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ROC Analysis of PVC Detection Algorithm using ECG and Vector-ECG Charateristics

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Abstract**—**ECG analysis method was developed using ROC analysis of PVC detecting algorithm. ECG signal of MIT-BIH arrhythmia database was analyzed by MATLAB. First of all, the baseline was removed by median filter to preprocess the ECG signal. R peaks were detected for ECG analysis method, and normal VCG was extracted for VCG analysis method. Four PVC detecting algorithm was analyzed by ROC curve, which parameters are maximum amplitude of QRS complex, width of QRS complex, r-r interval and geometric mean of VCG. To set cut-off value of parameters, ROC curve was estimated by true-positive rate (sensitivity) and false-positive rate. sensitivity and false negative rate (specificity) of ROC curve calculated, and ECG was analyzed using cut-off value which was estimated from ROC curve. As a result, PVC detecting algorithm of VCG geometric mean have high availability, and PVC could be detected more accurately with amplitude and width of QRS complex.

Keywords**—**Vectorcardiogram (VCG), Premature Ventricular contraction (PVC), ROC (receiver operating characteristic) curve, ECG

I. Introduction

ELECTROCARDIOGRAM (ECG) can be monitored non-invasively for long periods of time and gives us effective information on the heart condition. Especially, arrhythmia would be diagnosed by ECG. One of frequent symptoms of arrhythmia was premature ventricular contraction (PVC). PVC is found from normal people, but if it occurs frequently, it would leads to be serious. Since the pattern and axis of PVC are different from normal ECG signals definitely, PVC could be distinguished by ECG and vector ECGROC curve was applied to evaluate PVC detecting algorithm, which is based on ECG and VGC. ROC was one of the methods to evaluate the reliability of diagnostic check.In the study, 4 types of the PVC detecting algorithms were evaluated, parameters of which are maximum amplitude of QRS complex, width of QRS complex, r-r interval and geometric mean of VCG.

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II. Experimental Methods

A. Preprocessing of ECG signals

34 signals of period of 5 minutes using Lead II were analyzed by MatLab, which were based on MIT-BIH arrhythmia database. First of all, the baseline was removed by median filter to eliminate the noise from respiration and movement. The R peak of ECG was detected by DSPD (decay slope peak detection), which is used to the peak from periodic signals frequently.

B. Vector-ECG

The output of Lead I was plotted along the x-axis and the output of ${}_{a}V_{F}$ was plotted along the y-axis to acquire frontal plane VCG from two-channel ECG of subjects. VCG was presented by 2 ECG signals in case of MIT-BIH database although 2 ECG signals meet at right angles. ECG sample before and after R peak was used in consecutive order.

C. Algorithm for detection arrhythmia using ECG and vector-ECG

1. Algorithm using peak amplitude of QRS complex

As the significant characteristic of arrhythmia was the high amplitude, the parameter was developed by using peak amplitude of QRS complex during one period. Above all, peak amplitude was calculated by using the minimum and maximum of one period. The difference between peak amplitude means of reference pattern and instant ECG was calculated. The parameter (diff_QRS) was suggested using difference between peak amplitude means of reference pattern and instant ECG to diagnose PVC (equation (1), (2)).

$$diff\_QRS_{ref} = Mean(Max(ch_{ref}) - Min(ch_{ref})) \tag{1}$$

$$diff\_QRS = (Max(ch) - Min(ch)) - diff\_QRS_{ref} \tag{2}$$

2. Algorithm using peak width of QRS complex

As another significant characteristic of arrhythmia was the wide width, another parameter was developed by using with of QRS complex during one period to detect arrhythmia. To calculate the QRS width of raw data, the slope was calculated by derivative. The derived value was raised to the second power to set positive, and the result of derivative was also raised to emphasize the high frequency components. The QRS value was stressed while P and T wave was removed from moving window average. One parameter (QRS_width) was developed by applying 5 samples to derivative, square and moving window average through equation (3), (4), and (5).

$$\mathrm{y(nT)} = \frac{\mathrm{2x(nT)+x(nT-T)-x(nT-3T)-2x(nT-4T)}}{8} \tag{3}$$

$$\mathrm{y(nT)} = [\mathrm{x(nT)}]^2 \tag{4}$$

$$y(nT) = \frac{1}{N}[x(nT-(N-1)T)+x(nT-(N-2)T+\cdots+x(nT)] \quad (5)$$

3. Algorithm of R-R interval

One of the significant characteristic of PVC, compensatory pause right after PVC was applied to RR interval algorithm. Once R peak was detected, the i^{th} R was defined as R(i). The parameter (RR_inter) is presented in equation (6).

$$I(i) = R(i) - R(i-1),\ I(i+1) = R(i+1) - R(i) \quad (6)$$

4. PVC detection algorithm using VCG geometric average difference

The comparison of reference VCG and instant VCG can be calculated from equation (7).

$$\text{diff\_VCG} = \sqrt{(ch1 - ch1_{ref})^2 + (ch2 - ch2_{ref})^2} \quad (7)$$

Sum of reference pattern VCG and instant VCG, Sum_diff (equation (8)), was compared with the value of integrating the instant vector difference, diff_VCG, to detect PVC in each ECG period

$$\text{Sum\_diff} = \sum_{n=1}^{z} \text{diff\_VCG}(n) \quad (8)$$

5. ROC analysis and evaluation of PVC detecting algorithm

The threshold of signals after preprocessing was estimated to determine PVC, and the reliability of the algorithm was evaluated using ROC curve (receiver operating characteristic curve).

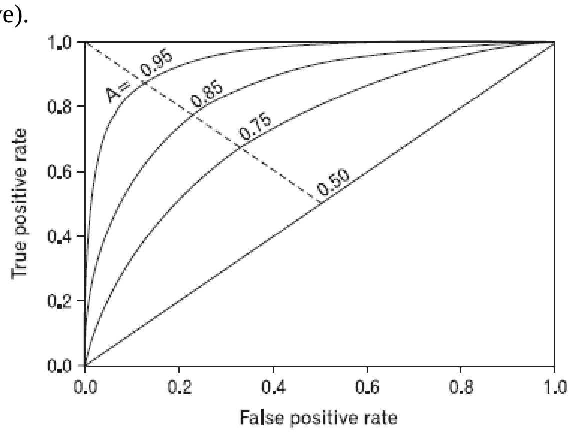


Fig. 1 The Receiver Operating Characteristic (ROC) graph

$$Detection\ rate = \frac{The\ numver\ of\ PVC-(FP+FN)}{The\ number\ of\ PVC} \quad (9)$$

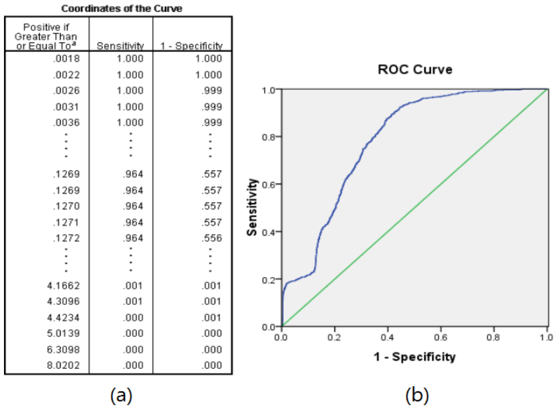
$$Sensitivity = \frac{TP}{TP+FN} \times 100 \quad (10)$$

$$Positive\ Predictivity = \frac{TP}{TP+FP} \times 100 \quad (11)$$

(TP : True Positive, FP : False Positive, FN : False Negative)

III. Experimental Results

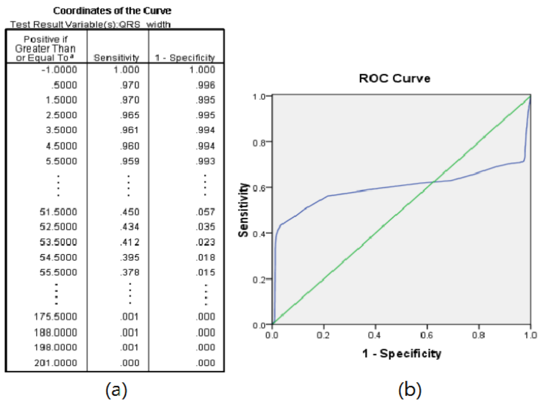
As the significant characteristic of arrhythmia was the high amplitude, the parameter was developed by using peak amplitude of QRS complex during one period. In the signal theory, a receiver operation characteristic curve, or simply ROC curve, is a graphical plot of sensitivity.In figure 2-5, how to change the sensitivity and specificity of 5-minute PVC data according to the threshold of each parameter was shown on the left, and ROC curves were shown on the right.



Coordinates of the Curve

Positive if Greater Than or Equal To[a]	Sensitivity	1 - Specificity
.0018	1.000	1.000
.0022	1.000	1.000
.0026	1.000	.999
.0031	1.000	.999
.0036	1.000	.999
⋮	⋮	⋮
.1269	.964	.557
.1269	.964	.557
.1270	.964	.557
.1271	.964	.557
.1272	.964	.556
⋮	⋮	⋮
4.1662	.001	.001
4.3096	.001	.001
4.4234	.000	.001
5.0139	.000	.000
6.3098	.000	.000
8.0202	.000	.000

Fig. 2 The ROC analysis of detection PVC using differences of QRS maximum magnitude: (a) The diff_QRS distribution according to the cut-off value, (b) ROC curve

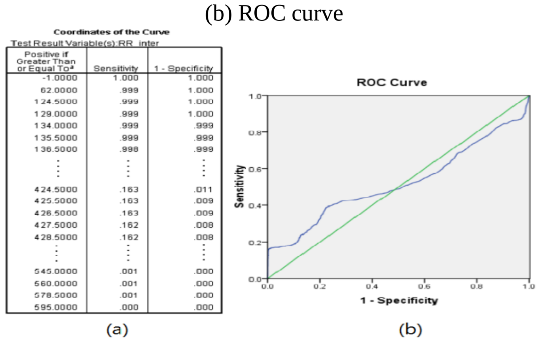


Coordinates of the Curve

Test Result Variable(s):QRS_width

Positive if Greater Than or Equal To[a]	Sensitivity	1 - Specificity
-1.0000	1.000	1.000
.5000	.970	.996
1.5000	.970	.995
2.5000	.965	.995
3.5000	.961	.994
4.5000	.960	.994
5.5000	.959	.993
⋮	⋮	⋮
51.5000	.450	.057
52.5000	.434	.035
53.5000	.412	.023
54.5000	.395	.018
55.5000	.378	.015
⋮	⋮	⋮
175.5000	.001	.000
188.0000	.001	.000
198.0000	.001	.000
201.0000	.000	.000

Fig. 3 The ROC analysis of detection PVC using differences of QRS width : (a) The QRS_width distribution according to the cut-off value, (b) ROC curve

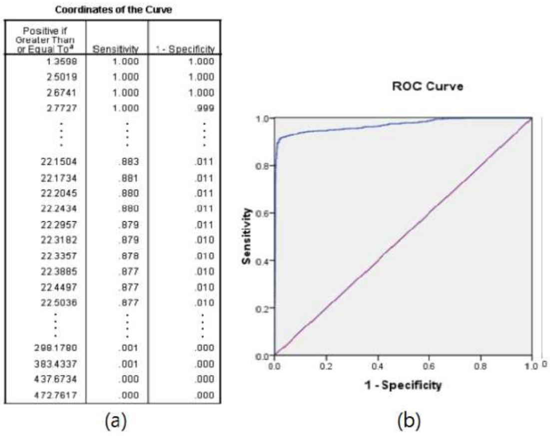


Coordinates of the Curve

Test Result Variable(s):RR_inter

Positive if Greater Than or Equal To[a]	Sensitivity	1 - Specificity
-1.0000	1.000	1.000
62.0000	.999	1.000
124.5000	.999	1.000
129.0000	.999	1.000
134.0000	.999	.999
135.5000	.999	.999
136.5000	.998	.999
⋮	⋮	⋮
424.5000	.163	.011
425.5000	.163	.009
426.5000	.163	.009
427.5000	.162	.008
428.5000	.162	.008
⋮	⋮	⋮
545.0000	.001	.000
560.0000	.001	.000
578.5000	.001	.000
595.0000	.000	.000

Fig. 4 The ROC analysis of detection PVC using differences of R-R interval : (a) The RR-inter distribution according to the cut-off value, (b) ROC curve



Coordinates of the Curve

Positive if Greater Than or Equal To[a]	Sensitivity	1 - Specificity
1.3598	1.000	1.000
2.5019	1.000	1.000
2.6741	1.000	1.000
2.7727	1.000	.999
⋮	⋮	⋮
22.1504	.883	.011
22.1734	.881	.011
22.2045	.880	.011
22.2434	.880	.011
22.2957	.879	.011
22.3182	.879	.010
22.3357	.878	.010
22.3885	.877	.010
22.4497	.877	.010
22.5036	.877	.010
⋮	⋮	⋮
298.1780	.001	.000
383.4337	.001	.000
437.6734	.000	.000
472.7617	.000	.000

Fig. 5 The ROC analysis of detection PVC using differences of geometric average : (a) The Sum_diff distribution according to the cut-off value, (b) ROC curve

To evaluate reliability of the PVC, the value of appropriate threshold was 22.32 in case of the algorithm using geometric mean through ROC analysis. The threshold was applied to the MIT-BIH PVC data. As a result, the total detection rate was 82.89%, and the sensitivity and specificity rates were 82.89% and 88.63% respectively. PVC detection rate was 90.53%, and the sensitivity was 99.52% in case of the algorithm using QRS width and amplitude.

IV. Conclusion

In the study, 4 types of the PVC detecting algorithms were developed, and ECG signal of MIT-BIH arrhythmia database was analyzed for evaluating the algorithm. The appropriate thresholds were set from ROC analysis to make the results more accurate.

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References

[1] J. Chee, R. Acharya U, K. Er, W. Tan and C. Kuang Chua, "Visualization of cardiac health using vector cardiogram", *IRBM*, vol.29, no.4, pp.245-254, 2008.

[2] A. Redz, "Presentation and Analysis of Vector Electrocardiograms", *Department of Numerical Analysis and Computer Science, Royal Institute of Technology*, Sweden, 1998.

[3] A. Shvilkin, B. Bojovic, B. Vajdic, I. Gussak, K.K. Ho, P. Zimetbaum and M.E. Josephson, "Vectorcardiographic and electrocardiographic criteria to distinguish new and old left bundle branch block.", *Heart Rhythm*, vol. 7, no. 8, pp. 1085-1092, 2010.

[4] Jekova and V. Krasteva, *"Fast Algorithm for Vectorcardiogram and Interbeat Intervals Analysis: Application for Premature Ventricular Contractions Cloassification."*, Bioautomation, vol.3, pp.82-93, 2005.

[5] R. Lazzara, "Spatial vectorcardiogram to predict risk for sudden arrhythmic death: phoenix risen from the ashes.", *Heart Rhythm.*, vol.7, no.11, pp.1606-1613, 2010.

[6] M. Ghasemi, A. Jalali, H. SadAbadi, M. Atarod, H. Golbayani, P. Ghorbanian and A. Ghaffari, "Electrocardiographic imaging of myocardial infarction using heart vector analysis.", *Computers in Cardiology*, vol.34, pp.625-628, 2007.

[7] G. T. Kang, K. T. Park, G. R. Kim, B. C. Choi and D. K. Jung, "Real time gait analysis using acceleration signal.", *J. of the Korean Sensors Society*, vol.18, no.6, pp. 449-455, 2009.

[8] A. R. Pérez Riera, A. H. Uchida, C. F. Filho, A. Meneghini, C. Ferreira , E. Schapacknik, S. Dubner and P. Moffa, "Significance of vectorcardiogram in the cardiological diagnosis of the 21st century.", *Clin. Cardiology*, vol.30, no.7, pp.319-323, 2007.

[9] J. K. Kim, D. H. Kang and M. H. Lee, "An Adaptive Classification Algorithm of Premature Ventricular Beat With Optimization of Wavelet Parameterization", *J. Biomed. Eng*., vol.30, pp.294-305, 2009.

[10] H. K. Jeon, I. S. Cho and, H. S. Kwon, "The Detection of PVC based Rhythm Analysis and Beat Matching", *KIMICS*, vol.13, no.11, pp.2391-2398, 2009.

[11] I. S. Cho and H. S. Kwon, "R Wave Detection Algorithm Based Adaptive Variable Threshold and Window for PVC Classification", *KICS*, vol.34, no.11, pp.1289-1295, 2009.

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