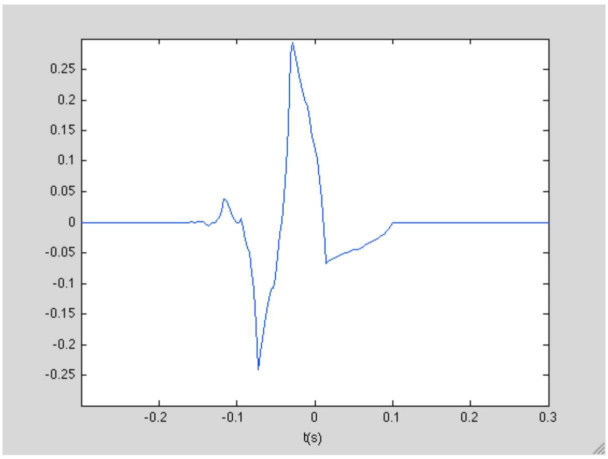


Figure 3. The Daubechies wavelet *Db2* at scale *28*.

The *Db2* wavelet functions at scale *28* to *31* were selected in the process to identify T-wave. The second step was to apply wavelet transform to the ECG signal. The *SDC(t,0.156,0.1)* calculation was then applied to the resulting wavelet coefficients of ECG signal as shown in Fig. 4a and b. The SDCs at the location of T-wave were close to *1*, which indicates the existence of T-wave. The local maxima in *SDC(t,0.156,0.1)* with amplitude of more than *0.85* were recorded as the location of

T-wave, as shown in Fig. 4c. The result suggested that SCD could be used to identify T-wave in ECG signal if the procedure was implemented using db2 wavelet at scale 28.

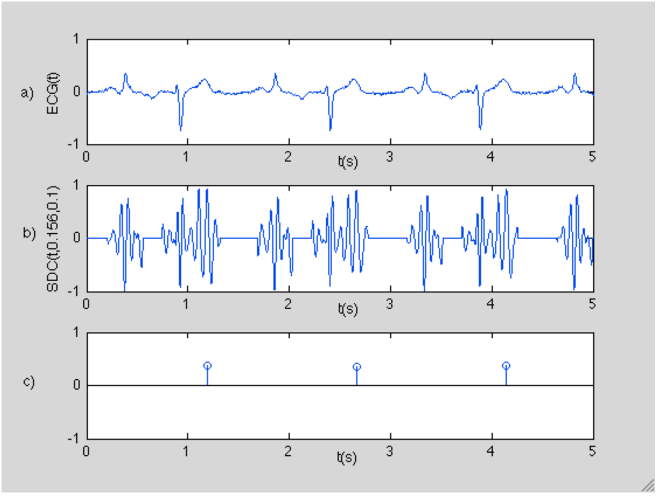


Figure 4. The SDC identification of T-wave using Daubechies wavelet *Db2* at scale*28*.

The same procedure was repeated using Daubechies wavelet *Db2* at scale *27*, *28*, *29*, *30*, and *31* to the whole duration of the ECG signal. The identification accuracy of the procedure was recorded as presented in Table 1. The table shows that SDC could identify T-wave when calculated using *Db2* at scale *28* with an accuracy of 100%.

Table 1. Identification Accuracy

Identification Method	T-wave in ECG	Correctly Identified (TP)	Incorrectly Identified (FP)	Incorrectly Rejected (FN)	Accuracy
SDC using Db2 scale 27	40	36	0	4	90.0%
SDC using Db2 scale 28	40	40	0	0	100%
SDC using Db2 scale 29	40	39	1	0	97.5%
SDC using Db2 scale 30	40	39	1	0	97.5%
SDC using Db2 scale 31	40	37	3	0	92.5%

To investigate the quality of the SDC identification procedure, time difference between the center of T-wave and the identified point were recorded. Table 2 presented the time difference of each identification method.

Table 2: Identification Time Accuracy

Identification Method	Average Time Difference (ms)	Maximum Time Difference (ms)
SDC using Db2 scale 27	4.3	7.9
SDC using Db2 scale 28	6.3	10.7
SDC using Db2 scale 29	8.1	41.1
SDC using Db2 scale 30	11.1	38.4
SDC using Db2 scale 31	11.8	38.4

The average time differences between SDC identification and the exact location of T-wave were between 4.3ms to 11.8ms. The average time difference of Db2 at scale 28 was 6.3ms or equivalent to *20.2%* of T-wave time support. The maximum time difference of Db2 at scale 28 was 10.7ms or equivalent to *34.3%* of T-wave time support. The results indicate the efficacy of SDC to identify T-wave in ECG signal.

Conclusion

This paper introduces a new parameter called *'symmetric distance coefficient'* (SDC) and the procedure to use SDC to identify transient in a signal. It is based on the fact that wavelet transform of a transient that has the same shape, as a wavelet function is always symmetric. The experiments reported in this paper demonstrate the ability of SDC to identify T-wave in ECG signals. SDC calculated using Db2 wavelet function at scale 28 could accurately identify all T-waves in the investigated ECG signal. The identification accuracies were ranging between 90% and 100%. The quality of SDC identification procedure was measured by the time shift of the identified points. The time shift is within an acceptable range of 6.3ms to 10.7ms. The whole procedure can also be used in the identification of other transients in ECG signals.

Reference

[1] Conover, M.B. (2003). *Understanding Electrocardiography* (8th ed.). St Louis, Mosby.

[2] Baas, T., Gravenhorst, F., Fischer, R., Khawaja, A., & O, D. (2010). Comparison of three T-Wave Delineation Algorithms based on Wavelet Filterbank, Correlation and PCA. *Computiers in Cardiology*, (37), 264–364.

[3] Sahambi, J.S., Tandon, S.N., & Bhatt, R.K.P. (1997). Using wavelet transfroms for ECG characterization. *IEEE Eng. Med. Biol. Mag.*, *16*(1), 77–83.

[4] Lin, C., Mailhes, C., & Tourneret, J. (2010). P- and T-Wave Delineation in ECG Signals Using a Bayesian Approach and a Partially Collapsed Gibbs Sampler. *2840 IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING*, *57*(12), 2840–2849.

[5] Wan, X. (2010). An ECG T Waves Detection Scheme Based on the Compensatory Criterion. In *3rd International Conference on Biomedical Engineering and Informatics (BMEI 2010)* (pp. 730–734).

[6] Zong, W., Saeed, M., Heldt, T., America, N., & Manor, B. (2006). A QT Interval Detection Algorithm Based on ECG Curve Length Transform Materials and methods. *Computers in Cardiology*, 377–380.

[7] Pah, N.D. (2010). Measuring Similarity between Wavelet Function and Transient in a Signal with Symmetric Distance Coefficient. In *Proceedings of the International Conference on Industrial and Applied Mathematics*. Bandung, Indonesia.

[8] Daubechies, I. (1992). *Ten Lectures on Wavelets*. Pennsylvania: SIAM.

[9] Mallat, S. (1999). *A Wavelet Tour of Signal Processing*. London: Academic Press.

[10] Abry, P., & Flandrin, P. (1994). Multiresolution Transient Detection. In *Proceedings of the IEEE-SP International Symposium on Time-Frequency and Time-Scale Analysis*.

[11] Goldberger, A.L., Amaral, L.A.N., Glass, L., Hausdorff, J.M., Ivanov, P.C., Mark, R.G., Stanley, H.E. (2000). PhysioBank, PhysioToolkit, and PhysioNet: Components of a New Research Recource for Complex Physiologic Sign. *Circulation*, *101*, e215–e220.