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T Wave Detection Based on Right Triangle Hypotenuse System

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Abstract: The T wave is the most important portion of the Electrocardiogram (ECG) since it detects abnormalities. Various ECG leads produce different T waves. In research, various waveform morphologies may present as an indication of benign or clinically significant injury or insult to the myocardium. The frequency of the QT interval and the shape of the electrocardiographic T-wave are both signs of abnormal ventricular repolarization, according to many scientific and clinical investigations. Furthermore, it is still unclear if T wave inversion has any clinical value in the ECG diagnosis of coronary artery disease (CAD). To obtain the accurate results of ECG of patients with CAD, this study aims to analyze the correlation using the right triangle hypotenuse for T wave detection. In this paper, we have proposed an algorithm for detecting T waves in ECG for all types of leads. We use the right triangle hypotenuse to determine T wave start and end points. Moreover, we determine the T wave upslope or downslope, as well as up or down peak value. An extensive experiment is performed on 53 datasets, including 18 databases from the MIT-BIH ST database and 35 databases from the European ST-T database with long duration, which exhibits a promising result.

Keywords: T wave, right triangle hypotenuse, electrocardiogram, cross correlation, T wave alternate detection.

基於直角三角形斜邊系統的T波檢測

摘要：T波是心電圖中最重要的部分，因為它可以檢測異常。不同的心電圖導聯會產生不同的T波。在研究中，各種波形形態可作為對心肌的良性或臨床顯著損傷或損害的指示。根據許多科學和臨床研究，QT間期的頻率和心電圖T波的形狀都是心室復極異常的跡象。此外，目前尚不清楚T波倒置在冠狀動脈疾病的心電圖診斷中是否具有任何臨床價值。為了獲得準確的冠狀動脈疾病患者心電圖結果，本研究旨在分析使用直角三角形斜邊檢測T波的相關性。在本文中，我們提出了一種用於檢測所有類型導聯心電圖T波的算法。我們使用直角三

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角形斜邊來確定T波的起點和終點。此外，我們確定了T波上升或下降斜率以及上升或下降峰值。對53個數據集進行了廣泛的實驗，其中包括麻省理工学院-波黑街數據庫中的18個數據庫和歐洲圣-T數據庫中的35個數據庫，持續時間長，顯示出有希望的結果。

关键词：T 波、直角三角形斜邊、心電圖、互相關、T 波交替檢測。

1. Introduction

T wave is essential in determining proper heart function and detecting ECG abnormalities. T wave anomalies are more commonly encountered in adult patients.

Different studies have focused on different types of T wave pattern on adult patients. T wave patterns may show gradual upstroke or rapid downstroke. Normally T wave upright in 4 leads which are I, II, V_2 and V_6. Negative T wave or inverted T wave finds in lead aVR. T wave pattern automatic changes in Lead III, aVL, aVF and I. Musculoskeletal chest pain is caused because of abnormal T wave inversion in lead III. T wave inversion is associated with ST segment elevation and depression, which is the pre-syndrome of myocardial ischemia [1]. The Support vector machine has been used for the simultaneous detection of P and T waves in [2]. The authors have used CSE (Common Standards for Electrocardiography) databases, MIT-BIH databases where every database contains 10s episode with 500Hz and 5000 samples. In [2] T waves contain various kinds of shapes with upslope and downslope in various leads. T wave has been estimated using the lead potential and SVD. It has been shown that downward slope curves take about 90-10% time approximately 100 msc. In other side repolarization time it had taken about 50 msc. QRST was also divided into two segments intervals. In paper [3] authors have focused on T wave morphology and its measuring process. T wave was measured using a surface density process with a parameter. In this paper, T wave location *r* was measured in time instance *t*. ECG T wave detection using Wireless Body Sensor (WBS) was performed in [4]. The authors monitored the ECG signal for 7 different leads. It has also provided an algorithm for detecting ECG T wave using WBS. ECG T wave has classified T wave into 2 main categories and one subcategory using seven supervised learning processes. Another work performed by Nada Vasic [5] has focused on ECG abnormalities after the surgery of lung. This paper has emphasized changes in ECG and finding the abnormalities after this type of surgery. Paper [6] focuses on a survey of 468 patients. Paper has compared the ECG signal with syncope type patient's ECG signal and has compared the QT signal with syncope patient. In [7] T wave alternates and QRSA complex alternates have been detected. Here main focused issue was detecting the T wave alternates and their significance in patients. The morphology of T waves using five categories those were T wave duration, amplitude, alternate nation, singular value decomposition and T wave loop morphology has been analyzed in [8]. T wave Alternate Detection (TWAD) algorithm has been developed in [9]. This TWAD article has focused on detecting T wave alternates based on 3rd order spline interpolation. TWAD was detected at different frequencies. The T wave peak detection process has also been developed based on the skewed Gaussian function in paper [10]. The authors have used physio Net QT and ST-T databases for validation purposes, where every database contains 15 min with 250Hz sampling. This article has detected only T wave peak value and T wave end points. In an article [11] T wave detection and alternation have been proposed based on wave variation. The authors have used the move average technique in [12]. P, QRS, and T wave patterns were detected on the basis of the wavelet transform system on a noisy ECG signal in 12 leads ECG in paper [13, 14]. A rule-based method for detecting Myocardial Ischemia Detection had been developed. In paper [17] focused on Support Vector Machine (SVM) Sparse Representation Classifier (SRC) for detecting T wave. For identifying the Myocardial Ischemia, it is important to detect the T wave and its pattern. Different types of ECG feature extraction techniques have also been developed. In [18] ECG feature extracts using a clustering method and T wave features have also detected. Other existing processes with T wave and its angle variation have been shown. In [8, 20] automatic detection of T wave and QRS complex alternan detection is also developed.

Fig. 1-3 show different ECG signals.

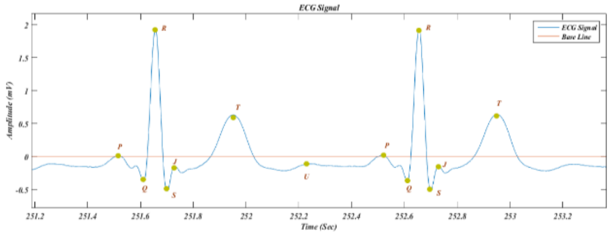


Fig. 1 ECG signal with P, QRS complex, T and U waves

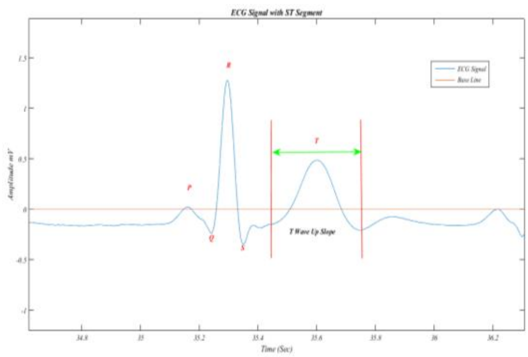


Fig. 2 ECG signal with T wave up slope

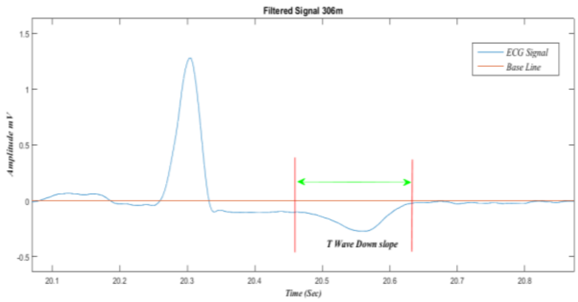


Fig. 3 ECG signal with T wave downslope

This paper uses a 106 ECG signal, classified based on smoker and non-smoker, male and woman. They tested a different ECG signal under different conditions, such as a stress test and so on. Before analysis, they also prepared the ECG signal. In an article [9] biomarkers based on T wave morphology have been proposed. In [10] T wave alternans detection in microvolt because of baseline wandering had also developed. This work also detected T wave alternan (TWA) beats, TWA segment, TWA segment length, TWA mean amplitude (mV) and TWA magnitude (mV). In an article [11] T wave peak detection and T wave end location detection had also developed. In this article, authors used a skewed Gaussian function and cross-correlation process. In [12] they detected the T waves and classified them into three categories. Those categories are Asymmetry, Notch and Flatness. According to results of T-wave alternative assessment showed that the least squares curve fitting (LSCF) is effective and promising in detecting and quantifying TWAs [13]. In another paper, we have proposed right triangle hypotenuse to determine T wave as well as up or down peak value. This research creates the possibility that precise T-wave detection might enhance MTWA quantization. For identifying T-waves, the fixed-window technique, the adjustable-window approach, and the triangular area approach were all tested. The ECG signals from the Physionet T-wave Alternans database were subjected to these techniques [27]. We have also figured out from another research that the Grid search technique and k-means clustering are used to determine the search limits and maximize the parameter values. The enhanced technique worked better, as shown by experiments conducted in the QT database and the European ST-T database [28]. The main contributions of this paper are

(a) We develop a new algorithm using right triangle hypotenuse for detecting T wave.

(b) We apply cross-correlation for detecting upslope or downslope in T wave

(c) Our proposed algorithm works well for long duration wave.

2. Materials and Methods

We have sketched out a rough outline of the proposed methodological architecture in Fig. 4.

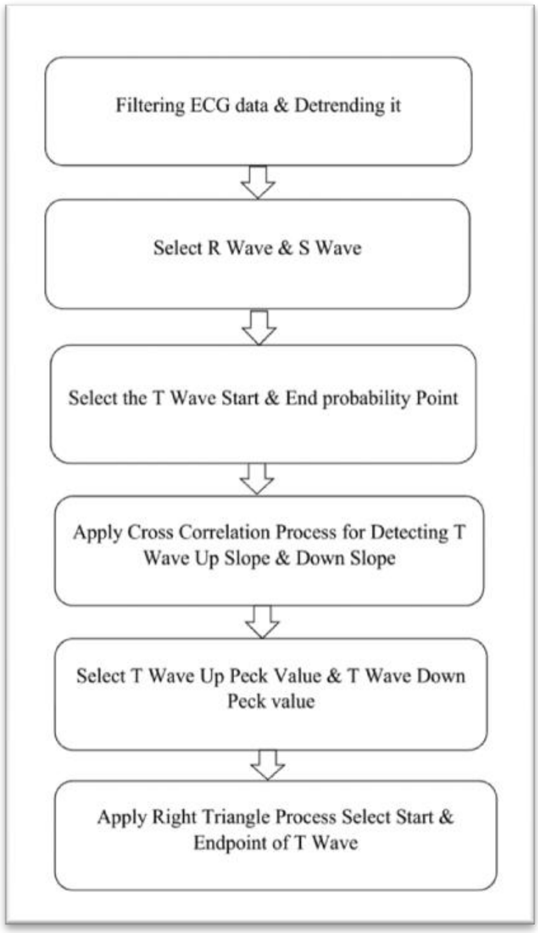


Fig. 4 T wave detection architecture

2.1. Data Pre-Processing

2.1.1. Filtering Data

As explained in [15, 20], there are numerous types of denoising approaches. We have used the MIT-BIH Data Base and the European ST-T Data Base, both of which have sampling frequencies of 350 and 250 Hz.

Various types of noise, such as trend ECG and pain signals are mostly present in the raw data. As a result, we must denoise it to accurately measure data and determine the peak value of ECG signals. As a result, in our proposed approach, denoising is required. We also employed a 100-order FIR band pass filter with a 0.05-45-Hz bandwidth and the Savitzky-Golay smoothing filtering approach [16]. Each ECG signal had at least one episode lasting 5 to 20 minute.

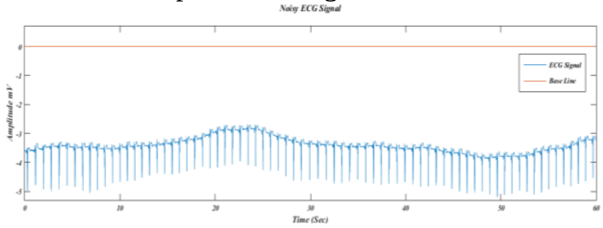


Fig. 5 ECG data with linear and non-linear trend

2.1.2. Detrending Data

It contained the trends after denoising the ECG signal with linear and nonlinear trends in every ECG signal. We use the polynomial equation (1) of degree n for detrending. The mean and standard deviation of the time series signal is then calculated. Fig. 5 and 6 depict the before and after detrending operations, respectively. We can easily recognize the base line after detrending.

$$P(x) = p_1x^n + p_2x^{n-1} + \ldots\ldots + p_nx + p_{n+1} \quad (1)$$

$$\hat{x} = (x - \mu 1)/\mu 2 \quad (2)$$

Here P_1, $P_{2\ldots\ldots}$ P_n are the coefficients of the polynomial, $\boldsymbol{x}$ is the independent variable of signal in time domain. μ_1 is the mean of x and μ_2 is standard deviation of x.

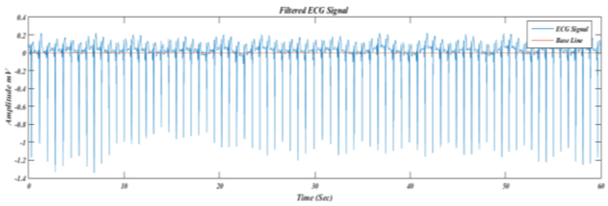


Fig. 6 ECG data after removing linear and non-linear trends

2.2. R Wave and S Wave Detection

For detecting R wave peak value, we use the following function:

$$f(d, h) = \{n, e(n) \text{ when } \Delta n \geq d \text{ and } e(n) \geq h \quad (3)$$

where *d* denotes minimum peak distance and *h* parameter denotes minimum peak height, is Δn the minimum peak distance after selecting the peak. For every ECG signal *n* is the time domain value and *e(n)* is the amplitude value at the time *n*. The above function – the primary R peak value described in [19], provides the local maxima in the minimum interval.

For detecting S wave peak value, we invert the ECG signal first and then find the local maxima using the following function.

$$f'\left(d', h'\right) = \{n, e'(n) \; when \; \Delta n \geq d' \; and \; e(n) \geq h' \ldots \quad (4)$$

where d' denotes minimum peak distance and h' parameter denotes the minimum peak height. Δn is the minimum peak interval after selecting the peak.

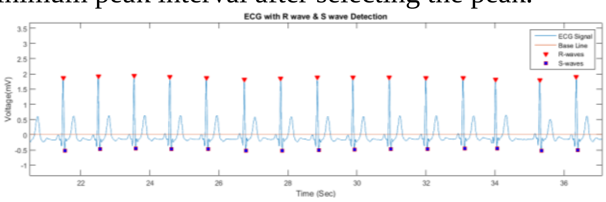


Fig. 7 R wave and S wave detection in ECG

We find the R wave and S wave peak values using functions (3) and (4). Fig. 7 shows R wave and S wave detection, where S wave is marked with "■" and R wave is marked with "▲."

2.3. Start and Endpoint Detection of ST Segment

The endpoint of the S wave and the start point of the T wave both define the ST segment [21].

2.3.1. J Point Detection

The J point marks the end and beginning of ventricular depolarization and repolarization. The J point denotes the start of the ST section. It may be detected using various R-R intervals, and it can also reveal a pattern of normalcy and abnormalities in the ST segment. On various leads, different J points can be found [22]. Based on another [23] study, we have applied R+X approach to find the J point.

For R-based we use,

$$\begin{Bmatrix} if \; \Delta R < 160 \; then \; x = 10 \\ if \; 160 \leq \Delta R < 180 \; then \;\; x = 12 \\ if \; 180 \leq \Delta R \leq 270 \; then \; x = 14 \\ if \; 271 < \Delta R \leq 390 \; then \; x = 16 \\ if \; \Delta R > 390 \; then \; x = 20 \end{Bmatrix} \quad (5)$$

For S-based we use,

$$\begin{Bmatrix} if \; \Delta S < 160 \; then \; x = 2 \\ if \; 160 \leq \Delta S \leq 180 \; then \; x = 8 \\ if \; 180 \leq \Delta S \leq 270 \; then \; x = 6 \\ if \; 271 < \Delta S \leq 360 \; then \; x = 8 \\ if \; \Delta S > 360 \; then \; x = 10 \end{Bmatrix} \quad (6)$$

Here ΔR is the difference between *R-R*,ΔS is the difference between *S-S* and *x* is the sampling value after detecting *R and S* waves for every interval that provides the starting point of the ST segment or *J* point.

Sometimes some leads contain less magnitude of the R peak. According to this study [24], they contain dissimilar R peak value. In these cases, miss of R wave, for example *Lead V1*, we use S wave and then apply the above method.

2.3.2. ST Segment Endpoint Detection

The start of the T wave is the endpoint of the ST section. The angle between the start of the ST segment and the T wave peak value is calculated.

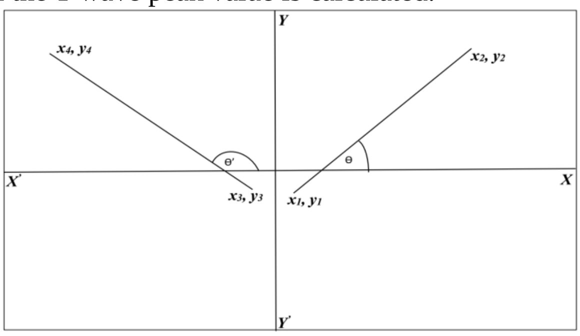


Fig. 8 Straight line angle in two-dimensional space

$$\tan\theta = \frac{y_2-y_1}{x_2-x_1} \Rightarrow \theta = \tan^{-1}\frac{y_2-y_1}{x_2-x_1} \quad (7)$$

We calculate the angle using equation (7) where x_1 y_1 is the starting point and x_2, y_2 is the endpoint.

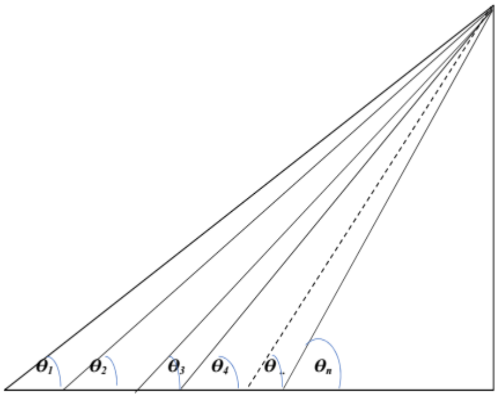


Fig. 9 Right triangle with different hypotenuse

From the angle value (Fig. 9), $\Theta_1 < \Theta_2 < \Theta_3 < \Theta_4 < \Theta_k < \Theta_n$ means when the angle goes closer to perpendicular it increases. We applied the above process for detecting T wave start point.

From the angle value, we calculate the maximum angle, and then select the start point of the T wave.

2.4. T Wave Detection

Different kinds of leads contain different kinds of T waves. Most of them are up slope, some of them are down the slope. Sometimes some leads contain flat or horizontal type T wave.

2.4.1. Probability of T Wave Start Point

The probability of T-wave means that J points to the main T wave start point. Those points we call T wave false start points. We detect the T wave false start point using formula (5) and (6).

2.4.2. Probability of T Wave End Point

If we select R-R or S-S interval, this dividing R-R or S-S interval is called beat difference. This beat difference is denoted as σ and to find the probability of T wave false end point, we use the formula (8). Fig. 10 indicates the probability of start and end points of T wave.

$$R + \sigma/2 \quad (8)$$

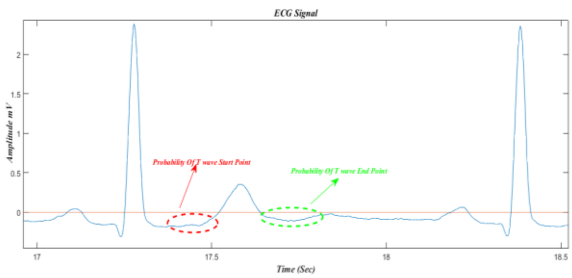


Fig. 10 Probability of T wave start and end points

2.4.3. Upslope and Downslope T Wave Detection

After detecting the T wave false start point and false end point, we select this segment for further process. If we select this T wave segment, we will not specify it upslope or downslope. To identify this T wave segment as upslope or downslope we apply cross correlation process with this selected segment to known T wave upslope and downslope databases. Similar types of T waves, such as upslope T wave segment cross-correlation with the upslope segment or downslope segment of T wave cross-correlated with the downslope segment, return positive values between 0 and 1. However, different types of T waves, such as upslope T wave segment cross correlation with downslope segments return negative values between 0 and -1. Applying this above process, we detect T wave types that are upslope or downsloped (Fig. 11–13).

Let us assume cross correlated values set *C*. If the maximum number of values of *C* is between 0 and 1 as $0<C<1$ then it is the same type. If the maximum number of values of *C* is between 0 and -1 as $-1<C<0$ then it is the different type.

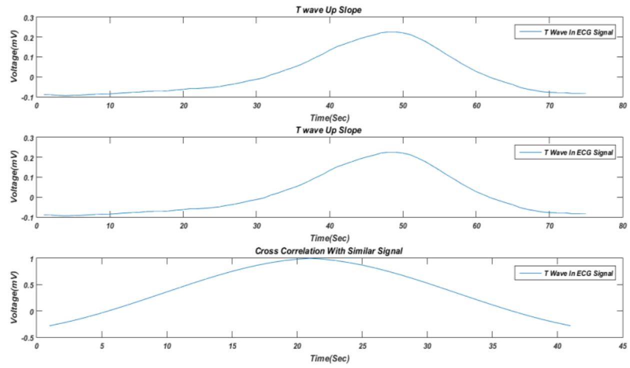


Fig. 11 Cross correlation with similar signal

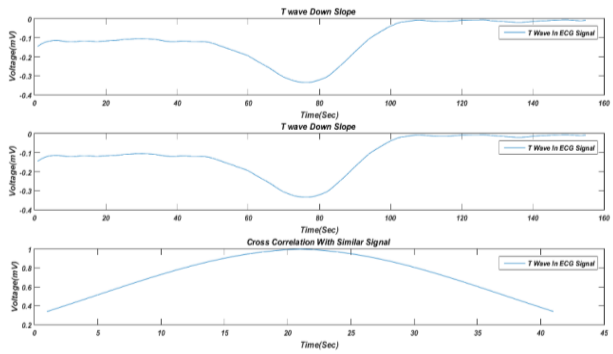


Fig. 12 Cross correlation with similar signal

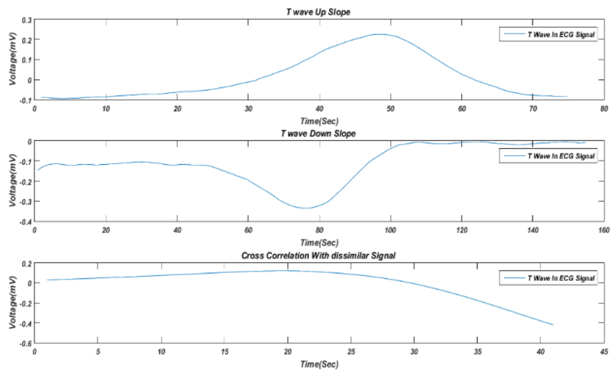


Fig. 13 Cross correlation with dissimilar signal

2.4.4. T Wave Upper Peak Value and Lower Peak Value Detection

After detecting T wave upslope or downslope type, we select the upper peak value for upslope and minimum lower peak value for downslope T wave.

The upper peak value detects from upslope T maximum value of the wave, and the lower peak value detects from minimum T wave value. If the T wave value is set peak value will be the maximum value from the T set for the upslope T wave (Fig. 14). However, lower peak value will be a minimum value from the T set for the downslope T wave (Fig. 15).

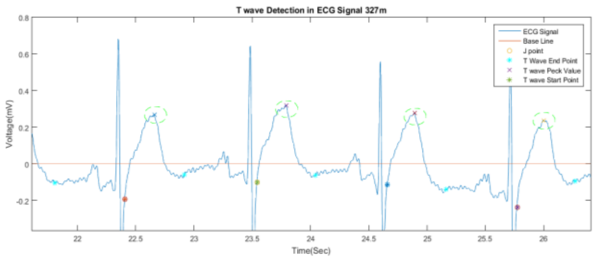


Fig. 14 T wave upper peak point detecting

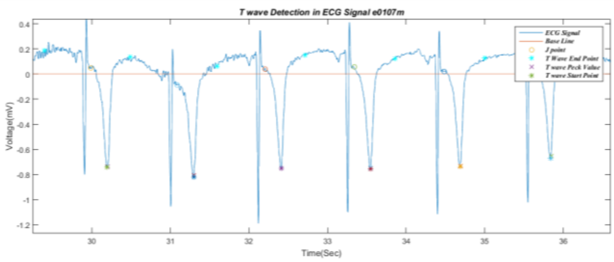


Fig. 15 T wave lower peak point detecting

2.4.5. T Wave Main Start Point and End Point Detection

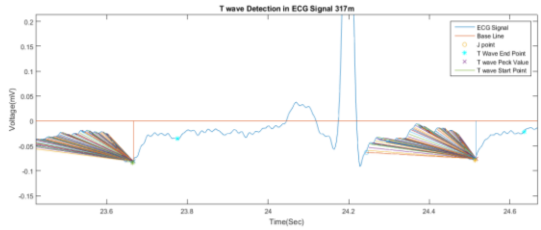
The T wave start point refers to the exact place on the T wave where it begins, whereas the T wave end point refers to the exact location on the T wave where it concluded, whether it was at the higher or lower peak value.

We discovered the following items in the preceding part:

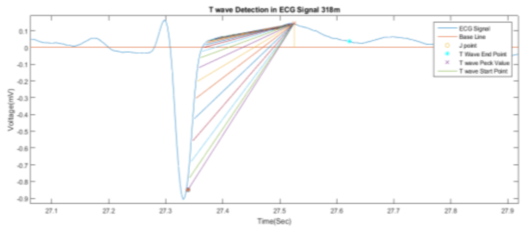
– T wave false start points
– T wave false end points
– T wave upper peak values
– T wave lower peak value

For T wave upslope start and end point detection, we have used formula (7). Using this formula, we have drawn lines from T wave false start points to T wave upper peak value or lower peak value if it is upslope or downslope, we calculate the angle for every line. For every line angle according to horizontal, it changes every time. At every point, angle value from the T wave false start point to the upper or lower peak point we take the highest angle. This highest angle point is the T wave actual start point (Fig. 16).

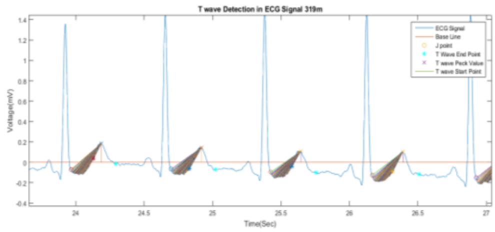
Simultaneously, we again apply this same process for detecting T wave actual end point.



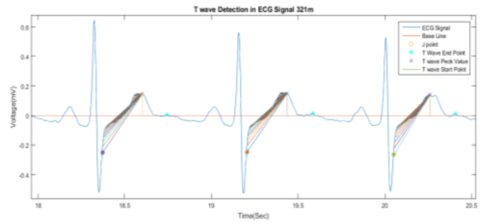
a)



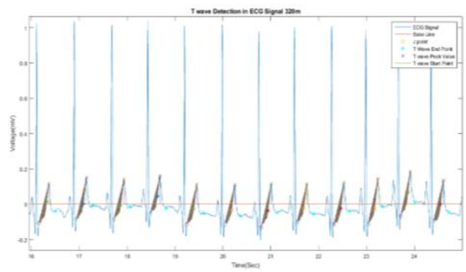
b)



c)



d)



e)

Fig. 16 T wave start point detecting process (a, b, c, d, e)

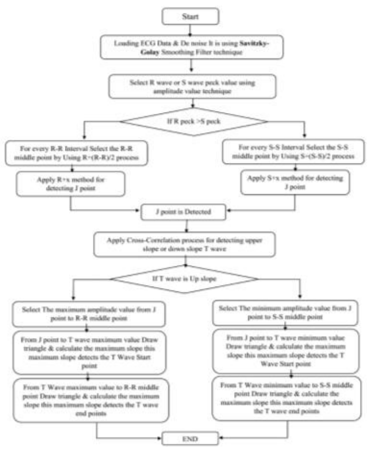


Fig. 17 Flowchart of T wave detection

```
Input:  ECGSignal From MIT-BIH ST Change Database and European ST-T Database
Output: TWaveStartPoint, TWaveEndPoint, TWavePeakValue(UpperOrLower),
        TWavePatternFindOut(UpslopeOrDownslope)
Start
Load ECG Data
Detect R wave, S wave using amplitude value and minimum distance returning R wave and S wave array lis
for array List Start to End-1 do
    for each RR interval do
        Divide RR value length by 2
        Selecting ST segment Start point using R+x method
        Detect T wave pattern Up Slope or down Slope
        if T wave==Upslope then
            Select maximum peak and Drawing Street line ST segment Start Point To T wave maximum Peak
              value
            Find the maximum Sloping value and Selecting this value as T Wave Start point
            Drawing Street Line from T wave maximum value To RR/2 value
            Find the maximum Sloping value and Selecting this value as T Wave Endpoint
        end
        if T wave==Downslope then
            Select minimum peak and Drawing Street line ST segment Start Point to T wave minimum Peak
              value
            Find the maximum Sloping value and Selecting this value as T Wave Start point
            Drawing Street Line from T wave minimum value To RR/2 value
            Find the maximum Sloping value and Selecting this value as T Wave Endpoint
        end
    end
end
End
```

Fig. 18 T wave detection algorithm

3. Results and Discussion

The T wave on an electrocardiogram (ECG) usually represents ventricular repolarization. From a study, the proposed strategy has been validated on a much more conventional QT-database with accuracy of 96.66%. In this process of detecting T-wave, they used two filters for preprocessing naming two-stage median filter and a Savitzky–Golay smoothing filter, resulting in elimination of P-QRS complex and amplification of the visibility of T-wave. But in this method, the data amount was limited [25]. By another research finding, the variable benign or pathologic myocardial states can cause changes in the T wave shape [30]. But in our proposed method, we have applied an algorithm based on right triangles hypotenuse and used a huge amount of raw data for preprocessing our strategy to extract those ECG features. Then, after detecting the S and R peck values through the peck detection process, we searched for T-wave starting and ending probability points. Then, using and applying the cross-correlation process for detecting T-wave's up or downslope, we detected upper peak or lower peak values accordingly. Finding the start end probability point and T wave final value, we applied the right triangle hypotenuse system to find the actual T wave start and end points. Firstly, we apply a data preprocessing process, which is more important for extracting ECG features. Then we have applied peck detection process to detect the S or R peck value using (3) and (4) equations. After selecting R and S peak values, we searched for T wave start probability points and end probability points using equation (5). Here, Equation (6) was used for detection T of the final start point of the wave and (7) was used for final end point detection. Then we apply the cross-correlation process to detect upslope or downslope T wave. If we find an upslope T wave, then we detect the upper peak value. If it is down slop T wave, then we detect the lower peak value. After finding the start and end probability points and T wave peak value we apply the right triangle hypotenuse system to find the actual T wave start and end points.

Moreover, our proposed method focuses on T wave detection in ECG signal. For detecting T wave, we have processed our algorithm on MIT-BIH ST data based a European ST-T change database. Applying our method, we constructed Table 1 by applying the proposed algorithm.

By applying all the process, if Tables 1 and 2 have been observed, then it can be shown that we use 5 to 25-minute length ECG data. Most of the time, our proposed algorithm gives better result (Table 1). Different types of ECG signals give different types of results. It occurs because of abnormal or highly noise ECG signals from ECG records such as 305 m, 321 m, e0415. Fig. 19(a)-(d) confirm our expected result in every figure, T wave start and end peak values are clearly detected, and it exhibits better results in comparison with existing methods for all types of amplitude values and alternates. Right triangle hypotenuse method for detecting T-waves provides much clearer detection of T-waves.

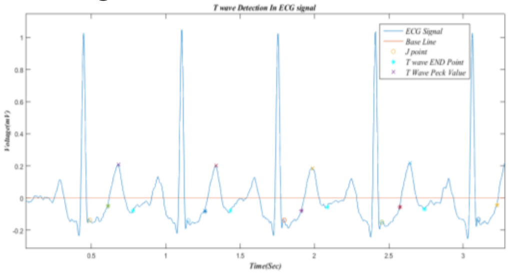
From another study, the proposed method used the ST segment to lead the ECG signal and classified it by using cross correlation [26]. Though the method achieved good accuracy while detecting the T-wave, they classified the ECG signal by using cross correlation. But in our process, we applied a cross-correlation process for detecting T-wave's up or downslope and detected upper peak or lower peak values accordingly. To determine the start end probability point and T wave peal value, we applied the right triangle hypotenuse system to find the actual T wave start and end points. In this way, we found much better detection of T-wave from the ECG signals. Our proposed method has achieved 90.015% of accuracy with having balanced with modern and updated databases compared to the method explained in this approach. Unlike those study methods, our approach yielded a massive amount of data [25, 26]. Based on this, we can guarantee that the output detection rate and accuracy will be executed successfully and satisfactorily using our process.

For finding accuracy of the proposed method we use the formula for detection of confusion matrix accuracy given below.

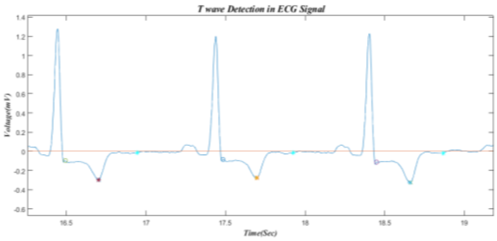
$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (9)$$

$$Error\ Rate = \frac{FP+FN}{TP+TN+FP+FN} \quad (10)$$

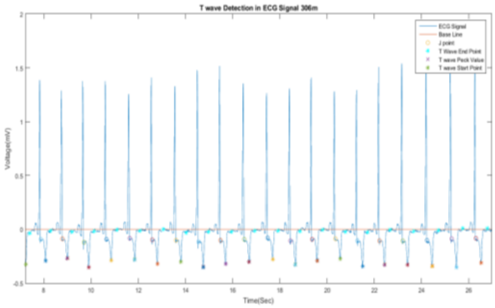
Using formula (8) and (9) we get Tables 1 and 2. We have used total 53 data samples where 18 from MIT-BIH ST data which accuracy is 87.49% and the rest from European ST-T change data samples which accuracy is 92.54%. The overall accuracy of our proposed algorithm is 90.015%. If we look through these calculations, the optimized parameters computed by the DE algorithm and the denoised ECG signal using the EKS framework were used to develop the new algorithm, which is an intelligent process of searching and subtraction for detection of, off, and peak locations of P and T waves without using an amplitude threshold. The usefulness of the suggested approach has been verified using a real-time QT database [29]. This way, an existing method is being executed. A comparison based on our proposed method and the existing method is described in Table 3.



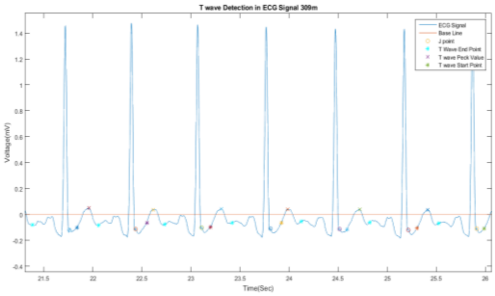
a)



b)



c)



d)

Fig. 19 T wave detection in ECG signal

Table 1 Databases

Data Name	Length (minutes)	Total Bit	TP	TN	FP	FN	T wave Type
MIT-BIH ST Change Database							
301 m	12	731	648	11	70	2	Up
302 m	25	2116	1803	0	312	1	Up
303 m	15	1275	1156	3	113	3	Down
304 m	15	795	676	32	75	12	Up
305 m	15	795	637	78	68	12	Up
306 m	25	1575	1324	17	228	6	Down
307 m	15	855	692	31	130	2	Up
308 m	5	275	240	10	23	2	Up
309 m	25	2100	1876	5	218	1	Up
312 m	25	1575	1377	3	195	0	Up
313 m	25	1950	1826	1	123	0	Up
317 m	25	2250	1855	11	383	1	Up
321 m	25	1806	1686	2	118	0	Up
324 m	25	1286	1062	3	221	0	Up
325 m	25	1842	1653	22	165	2	Up
326 m	25	1500	1335	15	146	4	Up
327 m	25	930	897	8	25	0	Up
Total	377	25906	22403	262	3191	50	
European ST-T database							
e0103m	25	1560	1409	2	149	0	Up
e0106m	25	1440	1195	14	228	3	Up
e0108m	25	1350	1218	4	128	0	Up
e0110m	25	1470	1246	17	206	1	Up
e0111m	25	1350	990	6	354	0	Down
e0112m	25	1515	1038	9	468	0	Down
e0113m	25	1515	1314	6	195	0	Up
e0114m	25	900	809	21	65	5	Up
e0115m	25	2250	2182	0	68	0	Up
e0116m	25	1035	980	26	26	3	Up
e0118m	25	1622	1545	13	64	0	Up
e0119m	25	1485	1398	2	85	0	Up
e0121m	25	1830	1688	0	142	0	Up
e0206m	25	2280	2074	3	203	0	Up
e0207m	25	1320	1303	2	15	0	Up
e0208m	25	1905	1822	11	72	0	Up
e0210m	25	1395	1341	2	52	0	Up
e0211m	25	1680	1512	3	165	0	Up

Continuation of Table 1

e0213m	25	1905	1786	3	116	0	Up
e0305m	25	1650	1503	12	134	1	Up
e0404m	25	1395	1257	9	129	0	Up
e0405m	25	1605	1473	4	128	0	Up
e0406m	25	1470	1338	21	109	2	Up
e0408m	25	1635	1508	2	125	0	Up
e0409m	25	1800	1725	0	75	0	Up
e0410m	25	1575	1507	0	68	0	Up
e0413m	25	1650	1540	4	106	0	Up
e0501m	25	1725	1707	5	13	0	Up
e0509m	25	1665	1647	0	18	0	Up
e0515m	25	2025	1957	0	68	0	Up
e0601m	25	1380	1358	0	22	0	Up
e0602m	25	2145	2057	22	65	1	Up
e0603m	25	1710	1487	27	194	2	Up
e0604m	25	1590	1489	32	65	4	Up
e0606m	25	1755	1672	3	80	0	Up
Total	875	56582	52075	285	4200	22	

Table 2 Accuracy

Data Name	**Total Data**	**Total Time (Min)**	**Total Bit**	**TP**	**TN**	**FP**	**FN**	**Accuracy (%)**
MIT-BIH ST Change Database	18	377	25906	22403	262	3191	50	87.49
European ST-T database	35	875	56582	52075	285	4200	22	92.54
Total	53	1252	82488	74478	547	7391	72	90.015

Table 3 Comparison and specialty of our proposed algorithm

Category	**Proposed Method**	**Existing Method**
Database	(i) MIT-BIH ST Change Database (ii) European ST-T Database	(i) MIT Database [8] (ii) QTDB, European ST-T,MIT-BIH ST Change Database [11] (iii) QT-database [24]
Slope Detection	(i) Detect Upslope with upper peak value (ii) Detect Downslope with lower peak value	(i) Lower and upper peak values detect only no upslope and downslope [11] (ii) Detect only upslope and upper peak values [25]
Duration	(i) Evaluated on long duration data minimum 5 min and 25 min	(i) Processed around 10 to 15 min [21] (ii) Processed from less than 30 sec data [25]

4. Conclusion

The T wave on the ECG signifies repolarization of the ventricular myocardium. Its shape and length are commonly used to diagnose illness and predict the risk of severe ventricular arrhythmias. T-wave anomalies have been investigated to determine whether they may predict benefit from early coronary angiography in people with non-ST-segment elevation acute coronary syndromes. Although ST-segment changes are the most important ECG feature, T-wave abnormalities are the most common ECG finding. One of the malignant diseases with the highest morbidity and mortality rates worldwide is cardio-cerebrovascular disease. Electrocardiogram (ECG) has essential reference relevance for the diagnostic and pathological investigation of cardiovascular and cerebrovascular disorders, according to medical research, which demonstrate the diversity of causes that cause heart blood cerebrovascular disease. While working on this paper, we had to face certain limitations. The limitations are described here. If there are numerous amounts of noise while doing ECG, the T wave in the ECG Signal Detect System may not be able to detect all of the noise at a time and the output may be improper. But using our approached Savitzky-Golay-smoothing filtering, this problem can be overcome in a very small amount. And if the length of the data exceeds 1 hour or 1.5 hours, it can take a long time.

Despite all of these facts, we have proposed a method in a way to detect T waves to measure patients' disorder precisely and quickly. T wave start, end, and peak values are detected using our suggested technique, which includes the right triangle hypotenuse tangent angle. The proposed algorithm's experimental findings for various data sets show that it is more accurate and precise in detecting cardiovascular illnesses, and its clinical application will enrich the diagnosis of cardiovascular diseases for a better treatment plan.

References

[1] BRADY W. *The Inverted T Wave: Differential Diagnosis in the Adult Patient*. 2014. [Online] Available from: https://www.patientcareonline.com/view/inverted-t-wave-differential-diagnosis-adult-patient

[2] MEHTA S.S., and LINGAYAT N.S. Detection of P and T-waves in Electrocardiogram. In: *Proceedings of the World Congress on Engineering and Computer Science, San Francisco, USA*, 2008: 22-24,

[3] VAN OOSTEROM A. The dominant T wave and its significance. *Journal of Cardiovascular Electrophysiology*, 2003, 14(s10). https://doi.org/10.1046/j.1540.8167.90309.x

[4] VAN OOSTEROM A. Measuring the T wave of the electrocardiogram; the how and why. *Measurement Science Review*, 2009, 9(3): 53-63, https://doi.org/10.2478/v10048-009-0011-9

[5] HADJEM M., and NAÏT-ABDESSELAM F. An ECG T-wave anomalies detection using a lightweight classification model for wireless body sensors. In: *Proceedings of the IEEE Communication Workshop (ICCW)*, 2015: 278-283. https://doi.org/10.1109/ICCW.2015.7247191

[6] VASIC N., DIMIC-JANJIC S., STEVIC R., MILENKOVIC B., and DJUKANOVIC V. Acute ‘Pseudoischemic’ ECG Abnormalities after Right Pneumonectomy. *Case Reports in Surgery*, 2017: Article ID 7872535. https://doi.org/10.1155/2017/7872535

[7] CHANG N.L., SHAH P., BAJAJ S., VIRK H., BIKKINA M., and SHAMOON F. Diagnostic yield of echocardiography in syncope patients with normal ECG. *Cardiology Research and Practice*, 2016: Article ID 1251637. https://doi.org/10.1155/2016/1251637

[8] BORTOLAN G., CHRISTOV I., SIMOVA I., and DOTSINSKY I. Noise processing in exercise ECG stress test for the analysis and the clinical characterization of QRS and T wave alternans. *Biomedical Signal Processing and Control*, 2015, 18: 378-385. https://doi.org/10.1016/j.bspc.2015.02.003

[9] BRENNAN T.P., and TARASSENKO L. Review of T-wave morphology-based biomarkers of ventricular repolarization using the surface electrocardiogram. *Biomedical Signal Processing and Control*, 2012, 7(3): 278-284, https://doi.org/10.1016/j.bspc.2011.05.010

[10] BURATTINI L., ZAREBA W., and BURATTINI R. Automatic detection of microvolt T-wave alternans in Holter recordings: Effect of baseline wandering. *Biomedical Signal Processing and Control*, 2006, 1(2): 162-168. https://doi.org/10.1016/j.bspc.2006.05.005

[11] MADEIRO J.P., NICOLSON W.B., CORTEZ P.C., MARQUES J.A., VÁZQUEZ-SEISDEDOS C.R., ELANGOVA, N., NG G.A., and SCHLINDWEIN F.S. New approach for T-wave peak detection and T-wave end location in 12-lead paced ECG signals based on a mathematical model. *Medical Engineering and Physics*, 2013, 35(8): 1105-1115, https://doi.org/10.1016/j.medengphy.2012.11.007

[12] XUE J., and ROWLANDSON I. The detection of T-wave variation linked to arrhythmic risk: An industry perspective. *Journal of Electrocardiology*, 2013, 46(6): 597-607. https://doi.org/10.1016/j.jelectrocard.2013.08.012

[13] WAN X., LI Y., XIA C., WU M., LIANG J., and WANG N.A. A T-wave alternans assessment method based on least squares curve fitting technique. *Measurement*, 2016, 86: 93-100. https://doi.org/10.1016/j.measurement.2016.01.046

[14] NARSIMHA B., SURESH E., PUNNAMCHANDAR K., and SANJEEVA REDDY M. Denoising and QRS detection of ECG signals using Empirical Mode Decomposition. In: *International Conference on Communications and Signal Processing (ICCSP)*, IEEE, 2011: 439-442.

[15] BLANCO-VELASCO M., WENG B., and BARNER K.E. ECG signal denoising and baseline wander correction based on the empirical mode decomposition. *Computers in Biology and Medicine*, 2008, 38(1): 1-13. https://doi.org/10.1016/j.compbiomed.2007.06.003

[16] ZHAO Z., and MA C. A novel cancellation method of powerline interference in ECG signal based on EMD and adaptive filter. In: *Proceedings of the11th IEEE International Conference on* Communication *Technology*, 2008: 517-520. DOI: 10.1109/ICCT.2008.4716100

[17] TSENG Y.-L., LIN K.-S., and JAW F.-S. Comparison of Support-Vector Machine and Sparse Representation Using a Modified Rule-Based Method for Automated Myocardial Ischemia Detection. *Computational and Mathematical Methods in Medicine*, 2016: Article ID 9460375. https://doi.org/10.1155/2016/9460375

[18] ZHU B., DING Y., and HAO K. A Novel Automatic Detection System for ECG Arrhythmias Using Maximum Margin Clustering with Immune Evolutionary Algorithm. *Computational and Mathematical Methods in Medicine*, 2013: Article ID 453402. https://doi.org/10.1155/2013/453402

[19] MOODY G.B., and MARK R.G. The impact of the MIT-BIH Arrhythmia Database. *IEEE Engineering in Medicine and Biology*, 2001, 20(3): 45-50. https://physionet.org/content/mitdb/1.0.0/

[20] YOCHUM M., RENAUD C., and JACQUIR S. Automatic detection of P, QRS and T patterns in 12 leads ECG signal based on CWT. *Biomedical Signal Processing and Control*, 2016, 25: 46-52. https://doi.org/10.1016/j.bspc.2015.10.011

[21] JEKOVA I., KRASTEVA V., LEBER R., SCHMID R., TWERENBOLD R., REICHLIN T., MÜLLER C., and ABÄCHERLI R. A real-time quality monitoring system for optimal recording of 12-lead resting ECG. *Biomedical Signal Processing and Control*, 2017. 34: 126-133. https://doi.org/10.1016/j.bspc.2017.01.009

[22] WANG J. Advances in ECG-Based Cardiac Ischemia Monitoring – A Review. In: *International Scientific Conference Computing in Cardiology*, 2021, 48: 1-4. https://www.cinc.org/archives/2021/pdf/CinC2021-289.pdf

[23] XU M., WEI S., QIN X., ZHANG Y., and LIU C. Rule-based method for morphological classification of ST segment in ECG signals. *Journal of Medical and Biological Engineering*, 2015, 35(6): 816-823. https://doi.org/10.1007/s40846-015-0092-x

[24] VELDKAMP R.F., SAWCHAK S., POPE J.E., CALIFF R.M., and KRUCOFF M.W. Performance of an automated real-time ST-segment analysis program to detect coronary occlusion and reperfusion. *Journal of Electrocardiology*, 1996, 29(4). https://doi.org/10.1016/S0022-0736(96)80090-2

[25] SHARMA L.D., and SUNKARIA R.K. Novel T-wave detection technique with minimal processing and RR-interval based enhanced efficiency. *Cardiovascular Engineering and Technology*, 2019, 10(2): 367-379. https://doi.org/10.1007/s13239-019-00415-4

[26] HARUN-AR-RASHID M., MAHMUD G., RAHMAN M.M., and DELOWAR HOSSAIN A.S.M. Classification of ST segment in ECG signals based on cross correlated supervised data. *SN Applied Sciences*, 2020, 2: Article number 1224. https://doi.org/10.1007/s42452-020-3050-3

[27] WINKERT T., and NADAL J. Comparison among Microvolt T-wave Alternans Detection Methods and the Effect of T-wave Delimitation Approaches. In: *XXVII Brazilian Congress on Biomedical Engineering*, 2020: 2033-2038. https://doi.org/10.1007/978-3-030-70601-2_297

[28] SHANG H., WEI S., LIU F., WEI D., CHEN L., and LIU C. An improved sliding window area method for T wave

detection. *Computational and Mathematical Methods in Medicine*, 2019, Article ID 3130527. https://doi.org/10.1155/2019/3130527

[29] PANIGRAHY D., and SAHU P.K. P and T wave detection and delineation of ECG signal using differential evolution (DE) optimization strategy. Australasian *Physical & Engineering Sciences in Medicine*, 2018, 41(1): 225-241. https://doi.org/10.1007/s13246-018-0629-8

[30] KENNY B.J., and BROWN K.N. *ECG T Wave*. Treasure Island: StatPearls Publishing, 2022. [Online] Available from: https://www.ncbi.nlm.nih.gov/books/NBK538264/

参考文:

[1] BRADY W. 倒置 T 波：成年患者的鑑別診斷。2014. [在線]可從：https://www.patientcareonline.com/view/inverted-t-wave-differential-diagnosis-adult-patient

[2] MEHTA S.S. 和 LINGAYAT N.S. 檢測心電圖中的P波和T波。在：世界工程與計算機科學大會論文集，美國舊金山，2008：22-24.

[3] VAN OOSTEROM A. 占主導地位的T波及其意義。心血管電生理學雜誌，2003，14(s10)。https://doi.org/10.1046/j.1540.8167.90309.x

[4] VAN OOSTEROM A. A. 測量心電圖的T波；如何和為什麼。測量科學評論, 2009, 9(3): 53-63.

[5] HADJEM M. 和 NAÏT-ABDESSELAM F. 使用無線人體傳感器的輕量級分類模型進行心電圖T波異常檢測。在：電氣和電子工程師學會通信研討會論文集，2015：278-283。https://doi.org/10.1109/ICCW.2015.7247191

[6] VASIC N., DIMIC-JANJIC S., STEVIC R., MILENKOVIC, B. 和 DJUKANOVIC V. 右肺切除術後急性"假性缺血性"心電圖異常。手術病例報告，2017年。文章ID7872535。https://doi.org/10.1155/2017/7872535

[7] CHANG N.L.、SHAH P.、BAJAJ S.、VIRK H.、BIKKINA M. 和 SHAMOON F. 正常心電圖暈厥患者超聲心動圖的診斷率。心髒病學研究與實踐，2016年，文章1251637。https://doi.org/10.1155/2016/1251637

[8] BORTOLAN G.、CHRISTOV I.、SIMOVA I. 和 DOTSINSKY I. 運動心電圖壓力測試中的噪聲處理，用於资历架构和T波交替的分析和臨床表徵。生物醫學信號處理與控制, 2015, 18: 378-385。https://doi.org/10.1016/j.bspc.2015.02.003

[9] BRENNAN T.P. 和 TARASSENKO L. 使用表面心電圖回顧基於T波形態的心室復極生物標誌物。生物醫學信號處理與控制, 2012, 7(3): 278-284, https://doi.org/10.1016/j.bspc.2011.05.010

[10] BURATTINI L.、ZAREBA W. 和 BURATTINI R. 動態心電記錄中微伏T波交替的自動檢測：基線漂移的影響。生物醫學信號處理與控制, 2006, 1(2): 162-168. https://doi.org/10.1016/j.bspc.2006.05.005

[11] MADEIRO J.P.、NICOLSON W.B.、CORTEZ P.C.、MARQUES J.A.、VÁZQUEZ-SEISDEDOS C.R.、ELANGOVA, N.、NG G.A. 和 SCHLINDWEIN F.S. 基於數學模型的12導聯起搏心電信號中T波峰值檢測和 T 波末端定位的新方法。醫學工程與物理, 2013, 35(8): 1105-1115, https://doi.org/10.1016/j.medengphy.2012.11.007

[12] XUE J. 和 ROWLANDSON I. 與心律失常風險相關的 T 波變化的檢測：行業觀點。心電學雜誌, 2013, 46(6): 597-607。https://doi.org/10.1016/j.jelectrocard.2013.08.012

[13] WAN X., LI Y., XIA C., WU M., LIANG J., 和 WANG N.A. 基於最小二乘曲線擬合技術的T波交替評估方法。測量，2016年，86：93-100。https://doi.org/10.1016/j.measurement.2016.01.046

[14] NARSIMHA B.、SURESH E.、PUNNAMCHANDAR K. 和 SANJEEVA REDDY M. 使用經驗模式分解對心電圖信號進行去噪和资历架构檢測。在：國際通信和信號處理會議，電氣和電子工程師學會，2011：439-442。

[15] BLANCO-VELASCO M.、WENG B. 和 BARNER K.E. 基於經驗模態分解的心電信號去噪和基線漂移校正。生物學和醫學計算機, 2008, 38(1): 1-13. https://doi.org/10.1016/j.compbiomed.2007.06.003

[16] ZHAO Z., 和 MA C. 基於EMD和自適應濾波器的心电图信號中電力線乾擾的新消除方法。在：第11屆電氣和電子工程師學會通信技術國際會議論文集，2008：517-520。土井：10.1109/ICCT.2008.4716100

[17] TSENG Y.-L.、LIN K.-S. 和 JAW F.-S. 使用改進的基於規則的自動心肌缺血檢測方法比較支持向量機和稀疏表示。醫學中的計算和數學方法，2016：文章 ID 9460375。https://doi.org/10.1155/2016/9460375

[18] ZHU B., DING Y., 和 HAO K. 一種新的心電圖心律失常自動檢測系統，使用最大邊緣

聚類和免疫進化算法。醫學中的計算和數學方法，2013：文章 453402。https://doi.org/10.1155/2013/453402

[19] MOODY G.B. 和 MARK R.G. 麻省理工学院-波黑心律失常數據庫的影響。電氣和電子工程師學會醫學和生物學工程，2001, 20(3): 45-50。https://physionet.org/content/mitdb/1.0.0/

[20] YOCHUM M.、RENAUD C. 和 JACQUIR S. 基於CWT的12導聯心電圖信號中P、资历架构和T模式的自動檢測。生物醫學信號處理與控制，2016，25：46-52。https://doi.org/10.1016/j.bspc.2015.10.011

[21] JEKOVA I., KRASTEVA V., LEBER R., SCHMID R., TWERENBOLD R., REICHLIN T., MÜLLER C., 和 ABÄCHERLI R. 實時質量監控系統，用於優化記錄12導聯靜息心電圖。生物醫學信號處理與控制，2017。34：126-133。https://doi.org/10.1016/j.bspc.2017.01.009

[22] WANG J. 基於心電圖的心臟缺血監測進展——回顧。在：國際心髒病學科學會議計算，2021年，48：1-4。https://www.cinc.org/archives/2021/pdf/CinC2021-289.pdf

[23] XU M., WEI S., QIN X., ZHANG Y., 和 LIU C. 基於規則的心電信號ST段形態分類方法。醫學與生物工程學報, 2015, 35(6): 816-823. https://doi.org/10.1007/s40846-015-0092-x

[24] VELDKAMP R.F.、SAWCHAK S.、POPE J.E.、CALIFF R.M. 和 KRUCOFF M.W. 用於檢測冠狀動脈閉塞和再灌注的自動實時圣段分析程序的性能。心電學雜誌，1996，29（4）。https://doi.org/10.1016/S0022-0736(96)80090-2

[25] SHARMA L.D. 和 SUNKARIA R.K. 具有最小處理和基於存款准备金率間隔的增強效率的新型 T 波檢測技術。心血管工程與技術, 2019, 10(2): 367-379. https://doi.org/10.1007/s13239-019-00415-4

[26] HARUN-AR-RASHID M.、MAHMUD G.、RAHMAN M.M. 和 DELOWAR HOSSAIN A.S.M. 基於交叉相關監督數據的心電信號中圣段的分類。SN應用科學，2020年，2：文章編號1224。https://doi.org/10.1007/s42452-020-3050-3

[27] WINKERT T. 和 NADAL J. 微伏 T 波交替檢測方法與T波劃界方法的效果比較。在：第二十七届巴西生物醫學工程大會，2020：2033-2038 https://doi.org/10.1007/978-3-030-70601-2_297

[28] SHANG H., WEI S., LIU F., WEI D., CHEN L., 和 LIU C. 一種改進的T波檢測滑動窗口區域方法。醫學中的計算和數學方法，2019年，文章 3130527。https://doi.org/10.1155/2019/3130527

[29] PANIGRAHY D. 和 SAHU P.K. 使用差分進化優化策略檢測和描繪心電圖信號的P和T波。澳大利亞醫學物理與工程科學, 2018, 41(1): 225-241. https://doi.org/10.1007/s13246-018-0629-8

[30] KENNY B.J., 和 BROWN K.N. 心電圖T波。金銀島：統計珍珠出版，2022年。[在線] 可從：https://www.ncbi.nlm.nih.gov/books/NBK538264/