ISSN(Online): 2320-9801
ISSN (Print) : 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijircce.com

Vol. 6, Issue 11, November 2018

Feature Extraction of the T Peak and Its Analysis

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ABSTRACT: An Electrocardiogram (ECG) is a graphical representation of the electrical signals generated during the heart activity. Analysis of ECG by identifying the various features and traits could help us detect the various cardiac peculiarities, thus providing valuable information about the activity of the human heart. Automatic classification of ECG has evolved as an emerging tool in medical diagnosis for effective treatments. A basic algorithm has been defined in this paper in order to detect the T peaks and its related features. Also, the work proposed in this paper reviews and summarizes the various techniques used by researchers in order to detect and delineate T waves (peaks). ECG signals in this work are collected from MIT-BIH database and it has been implemented using MATLAB routine. Lead-II ECG signals were used in processing of data.

KEYWORDS: Electrocardiogram (ECG), Matlab, T wave, Heart,Lead-II Configuration,

I. INTRODUCTION

The Electrocardiogram (ECG) is a way or a method to diagnose and detect any heart defect by analysing the captured electrical impulses and is mostly used in the clinical practice due to its excellent benefit-cost relationship. Invented by Willem Einthoven in 1901 in Netherlands, usually the ECG is recorded in an image consisting of all 12 channels or lead recordings interlaced by 3 second intervals from combinations of leads per row.

They often occur in the same order all occurring aligned in columns:

- **First row: I, AVR, V1, V4; Second row: II, AVL, V2, V5; Third row: III, AVF, V3, V6**

Since distinct diseases manifest differently in each of the leads, it is important to isolate the different leads involved.

Accurate measurements of ECG parameters are an important requirement for ECG analysis and this could be done using signal processing.

II. THE HEART MORPHOLOGY

The whole ECG signal recording is a combination of several consecutive cardiac cycles that results due to the depolarization and repolarization of the ions in the blood which include a fairy period of waves and peaks corresponding to the consecutive heart action phases [1 and 2].

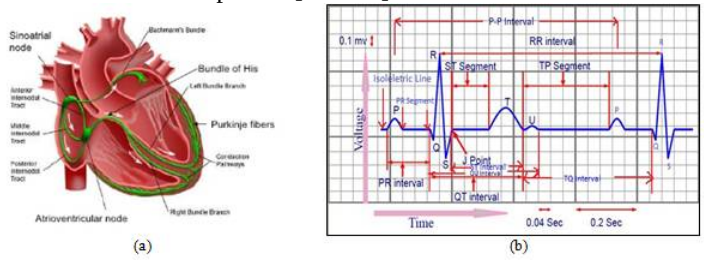

Fig. 1:The Human Heart (a) and a General ECG Waveform (b)

ISSN(Online): 2320-9801
ISSN (Print) : 2320-9798

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The sinus (Sino-atrial node) node located near the entrance of the superior vena cava vein, acts as a generator of the sinus rhythm that produces the heart frequency at about 60-100 cycles per minute, propagated to the right and left atria muscle tissues. There is a delay at the atrioventricular node, to allow the ventricles to fill with blood from atrial contraction. This is then followed by the depolarization propagating to the ventricles through the Bundle of His which spreads along the Purkinje fibers activating the ventricles that contract and pump blood to the aorta and to the rest of the body. Finally, depolarization occurs followed by repolarization and this cycle is repeated [3].The track of each heartbeat would consist of several waves/ peaks, segments, intervals and joints as a recurrent wave sequence as shown in the Figure 1 (b).

The table 1 shows the ECG features and descriptions.

Table 1: ECG Features and their Description

FEATURES	DESCRIPTION
P WAVE	P-waves represent atrial depolarization.
Q WAVE	The normal Q wave represents septal depolarization and is any initial downward deflection after the P wave.
R WAVE	The R wave represents early ventricular depolarisation and is normally the easiest waveform to identify on the ECG.
S WAVE	The first negative deflection after the R wave represents the S wave indicating the late ventricular depolarization.
T WAVE	The T-wave represents ventricular repolarization.
U WAVE	U waves represent re-polarization of the Purkinje fibers that indicates the last remnants of the ventricular repolarization. Generally it is 0.05mV and has duration of 0.1s.
P-R SEGMENT OR PQ SEGMENT	The PR or PQ segment is the flat, usually isoelectric segment between the end of the P wave and the start of the QRS complex. This segment represents the time the impulse takes to reach the ventricles from the sinus node.
P-R INTERVAL OR PQ INTERVAL	The time taken for electrical activity to move between the atria and ventricles is represented by this interval.
R-R INTERVAL	The RR-interval begins at the peak of one R wave and ends at the peak of the next R wave and represents the time between two QRS complexes.
P-P INTERVAL	It indicates the duration of atrial cycle (atrial rate).
QRS COMPLEX	The depolarization of the ventricles is represented by the QRS Complex.
QT INTERVAL	It represents the time taken for the ventricles to depolarize and then repolarize.
ST SEGMENT	The isoelectric line that represents the time between depolarization and repolarization of the ventricles (i.e. contraction) represents the ST segment.
J-POINT	The J point is the junction between the termination of the QRS complex and the beginning of the ST segment.
T-P INTERVAL	The isoelectric interval on the electrocardiogram (ECG) is TP segment that represents the time when the heart muscle cells are electrically silent.
T-Q INTERVAL	Termed as the diastolic interval through the ECG.
Q-U INTERVAL	The QU interval is a measure of the time between the start of the Q wave and the end of the U wave in the heart's electrical cycle.

III.PECULAR CARDIAC DEFECTSAND THE T WAVE MORPHOLOGY IMPORTANCE

In the morphology of ECG signal where the normal rhythm of the heart represents no disease or disorder is called Normal sinus rhythm (NSR).Although cardiac arrhythmia is one of the leading causes of death, it can be treated if detected on time [4, 5, 6 and 7]. Under the expert guidance of the doctors and after lots of literature review, it was seen that Lead II is the most preferred monitoring lead of choice for continuous ECG monitoring. Nowadays, ECG has become a golden medium for detecting Arrhythmia and Cardiovascular diseases and also could detect bifid P wave in lead II (P Mitrale).

The ECG deflection is said to be in rhythm if the tracing follows the following sequence usually composed of these components; P wave followed by QRS Complex followed by T wave and then U wave. U wave is normally invisible in 50 to 75% of ECGs because it is generally hidden by the T wave [1]. The T wave represents rapid ventricular repolarization of the contractile cells or recovery of the ventricles. It occurs right after the QRS Complex and has to be concordant and is found to be upright (positive), smooth and round in all the leads except for AVR and V1, also its biphasic in V1 during sinus rhythm. A slight peaking of the T wave may occur as a normal variant. The T wave is normally slightly asymmetric and large, since its descending limb or the downslope is steeper and more slanted than its

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ascending limb or the upslope. In case of athletes the T waves become larger than usual as the heart responds to regular dynamic exercise by becoming larger along with thicker walls of the left ventricles [8].

The mean T vector is directed relatively parallel to the direction of the mean QRS vector in a normal person. The T wave is labile and an unusual change observed in it could be a sign of something that is abnormal. A long list of possible causes of T wave changes can exist in the form of T wave being symmetric, flat, notched, broad, peaked, prolonged, strained, wide, shortened, inverted and bifid which could really provide clues to an obscure illness. The T wave is a representation of the repolarization of the membrane as it provides a lot of details about correct heart functioning and rhythm. A disruption in repolarization or another segment of the heartbeat could be due to an absent or strangely shaped T wave. Abnormalities, major or minor can be indicative of seriously impaired physiological functioning, each stemming from different bodily malfunction.Therefore, it is very necessary to determine and analyze it in order to be aware of diseases and treat the defects followed by its related features.

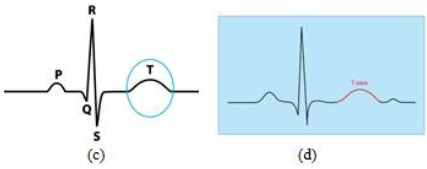

Fig. 2: The Normal T Wave Highlighted in the ECG Complex (c, d resp)

IV.LITERATURE SURVEY

In a paper proposed by Namitha Thomas et al, the detection and delineation of P and T wave using an ECG signal has been done using the proposed methodology where they have first detected the QRS Complex using the Pan Tompkins algorithm and eliminated the frequencies using the Linear filters. The pre-processed ECG signal and the extracted wave search region are then applied to the partially collapsed Gibbs sampler. To determine P and T-waves from collapsing samples they used a Partially Collapsed Gibbs Sampler (PCGS). The output of PCGS is then applied to Wave Indicator Estimation, amplitude estimation and amplitude estimation block. The wave indicator was done by using Local Map A Posteriori (MAP) method. The amplitude estimation is done by using fuzzy theory. The waveform estimation is done by using neural network. The estimation of noise variance of the wave is done by using MMSE method [9].

A modified combined wavelet transforms technique was developed by Saxena et al. The technique has been developed to analyze multi lead electrocardiogram signals for cardiac disease diagnostics. Two wavelets have been used, i.e.a quadratic spine wavelet (QSWT) for QRS detection and the Daubechies six coefficient (DU6) wavelet for P and T detection. A procedure has been evolved using electrocardiogram parameters with a point scoring system for diagnosis of various cardiac diseases. The consistency and reliability of the identified and measured parameters were confirmed when both the diagnostic criteria gave the same results [10].

In a paper proposed by Yan Sun et al, detection of the characteristic waves were done using a multiscale morphological derivative (MMD) transform based singularity detector which detected the fiducial points related to these characteristics by substituting the conventional derivative and was also proven to be successful in detecting the wave boundaries. The MMD method exhibited good potential for automated ECG signal analysis and arrhythmia recognition and gave better results as compared to wavelet transform based and adaptive thresholding based techniques [11].

In a paper prosed by Vandana Verma et al, it was seen that an algorithm for removal of noise, detection of QRS Complex along with P and T wave detection and Heart Rate were done using the wavelet based threshold method. The multi-resolution, threshold, minima/maxima pairs with window searching feature of wavelet transform has been used for the implementation of the algorithm [12].

In a paper written by Mohamed Elgendi,A robust and numerically efficient method base on two moving average filters followed by a dynamic event duration threshold has been developed to detect P and T waves in ECG signal [13].

In a paper proposed by Carlos R Vázquez-Seisdedos et al, a new approach and algorithm for T-wave end location based on the computation of Trapezium's areas is proposed and validatedusing signals from the PhysioNet QT

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Database. The performance of the proposed algorithm in noisy conditions has been tested and compared with threshold technique for estimating the T-wave end point. The results indicated that the proposed approach based on Trapezium's areas outperformed the baseline method with respect to accuracy and repeatability. Also, the proposed method is more robust to wideband noise [15].

In a paper proposed by Chao Lin et al, The delineation of P and T waves were done using a sequential Bayesian detection-estimation algorithm for simultaneous P and T wave detection, delineation, and waveform estimation on a beat-to-beat basis. The core of the method is a marginalized particle filter that efficiently resolves the unknown parameters of the dynamic model. The proposed algorithm was evaluated on the annotated QT database and compared with state-of-the-art methods. Its on-line characteristic is ideally suited for real-time ECG monitoring and arrhythmia analysis [16].

V.S. Chouhan et al proposed a method of feature extraction for detection of P- and T- waves followed by detecting QRS Complex by using the QRS detection algorithm that uses computation of gradient, in a sliding window; to ensure sufficient magnitude of the extracted feature, so as to meet the thresholding needs, the proposed algorithm extracts multiple feature components and combines them to attain the final feature signal and also using the sampling instants [17].

Zeeshan Ahmad et al proposed a paper where in P and T Peak parameters were detected using an algorithm. The algorithm had two stages; first stage processed the QRS complex using dynamic thresholding technique. The second stage processed P and T waves using Elgendi's algorithm depending upon the information extracted from first stage [18].

In a paper proposed by Chao Lin et al, a Bayesian detection-estimation algorithm was used for simultaneous detection, delineation, and estimation of P and T waves. A block Gibbs sampler exploited the strong local dependencies in ECG signals by imposing block constraints on the P and T wave locations [19].

In a paper proposed by H. K. Chatterjee et al, illustrated a technique for real time detection of P and T wave peaks from ECG signal. The technique was implemented on Xilinx field programmable gate array. The characterization of P and T wave was also done during the training period [20].

V. METHODOLOGY IN STEPS

Step 1: ***The Database Collection of ECG***

1. ECG signals were collected from variety of databases like the MIT-BIH (The Massachusetts Institute of Technology– Beth Israel Hospital Arrhythmia Database), AHA (The American Heart Association ECG Database), ESC (The European Society of Cardiology ST-T Database) and UCI (Machine Learning Repository).
2. The database consisted of several different ECG format waveforms like .mat, .csv, .xml, .dat or .txt. acrossdatabase banks, ECG Simulators, ECG Machines along with an ECG Amplifier in the practical laboratories in college and Electrocardiographs from the hospitals.

Step 2: ***ECG SignalInitialization***

1. Our Project has been implemented using the multipurpose tool i.e. the MATLAB Environment.
2. In order to read, plot and process a signal, if the signal is raw, which usually is, unless it's taken from a filtered database, we need to perform initialization and remove the base and gain by using the following formula:

$$Xi = \frac{Xi - Base}{Gain} \qquad (1)$$

Where Xi= ECG Sample Base= Baseline Value
Gain= Gain Factor

3. Once done, depending upon the various formats, some signals could be plotted directly (.mat) and some required conversion from one format to the required format ((.csv, .xml, .dat or .txt) to .mat) by choosing the appropriate frequency and threshold along with re-dimensioning of the variable matrix.

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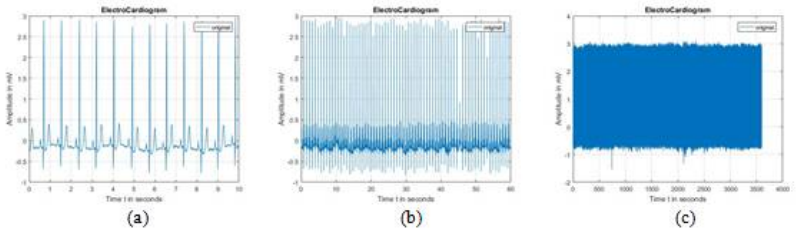

Fig.3:The Original ECG Signals (10 sec, 60 sec and 3600 sec) (Normal) (a,b,c)

Step 3:*Preprocessing Phase*

1. In the preprocessing stage, the noise is removed or suppressed using specific filters in order to extract the required information from the signal and for noise reduction.
2. This could be done either by performing Amplitude Normalization where in each sample of signal is divided from max of absolute value of signal in order to limit signal dynamic range from -1 to 1, i.e.

$$\boldsymbol{Variable} = \frac{\boldsymbol{xi}}{\boldsymbol{max}\,(|\boldsymbol{x}|)} \qquad \textbf{(2)}$$

Where xi= ECG Sample at a point
x= ECG Sample

3. The .mat format signal could be directly plotted in Matlab using a specific command.

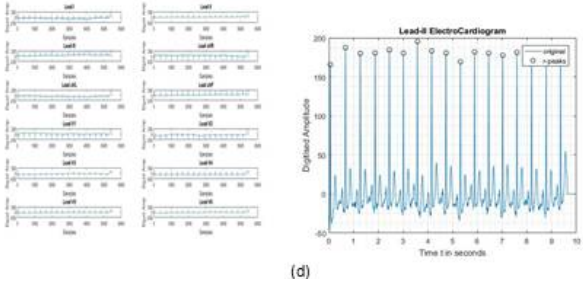

Fig. 4: Plotting of 12 Lead Configuration ECG Signal from the .xml format to .mat signal and A Lead-II ECG Configuration extracted from 12 Lead Configuration ECG signal (d from Left to Right resp)

4. Considering the .csv and .dat format signals, Conversion and Zero Phase Filtering were done in order to plot it. In case of the .xml format signal, the same procedure was carried out in order to plot the signal which represented all the 12 Lead Configurations followed by extracting the required signal configuration needed to work on (Lead-II).
5.

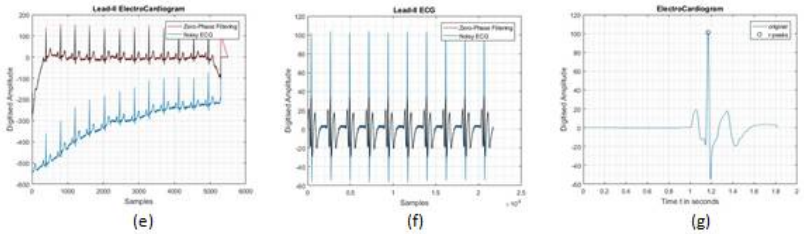

Fig. 5: Zero Phase Filtering of Extracted Lead-II ECG Signals to (.mat) from (.xml) (e), (.mat) from (.csv) (f) and Detecting R Peak (g)

Step 4:*Feature Extraction and Evaluation*

1. The feature extraction stage is used to extract diagnostic information from the ECG signal.
2. Feature extraction and evaluation can be either done to find out:

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Vol. 6, Issue 11, November 2018

- Morphological Features
- Dynamic Features

3. Morphological Features would mean determining the size, shape and structure of the ECG signal including the fiducial points like the amplitudes, peak points, onset and offset (wave boundaries), segments and interval durations.
4. Dynamic features would mean extracting the RR interval, PP interval features, Heart rate, HRV and the R/P ratio.
5. In this paper, what we present to propose is to extract and analyze the T peaks and its related features as a basic procedure for ECG processing and analysis.
   (a) So in order to begin with this we first identified the QRS Complex which would help us identify the R peak using the Pan Tompkins Algorithm.
   (b) R peak detection is a good start for the identification procedure as it is the sharpest component with respect to all the other peaks in a Normal Lead-II ECG Signal and is easier to detect.
   (c) In the Pan Tompkins Algorithm, ECG was first filtered using a band pass filter followed by differentiating the signal in order to get the slope information. This was then followed by squaring the signal which made the entire signal values positive concluding it with moving window integration which was done to obtain the waveform feature information. After moving window integration, thresholding of the obtained signal was done. If a peak exceeded the threshold during the first step of analysis, it was classified as a QRS peak (Complex).

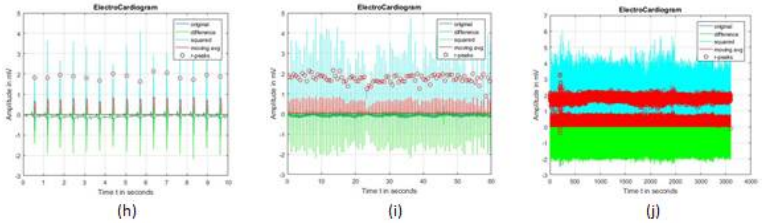

Fig. 6:Detection of QRS Complex using Pan Tompkins Algorithm for (10s, 60s, 3600s) (h, i, j resp.)

   (d) This was then followed by calculating the R-R Interval using the R-Spike Detection Method which is basically calculating the interval between one R-Spike and the next R-Spike (successive R's).This was then used to calculate the heart rate which could be defined as how fast the person's heart could beat in a minute. Initially the mean value of the R-R Interval is calculated and then this duration is then divided into 60. The resulting equation would be:

$$\boldsymbol{Rate} = \frac{\boldsymbol{60}}{\boldsymbol{R{-}R\ Interval\ (Avg)}} \qquad \textbf{(3)}$$

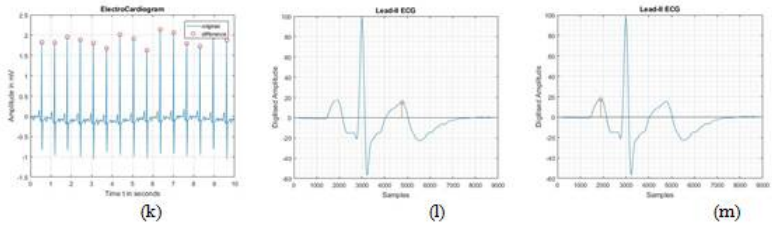

Fig. 7:Evaluating the R-R interval and the fiducial features (k), Detecting T and P Peak (l and m resp)

   (e) Using the Moving Window Integration technique along with the Threshold Detection method, we could detect T peaks in the ECG signal along with their amplitude and locations.This was followed by determining the wave boundaries of the T wave, i.e. the onset and the offset; Ton and Toff resp.
   (f) Thus, the T wave duration could be found as:

$$\boldsymbol{T\ Wave\ Duration} = \boldsymbol{Toff - Ton} \textbf{(4)}$$

ISSN(Online): 2320-9801
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Vol. 6, Issue 11, November 2018

(g) Considering the similar procedure, by using Moving Window Integration technique along with the Threshold Detection method, we could detect the P peaks in the ECG signal along with their amplitude and locations.This was followed by then determining the wave boundaries of the P wave, i.e. the onset and the offset named as Pon and Poff resp.

(h) Using this feature, we could find out the TP Segment with the equation,

$$TP\ Segment = Pon - Toff \quad (5)$$

(i) The next step was to detect the Q peak by finding out the first local minimum from the left of the positive R wave and the onset of the Q peak; Qon, using the same thresholding technique.

(j) Using this feature, we could find out the QT Interval with the equation,

$$QT\ Interval = Toff - Qon \quad (6)$$

(k) The next step was to detect the S peak by finding out the first local minimum from the right of the positive R wave and the offset of the S peak; Soff, using the same thresholding technique.

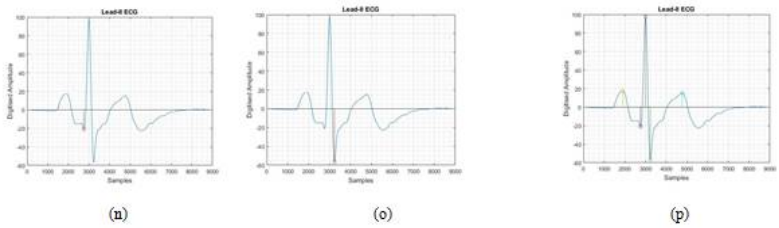

Fig. 8:Detecting Q Peak (n), S Peak (o) and Peak Points, Locations and Wave Boundaries (p)

(l) Using this feature, we could find out the ST Segment with the equation,

$$ST\ Segment = Ton - Soff \quad (7)$$

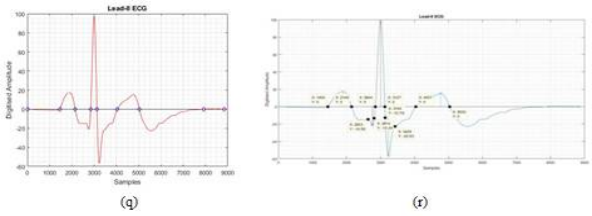

Fig. 9: Detecting Peak Points, Locations and Wave Boundaries; P, Q, R, S, T Waves (q) and evaluating the Dynamic Features(r)

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Vol. 6, Issue 11, November 2018

VI. RESULTS

The table displayed below gives the value of the average signals of more than 80 samples taken and analyzed in Matlab and that could be considered as Normal ECG based on the characteristics observed.

Table 2: ECG Signal Features and their Respective Values (Normal)

FEATURES	**VALUES**	
General Factors	**Values**	
Heart Rate	60-100 bpm*	
R-R Interval	0.6*s to 1.2*s	
Waves	**Amplitude(mV)**	**Duration(s)**
P Wave	0.1*-0.35*	0.07*-0.12*
Q Wave	0.1*-0.3*	<0.04*
R Wave	0.8*-1.5*	0.035*-0.09*
S Wave	0.5*-0.9*	0.03*-0.05*
T Wave	0.15*-0.6*	0.1*-0.250*
Segments/Intervals	**Duration(s)**	
QRS Complex	0.06*-0.12*	
ST Segment	0.07*-0.12*	
QT Interval	0.320*-0.450*	
TP Segment	<0.420*	

- *These obtained values in the table are calculated manually as well as using specific algorithms through computer processing in Matlab by analyzing more than 80 samples and is verified by doing a lot of literature review and is approved by the doctors.

Any value or feature that does not fall into the criteria and has a haphazard shape that does not have regularity and rhythm as defined in table 2 would be considered as an abnormal ECG.

After processing 10 such similar signals, it was seen that these signal tracings followed the particular sequence, a P wave followed by a regular QRS Complex followed by T wave with a round and smooth shape.

Also signal in Fig. 10 (s) maintains a heart rate within 60 to 100 BPM at rest along with the specific values of the features as obtained in the table. After a lot of literature review and processing, it could be learnt that the following traits correlate to a normal sinus rhythm criteria and therefore, it could be said that the subject could be in Normal Sinus Rhythm.Following figures represent several other signals with a chaotic rhythm and immeasurable segment and interval and with a missing T wave in few, Fig 10 (t and u).

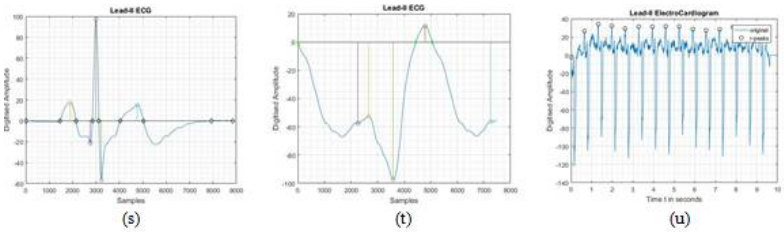

Fig. 10: ECG in Normal Sinus Rhythm (s), Chaotic Plotted Waveforms (t and u)

ISSN(Online): 2320-9801
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VII. CONCLUSION

Biomedical signals are non-stationary signals whose complex processing and analyses require better time and frequency resolution. The work presented the algorithm, a new method to estimate the T-wave and also evaluate it with a low computational cost and mathematical simplicity. The proposed method showed a good performance in noisy conditions. Also, in this paper the proposed work talks about the detection and processing of the T wave and its related features using a specific algorithmic method and techniques.The actual evaluation, classification and detection of the defects in depth using Lead-II configuration would require many more samples. Future research heading in this direction is necessary with a larger sample size in order to accurately pinpoint the various heart defects individually.

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