



Sürekli Dalgacık Dönüşümü Tabanında QT Zaman Aralığı Tespiti Yapabilen Yeni Bir Tam Otomatik Metot

A Fully Automatic Novel Method to Determine QT Interval Based on Continuous Wavelet Transform

Abdurrahman YILMAZ¹, Mehmet İŞCAN¹, Cüneyt YILMAZ¹
¹Mekatronik Mühendisliği Bölümü, Yıldız Teknik Üniversitesi, İstanbul, Türkiye
{abyilmaz,miscan,cuneyt}@yildiz.edu.tr

Özetçe—Günümüzde bilgisayar tabanlı otomatik tanı programları özellikle kalp hastalıklarının tespitinde sıklıkla kullanılmaktadır. Bu çalışma kapsamında, sürekli dalgacık dönüşümü tabanında tam otomatik çalışabilen ve QT zaman aralığı tespiti yapabilen yeni bir algoritma geliştirilmiştir. Bu bağlamda, kalbin depolarizasyonun başlangıcını ve gevşemesinin son noktasını yüksek hassasiyetle bulunması gerçekleştirilmiştir. Özellikle T dalgasının sonunun tespiti elektrokardiyogram sinyallerindeki en zor işlemlerden biridir. QRS kompleksinin başlangıcının tespiti ve T dalgasının sonunun bulunması için geliştirilen metot kullanılmıştır. Sunulan algoritma QT veri tabanı verileri üzerinde işaretlenmiş olan MIT-BIH-NSR veri tabanına ait kayıtlar üzerinde denenmiş, gümüş standartta 15.17 milisaniye ve 17.19 karekök ortalama, altın standartta ise 19.22 milisaniye ve 20.22 karekök ortalama hata ile işlemlerini gerçekleştirebilmiştir. Sonuç olarak, önerilen algoritma değişen EKG formlarında yüksek performansla çalışabilen yeni bir metot olarak sunulabilmektedir.

Anahtar Kelimeler — EKG sinyali, QT zaman aralığı, Sürekli Dalgacık Dönüşümü, EKG sinyali sınıflama

Abstract—Nowadays, computer-aided recognition programs is being frequently utilized to diagnose cardiac abnormalities. In this study, a fully automatic novel method based on continuous wavelet transform (CWT) was developed for determination of QT interval in various ECG signals. Especially, the determination of T-wave end is the most difficult problem. Developed method was performed to find the beginning of QRS complexes and the end of T-wave. The proposed algorithm was tested on MIT-BIH-NSR database signed by QT database, then, the algorithm had scores 15.17 milliseconds and 17.19 root-mean-square error at silver standard, 19.22 milliseconds and 20.22 root-mean-square error at gold standard, respectively. In conclusion,

the proposed algorithm is a fully automatic method to attain high performance in various ECG patterns.

Keywords—ECG Signal, QT interval, ECG signal classification, Continuous Wavelet Transform

I. INTRODUCTION

QT interval is defined as duration between the beginning of the depolarization and the end of the repolarization in heart ventricles. There is a strong relationship between QT interval and several heart diseases, in which it is utilized to diagnose some of the abnormalities [1]. However, the performance of the manual QT measurement is reduced because of long records, fatigue in reading, individual evaluation and ECG device feature [2]. Therefore, automatic algorithms have been developed to determine the beginning of the QRS complex and the end of the T-wave.

Numerical methods based on derivative feature were performed to measure QT interval [1,3]. Despite of reduction in calculation cost, the performance of QT measurement are affected by T wave amplitude, isoelectric baseline changes, and false detection. Also, the T-wave slope and isoelectric level are required to be applied these algorithms. Additionally, intra-beat variation reduces to find boundary points in ECG pattern.

Some of the methods related to formulation of ECG patterns were established to analyze the start and end points of ECG waves [4, 5]. Although, these algorithms can be effectively applied to classify basic waves such as QRS and T, they had a poor score for the determination of boundary points in non-deterministic ECG signal.



Sinyal İşleme 2

1. Gün / 27 Ekim 2016, Perşembe

In order to process non-deterministic ECG signals, neural network applications were developed [6-8]. Neural networks can be efficiently achieved to measure QT interval regardless of frequency characteristic of ECG, after training the neural network. However, this process requires too long training data, and is not automated method.

Some methods to be independent of ECG level were implemented in frequency domain [9]. It is noteworthy that measurement performance decreases with significant waveforms removed even the algorithms are fully-automated. On the other hand, these algorithms cannot be achieved to apply on the signal obtained by different channels of ECG because T wave and QRS complexes orientations change.

Due to all reasons explained above, in this study, a novel full-automatic algorithm based on continuous wavelet transform (CWT) was proposed to recognize the beginning of depolarization and the end of repolarization in heart ventricle. In the presented algorithm, the ECG signals were preprocessed by filtering and flattening. Then, the ECG boundaries are marked by using CWT. The algorithm performance was evaluated in terms of gold standard and silver standard which are comparison with manual annotation and comparison of standard automatic algorithms, respectively.

II. METHOD

In this study, the QT interval computed for each beat, and the results were compared with the annotations. Primarily, for this purpose evaluated ECG record was filtered by using band-pass finite impulse response (FIR) filter with the corner frequency 0.5 and 40 Hz. Coiflet 1 type CWT was applied to filtered record and the resulting signal was used for locating the R peaks and T-wave end points. Since the amplitude of signal obtained after CWT analysis is high in the vicinity of R peaks, the first decision making in Fig. 1 was used to keep only high amplitude signal parts. Kept parts where the peaks are high amplitude were examined by the second decision mechanism in Fig 1 and ± 160 ms (R scan range) in the presence of the largest amplitude peaks were determined as R peak.

In order to catch the moment when the signal reach its isoelectric level, 8 ms back of minimum or maximum point at left side of R peaks according to its direction was marked as QRS complex start points, the starting point of the QT interval. RR interval values mentioned in Fig. 2 were achieved by calculating the times between consecutive R peaks. In order to detect T-wave peaks, the time half of RR interval after QRS complex was scanned and both the highest and lowest points were marked. By using decision mechanism seen in Fig. 2, with underlying area calculation the T-wave peak direction (positive or negative) was determined and ultimately, max or min point marked before was selected as T-wave peak point. Since the amplitude of the signal obtained after CWT analysis is

low around T-wave peaks, high amplitude parts of the signal were set to zero by means of decision mechanism in Fig. 3. After that by normalizing the rest of the signal the amplitudes around T-wave based peaks were amplified. In Fig. 3 the region called CAR starts from one fifth of RR interval left side of R peak and ends at T-wave peak for each beat. After CAR regions were also cleared, the rest of the signal peaks were used to determine T-wave end locations. T-wave end points were marked with respect to last decision mechanism in Fig. 3 and then QT interval values for both our algorithm and annotations were calculated. In score calculation part seen in Fig. 4, mean squared error (MSE) calculation has been executed based on previously calculated QT interval mean error for each ECG record.

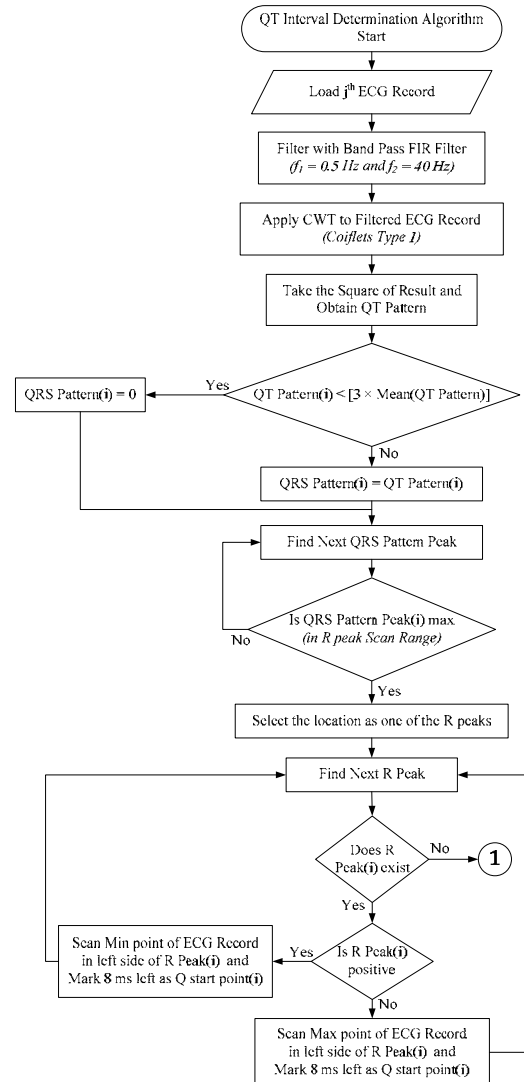


Figure 1. QT interval algorithm Q start location determination part

Sinyal İşleme 2

1. Gün / 27 Ekim 2016, Perşembe

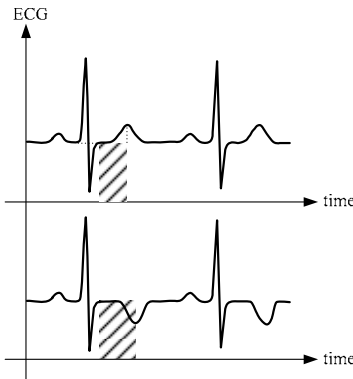


Figure 2: Positive or Negative T Peak Determination

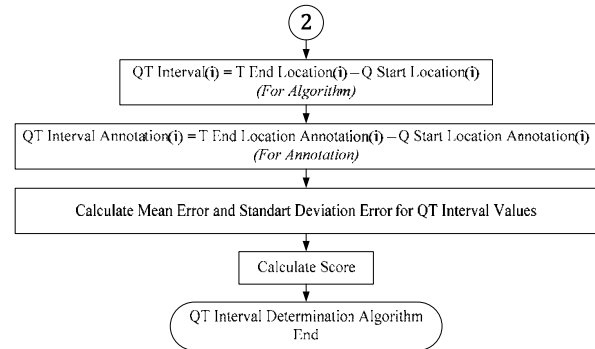


Figure 4: QT interval algorithm annotation and algorithm results comparison part

III. EXPERIMENT

The experiment were performed by using MIT-DB-NSR and MIT-BIH Long-Term ECG signal records in QT-database[10]. In MIT-DB-NSR and MIT-BIH Long-Term ECG database, there are fifteen records annotated by experts and standard automatic algorithms. All records are sampled at 250 Hz, and are normalized to remove changes of amplitude level in ECG.

Manual annotations were applied on representative beats in all records. Automatic annotations for waveform onset and offset were provided by using differentiated threshold method in ECGPUWAVE [11]. Manual annotations contain 441 beats to evaluate representative beats of ECG records.

When applying the experiments, the proposed algorithm had the following scores illustrated at table 1.

	Automatic	Manual
Mean Error	15.17 ms	19.22 ms
RMS Error	17.19 ms	20.22 ms

Table 1. Test Results

Table 1 shows manual and automatic measurement errors in experiment. According to these results, automatic test had better score than manual test since automatic annotation is only obtained from standard algorithms leading to same errors.. Also, automatic test was performed on all ECG records including broken patterns by using ECGPUWAVE method which its performance can be challengeable. These results are deeply discussed in next section.

IV. DISCUSSION

In this study, a novel fully automated method was proposed to analyze QT interval in ECG signal. The algorithm achieved QRS complex recognition, finding T-wave peak and end point in all records. All ECG records were obtained by QT-database which was annotated by the experts and automatic algorithm. However, QT-database contains five different abnormalities group which was not included in this study.

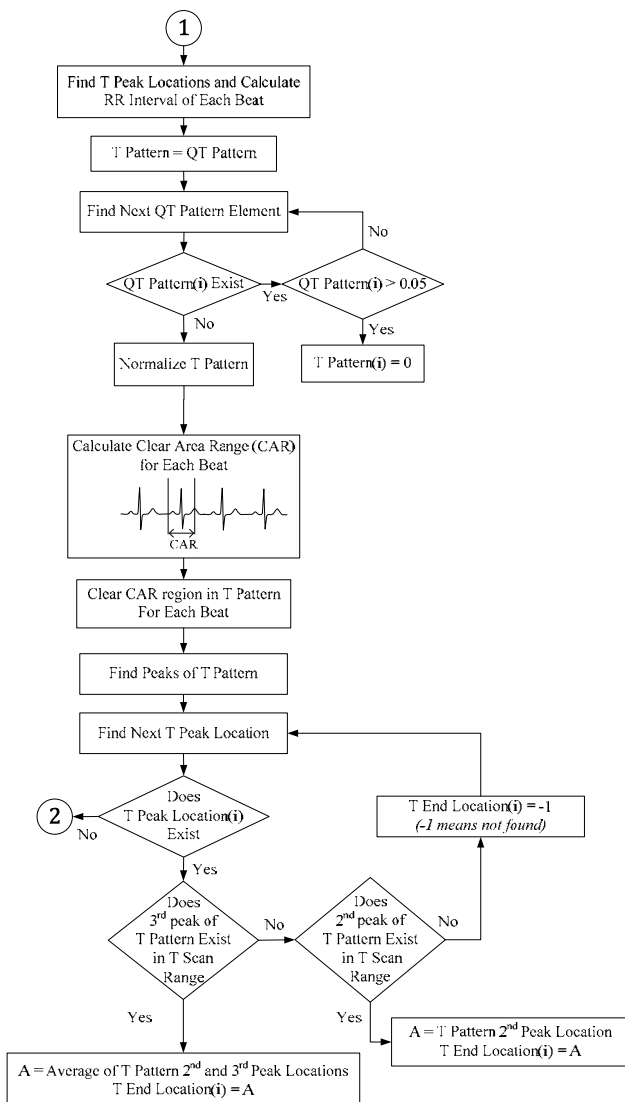


Figure 3: QT interval algorithm T end location determination part



Sinyal İşleme 2

1. Gün / 27 Ekim 2016, Perşembe

European ST-T Databases includes many different patients with myocardial infarction, cardiac artery diseases and hypertension causing ST elevation and rippling isoelectric baseline in ECG. Generally, V4-V5 channels of ECG were used to collect cardiac signal. Due to these reasons, CWT produced a lot of wrong results in test. There is no consensus where the T-wave peak are even in standard automatic algorithm. MIT-BIH Supraventricular arrhythmia database was sampled at different frequency, then, we cannot include the results of those. Records from Sudden Death patients in BIH database have different T wave morphology, positive negative T-wave. The proposed algorithm was only utilized at positive or negative T-wave morphology. Nevertheless, these databases results have poor results obtained by standard automatic annotation. Additionally, T-wave morphology is not easily discriminated even by observation. As the same way, MIT-BIH ST change database contains records with the high heart rate, so, the ripple in the signal is too high level. MIT-BIH Arrhythmia database was sampled at different frequency, and contained different T-wave morphology which our algorithm cannot be applied. Additionally, this databases consists of many premature ventricular contraction (PVC) record which means that RR interval mostly changes causing to impact on QT interval variation, and the proposed algorithm performance too.

On the other hand, the proposed algorithm does not require the determination of isoelectric level. The algorithm searches specific frequency energy which includes T-wave end. The algorithm is not affected by the amplitude level, but frequency changes. It discriminates T-wave positive or negative peaks in MIT-BIH-NSR and Long-term records. Additionally, decision mechanism related to finding T-wave positive-negative is mostly affected by Q points deflection because some of the changes such as ST-T elevation, PVC shift the level of Q points. Mostly, the other databases errors are caused because of that.

Generally, manual test had a poor score due to lack of representative beat selection. Additionally, automatic algorithm results may be improved by adding representative beat controls in classification performance.

V. CONCLUSION

In this study, a fully automated technique based on CWT was proposed to measure QT interval in various ECG signal patterns. Especially, marking T-wave end is the most difficult problem. In this study, CWT was firstly applied on the ECG signal to detect Q position, and then T-wave end location was obtained by the algorithm. The presented algorithm had achievements both at 15.17 ms mean error and 17.19 RMS error in automatic test and at 19.22 mean error and 20.22 RMS error in manual test.

The proposed algorithm does not need any training data, or manual intervention. Also, the presented algorithm is not influenced by isoelectric level changes and intra-beat

variation. However, it is only performed on positive or negative T-wave morphologies. Also, All QT-databases were not included in the test because of existence of different abnormalities and restriction on the present algorithm.

In the future work, RR interval changes and selective representative will be included to the presented algorithm. Additionally, six different T-wave morphologies will be examined to update the presented algorithm.

In conclusion, the results showed that the presented algorithm can be effectively used to attain high performance in determination of QT interval automatically.

REFERENCES

- [1] Zhang, Q., Manriquez, A. I., Médigue, C., Papelier, Y., & Sorine, M., "An algorithm for robust and efficient location of T-wave ends in electrocardiograms", *IEEE Transactions on Biomedical Engineering*, 53(12), 2544-2552, 2006.
- [2] Murray, A., McLaughlin, N. B., Bourke, J. P., Doig, J. C., Furniss, S. S., & Campbell, R. W., "Errors in manual measurement of QT intervals", *British Heart Journal*, 71(4), 386-390, 1994.
- [3] McLaughlin, N. B., Campbell, R. W. F., & Murray, A., "Accuracy of automatic QT measurement techniques". *Computers in Cardiology*, Proceedings. 863-866. IEEE, 1993.
- [4] Hayn, D., Kollmann, A., & Schreier, G., "Automated QT interval measurement from multilead ECG signals", *Computers in Cardiology*, 381-384, IEEE, 2006.
- [5] Clifford, G. D., & Villarroel, M. C., "Model-based determination of QT intervals", *Computers in Cardiology*, 357-360, IEEE, 2006.
- [6] Alexander A. Suarez Leon et al, "Neural Network Approach for T wave End Detection: A comparison of Architectures", *Comput. Cardiol.*, vol. 42, pp. 589-592, 2015.
- [7] Mehmet İscan; Cüneyt Yilmaz; Faruk Yiğit, " T-wave end pattern classification based on Gaussian mixture model", DOI: 10.1109/SIU.2016.7496149, Pages 1953 - 1956, 2016.
- [8] Mehmet İscan, Faruk Yiğit, Cüneyt Yilmaz, " Heartbeat Pattern Classification Algorithm Based on Gaussian Mixture Model", *Inter. Symp. on Med. Meas. and App.*, Italy, 2016.
- [9] Chesnokov, Y. C., Nerukh, D., & Glen, R. C., "Individually adaptable automatic QT detector". *Computers in Cardiology*, 337-340, IEEE, 2006.
- [10] Laguna P. R. G. Mark, Goldberger A., Moody G. B., "A database for evaluation of algorithms for measurement of QT and other waveform intervals in the ECG", *Comput. in Card.*, 1997.
- [11] Laguna, P., Jané, R., & Caminal, P., "Automatic detection of wave boundaries in multilead ECG signals: validation with the CSE database." *Computers And Biomedical Research*, 27(1), 45-60, 1994.