

# **ECG Image Features Extraction**

**Khalid Alaa Aldine Mahmood**

Ministry of Higher Education & Scientific Research

Foundation of Technical Education

Institute of Medical Technology Baghdad

Assist Lecturer



## الخلاصة:

أن توفر صور الـ ECG قد زاد بشكل مطرد في الآونة الأخيرة. والذي أفسح المجال لإيجاد تقنيات فعالة ومرنة لاستخلاص عناصر وخصائص تلك الصور بشكل ممكن. وإذا اعتمادية عالية وبالتالي تكون داعمة لتلك التقنيات التقليدية والمعتمدة على الخبرة البشرية والتي قد تعاني من بعض المشاكل في هذا المجال , ولذلك , فإن الحاجة لتطوير تقنيه فعالة لأجل زيادة كفاءة وتسهيل عملية إمكانية الوصول لتفاصيل معالم صورة الـ ECG عن طريق تحليل إشارة تلك الصورة بتحليل المحتويات المرئية الموجودة داخل تلك الصورة.

أن واحدة من هذه التقنيات هي استرجاع عناصر الصورة اعتمادا على محتويات عناصرها والتي تعتبر طريقة فعالة لبناء عناصر الصورة من خلال الاعتماد على تحليل البيانات الأساسية للصورة وعناصرها بشكل تلقائي أو ممكن باستخدام الحاسوب وذلك باتخاذ العناصر المرئية الموجودة داخل الصورة كأساس في العمل .

في هذا البحث قد تم تصميم وتشكيل نظام برمجي لتحديد وتحليل عناصر وخصائص الصورة الخاصة برسم ضربات القلب للشخص السليم الـ ECG من خلال أخذ الصورة الرقمية الثنائية وتحليلها باستخدام :

1- طريقة استخدام جدول عناصر الصورة والتي تستخدم الجدول الرقمي الذي يكون من خلال عمليات تحليل وترميز وبناء نقاط العناصر المكونة للصورة وكثافة الألوان داخل الصورة (Run Length Coding) .

2- طريقة تحديد حدود الصورة والتي تحدد الصور باستخدام نقاط الحواف المحددة حاسوبيا لها عن طريق استخدام عمليات تحديد عناصر الحدود المحيطة بالصورة .

أن خصائص الـ ECG والتي تتمثل بتوصيف مواقع النقاط T, S, R, and Q كنقاط قد أمكن استخلاصها وتحديد استخدامها باستخدام ثلاث إشارات رقمية ثنائية مستقاة من صورة الـ ECG .

لقد أظهرت النتائج بأن استخدام النظام البرمجي المقترح قادر على الوصول وتحديد التفاصيل لعناصر صورة

الـ ECG اعتمادا على جودة وضوح الصورة الثنائية (Enhanced) لإشارة الـ ECG (Electrocardiography) .

, تحسين معالم الصورة , معالجة ECG الكلمات المفتاحية: رسم تخطيط موجة كهربائية كإشارة لضربات القلب ,

RLC الصورة , استرجاع الصورة , استخلاص معالم صورة , تحديد حدود صورة ,

## Abstract

In recent time the availability of ECG image resources on the world has increased tremendously. This has created a demand for effective and flexible techniques for automatic ECG image features extraction. That can assisted the traditional techniques that still depending on the human experts , that it may be suffer from some problems that made it inefficient in this issue , therefore ; one needs to develop techniques in order to increase efficiency and effectiveness of ECG image features extraction by analyzing ECG wave image and extracting the visual content of these images .

One of these techniques is the content base image retrieval which is an efficient way for retrieving images features from the image database automatically based on their visual contents.

In this paper a software system are designed and implemented to detect normal ECG image features by extracting features from the digital binary ECG image by applying two methods that are:

(1) Histogram detection method which detect image using a histogram that extracted by performing histogram Run Length Coding (RLC) generation operations.

(2) Contour detection method which detected images using (The prominent edge point) of the images that extracted using boundary detection.

Q, R, S, and T peaks features are carried out between the three digital ECG wave image. The results show that the proposed software system is robust and works depending on a good enhanced binary ECG wave image.

**Keyword:** ECG, Image Enhancement, Image processing, Image restoration, Image Features, Edge Detection, and RLC.

## 1-Introduction

In the proposed software system the ECG wave image has already been segmented from it's background and converted to it's digital binary shape, this is a very important step because the digital binary ECG wave image features detection will produce non-homogeneous regions often containing more than one object ( binary ECG wave object).

Detecting of image features based on its pictorial data is an interesting and challenging problem, while manual ECG image annotations can be used to a certain extent, the feasibility of such an approach is a questionable issue.

The objective of this paper is to proposed a software system that can be used to detect Q, R, S and T peaks the features of ECG wave image from its digital binary image.

### 1-1 Image Analysis

Image analysis involves manipulating the image data to determine exactly the information necessary to help solve computer image problem.

Image analysis is primary a data reduction process. As we have seen, image contain large amounts of data, often much of this information is not necessary, so a primary part of the image analysis task is to determine exactly. [1]

Image analysis process can be broken down into there primary stapes: 1) Preprocessing, 2) Data Reduction, and 3) Feature Analysis see figure (1)

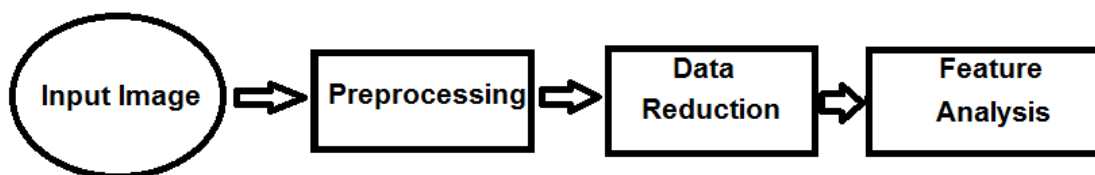


Figure (1) Image Analysis

In the proposed software system first stage preprocessing is used to remove noise and eliminate irrelevant, visually unnecessary information. Other preprocessing steps used to finding regions of interest for further processing. The second stage, data reduction, involves reducing the data in the spatial domain and the extracting feature for the analysis process. In the third stage feature analysis, the features extracted by the data reduction process and examined and evaluated for evaluated for their use in the application see figure (2).[1]

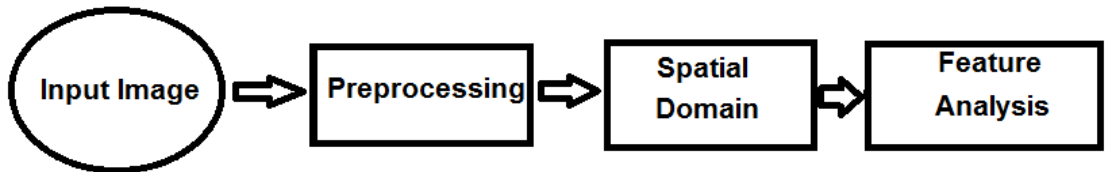


Figure (2) the proposed image analysis domain

After each stage we have a feedback loop that provides for an application – specific review of the analysis results. This approach often leads to an iterative process that is not complete until satisfactory results are achieved .The application feedback loop is a key aspect of the entire process. [1]

### 1.2- Operation Method

The term spatial domain refers to the aggregate of pixels composing the image, and spatial domain methods are procedures that operate directly on there pixels. Image processing functions in the spatial domain may be expressed as:

$$Pr(r,c)= T[f(r,c)] \text{ ----- (1)}$$

Where  $f(r,c)$  is the input image ,  $pr(r,c)$  is the processed image, and  $T$  is an operator on  $f$  , defined over some neighborhood of  $(r,c)$ . In addition  $T$  can also operate on a set of input images; such as performing the pixel– by–pixel sum of  $M$  images for noise reduction. The principal approach to defining a neighborhood about  $(r,c)$  is to use a square or rectangular sub image area centered at  $(r,c)$  , as shown in figure (3). [2]

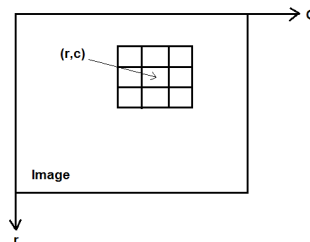


Figure (3) a 3x3 neighborhood about a point  $(r,c)$  in an image

The center of the sub image is moved from pixel to pixel starting, say at the top left corner and applying the operator at each location  $(r,c)$  to yield  $pr$  at that location. Although other neighborhood shapes, such as approximation to a circle, sometimes are used, square and rectangular arrays are by for the most predominant because of their ease of implementation.

The simplest form of  $T$  is when the neighborhoods are  $|X|$ . In this case  $pr$  depends only on the value of  $f$  at  $(r,c)$ , and  $T$  becomes a gray level transformation (also called mopping) function of the form :

$$S = T(r) \dots\dots\dots (2)$$

Where, for simplicity in notation,  $r$  and  $s$  are variables denoting the gray level of  $f(r,c)$  and  $pr(r,c)$  at any point  $(r,c)$ . The effect of this transformation is to produce an image specific contrast than the original image.  $T(r)$  produces a two-level (binary) image. [2]

## 2- Binary Image

Binary image are the simplest type of image analysis and can take on two values black and whit or '0' or '1' see figure (4)

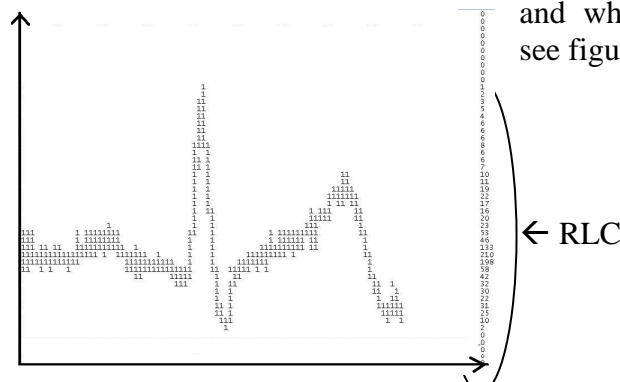


Figure (4) binary image simulated by 0,1 with it's RLC

A binary image is referred to as a (1bit/pixel) image because it takes only on binary digital to represent each pixel. [7]

### 2.1- Binary Image Enhancement

The aim of image enhancement is to improve the interpretability or perception in images of human viewers, or to provide 'better' input for other auto mated image processing techniques.

The principal objective of enhancement techniques is to process a given image so that the result is more suitable than the original image. [2]

The proposed image enhancement methods presented in this paper based on spatial domain techniques. The spatial domain refers to the image plane itself, and approaches in this category are based on manipulation of pixels in an image. Enhancement techniques based on various combinations of methods, the basic methodology underlying this section's material will be presented here. As we present in 1.2,  $T$  is an operator of  $f$ . So in binary image  $T$  becomes one of the two color levels 0 or 1. Where, for simplicity in notation,  $r$  and  $s$  are variables denoting 0 or 1 color of  $f(r,c)$  and  $pr(r,c)$  at any point  $(r,c)$ .

Larger neighborhoods allow of processing functions that go beyond just image enhancement. Regardless of the specific application, however, the general approach is to let the values of predefined neighborhood of  $(r,c)$  determine the value of  $pr$  at  $(r,c)$ . One of the principal approaches in this formulation is based on the use of so-called

masks (also referred to as templates, windows or filters). The operation called convolution.

Basically, a mask is small say 3x3 2-D array, such as the one shown in figure (3), in which the values of the coefficients determine the nature of the process, such as image sharpening. [2]

In the proposed software system the digital binary image has already been enhancement by proposing a several masks this technique, known as contrast stretching point processing to reduce undesired information or help to connect regions. We can check if the binary image clear (noise – free) or not by the response of the system that gives three solutions:

- 1- By zooming 1x4 to the selected area to see if there is a problem or not in the domain see figure (5).

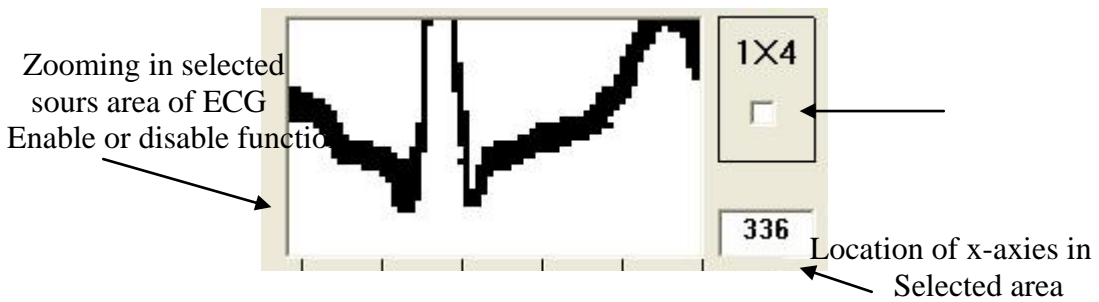


Figure (5) enlarging technique

- 2- Noise in the image can create problems that are why it is best to preprocess the image to eliminate, or at least minimize noise effects. Mean filtering, edge preserved filtering, and self-adaptive median filtering were used for smoothing and sharpening operations with undo procedure that permitted a wide solutions of choices to get a suitable enhancement see figure (6). [12][13][14]



Figure (6) a group of enhancement filters with its undo

- 3- In some cases a manual edit may be needed to solve any probability that may appear or not taken in account see figure (7).

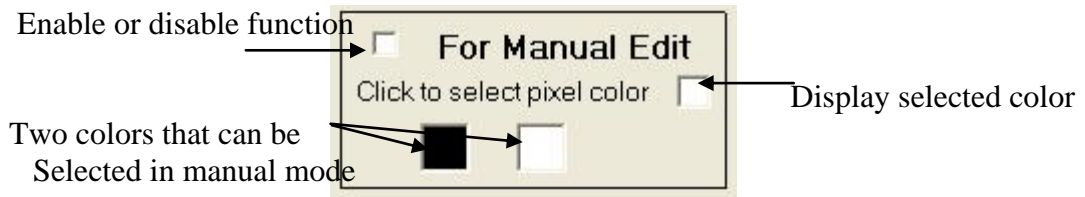


Figure (7) manual edit

## 2.2- Electrocardiography

Electrocardiography (ECG or EKG) is a trans thoracic interpretation of the electrical activity of the heart over time captured and externally recorded by an electrocardiographic device [8]. The etymology of the word is derived from the Greek electro , because it is related to electrical activity, cardio, Greek for heart, and graph, a Greek root meaning "to write" in english speaking countries, medical professionals often write EKG (The German abbreviation) in order to avoid confusion with ECG [9].

The ECG works mostly by detecting and amplifying the tiny electrical changes on the skin that are caused when the heart muscle "depolarises" during each heart beat. At rest, each heart muscle cell has a charge across its outer wall, or cell membrane. Reducing this charge towards zero is called de – polarization, which activates the mechanism in the cell that cause it to contract. During each heartbeat a healthy heart will have an orderly progression of a wave of depolarization that is triggered by the cells in the sinoatrial node, spreads out through the atrium, passes through "intrinsic conduction pathways" and then spreads all over the ventricles. This is detected as tiny rises and falls in the voltage between two electrodes placed either on a screen or on paper. This display indicates the overall rhythm of the heart and weaknesses in different parts of the heart muscle. [10]

Usually more than 2 electrodes are used and they can be combined into a number of pairs. (For example: Left arm (LA, right arm (RA) and left leg (LL) electrodes from the pairs: (LA +RA), (LA + LL), and (RA + LL). The output from each pair is known as a lead. Each lead is said to look at the heart from a different angle. Different types of ECG, can be the number of leads that are recorded, for example 3-lead, 5-lead or 12-lead ECG's (sometimes simply "a 12-lead"). [11]

## 2.3- Analyzing Normal ECG Image

The ECG records the electrical activity of the heart, where each heart beat is displayed as series of electrical waves characterized by peak and valleys. Any ECG gives two kinds of information. One, the duration of the electrical wave crossing the heart which in turn decides whether the electrical activity is normal or slow or irregular and the second is the amount of electrical activity passing through the heart muscle which enables to find whether the parts of the heart are too large or overworked.



Normally, the frequency range of an ECG signal is of 0.05-100 Hz and its dynamic range of 1-10mV. The ECG signal is characterized by five peaks and valleys labeled by the letters P, Q, R, S, and T.

The performance of ECG analyzing system depends mainly on the accurate and reliable detection of the QRS complex, as well as T – wave.

The QRS complex and T – wave represent the excitation of the ventricles or the lower chamber of the heart. The detection of the QRS complex is the most important task in automatic ECG signal analysis. Once the QRS complex has been identified a more detailed examination of ECG signal including the heart rat, the ST segment etc. can be preformed [3]. In the normal sinus rhythm (normal state of the heart) the R interval is in the range of 0.12 to 0.2 sec. The QRS interval is from 0.04 to 0.12 sec.

The Q-T interval is less than 0.42 sec and the normal rate of the heart is from 60 to 100 beats per minute. So from the recorded shape of the ECG, the heart activity was seen whether normal or abnormal .

The Q, R, S, and T – waves reflect the rhythmic electrical depolarization and repolarization of the myocardium associated with the contractions of the atria and ventricles see figure (8). [4]

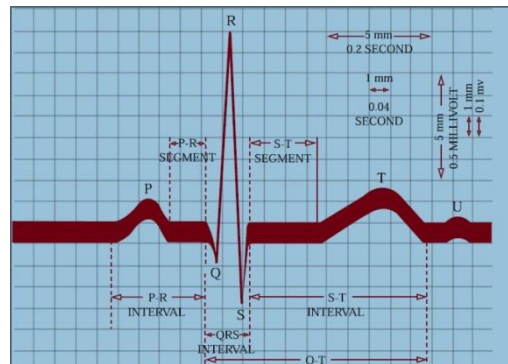


Figure (8) the normal ECG wave form

### 3- The proposal software

The ECG image analysis process can be broken down into:

- 1) Histogram Run Length Coding generation operation.
- 2) Contour detection method.

An important first step in a normal digital binary ECG image analyzing is to determine which feature must be detected or can be detected on a given ECG lead, each monophasic cardiac waveform may have a positive or negative polarity depending on the orientation of the cardiac electrical activity with respect to the derivation under consideration. These individual waves may be flat or tall, narrow or wide. The proposed software is conceptually more complex and has a slightly complicated computation, yet this software picks up the coordinates details of the normal binary ECG image.

#### 3.1- Histogram Run Length Encoding generation

Run length coding (RLC) is an image compression method that works by counting the number of adjacent pixels with the small gray –level value. This count called the run length, basic methods that are used primarily for binary (two – valued) images, but can

work – with complex images that have been preprocessed by thresholding to reduce number of gray levels to two. There are various ways to implement basic RLC, and the step is to define the required parameters. Can be used horizontal RLC, counting along the rows. In basic horizontal RLC the number of bits used for the coding depends on the number of pixels in a row. If the row has  $2^n$  pixels, then the required number of bits is  $n$  so that a run whose length is the entire row can be coded. [4]

A black – and – white image that is mostly white, will encode very well, due to the large amount of contiguous data that is all the same color. First approach is to put RLC for each counting numbers of adjacent pixels for each horizontal row in a histogram table see figure (9).

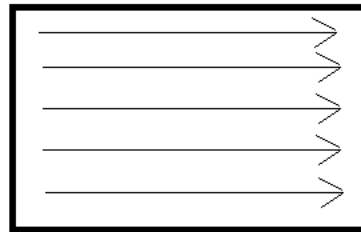


Figure (9) encoding along the x-axis

### 3.1.1- Base Line ECG Detection Process

A second approach is to use histogram RLC in detecting base line of input ECG wave, thus after RLC long runs of each horizontal column counting the number of adjacent pixels see figure (4).

By far the most common approach for detecting meaningful is the maximum response of the horizontal RLC that accrued when line of the ECG wave image passed through the middle of the wave, it would result when the ECG wave has no change in signal and the number of adjacent pixels has the most number in the RLC table. In some cases it may be better detect base line manually instead of auto detection, this is possible by using human experts and allowed with mouse and direct entries see figure (10).

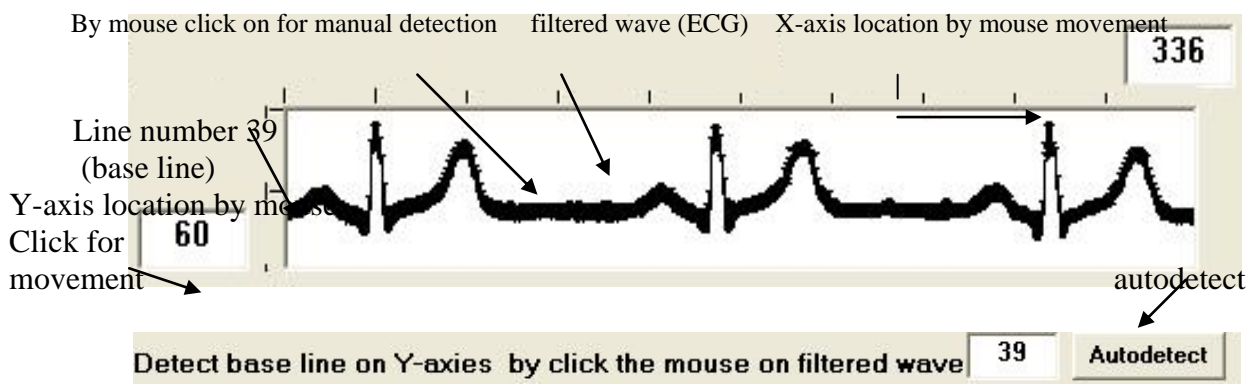


Figure (10) manual base line detection

### 3.1.2- R – Peak Detection

Since the R – peak is the sharpest component in the ECG signal it is captured by the lower order which also contain high frequency noise, which typically presented in the first three ECG waves. [6]

In our analysis, it was found a similar result. The oscillations associated in single ECG the R – peak detected by taken the first right lowest number of pixels in the RLC histogram table, therefore, the R – peak detection comprises the following two steps:

1- Sum of the first three R – peak pixels are the lowest in RLC horizontal table.

3- R – peak position is at the first upper right positions until the end of the three amplitudes of ECG wave reached.



Figure (11) R – peak coordinates

After finding the R – peak position, then it can be fined whether the peak is positive or negative according to the value of base line location, since the base of base line is zero see figure (11).

### 3.2- Contour Detection Method

The boundary detection is one in which the contour represented and described by one of two choices for representing a region:

- 1- We can represent the region based on it's external characteristics (i.e., it's boundary).
- 2- We may choose to represent it in terms of it's internal characteristics (i.e., the pixels comprising the region).

The contour detection by point processing is undertaken. The detection logic is described below:

With the data in the form of pixels along an ECG boundary or pixels contained in a region, chain codes are used to track figure(12)(a) by a connected sequence of straight line segments of specified length and direction. [2] The initial point is form R – peak and the tracing ends when reaching Q – peak, S – peak, or T – peak, similarly for all peaks, single peak detection can have numbers 8 – directional chain codes depending on its direction. Conventionally, the chain code with the least magnitude is taken into consideration, figure (12) shows the 8 – directional chain code convention.

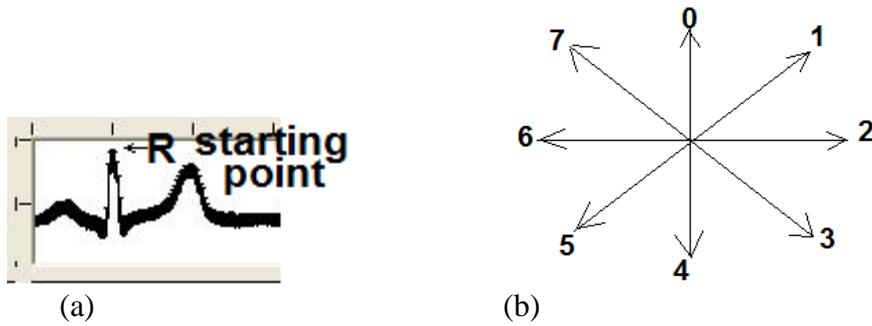


Figure (12) directional chain coding

For the sake of simplicity, the starting point is considered to be the top most pixel in the contour. Then, by proceeding in the counter clockwise direction, the direction of the next pixel in the contour is determined.

The starting point of the contour is already determined as the R – peak (top most) pixel in the contour. As it has been already detected that the chain coding has to proceed in a counter clockwise direction, there are only two directions in which the chain coding can proceed after the first pixel.

This concept can be better understood by observing the figure (13).

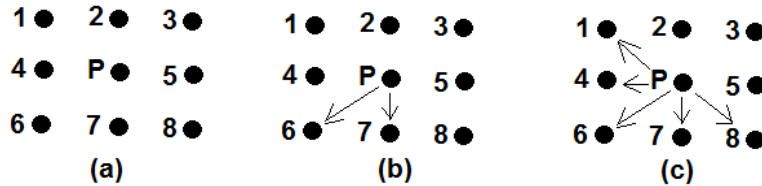


Figure (13) chain coding logic

- a: pixel 'p' under consideration
- b: chain code moves in direction toured 5
- c: chain code directions in which it can proceed

The pixel arrangement is shown in figure 13(a). The pixel 'p' represents the pixel under consideration. As it can be seen, there are eight pixels surrounding it. Coming back as to why there are only two directions for the chain code to proceed, it has been noted that when pixel 'p' is under consideration, the pixels 1,2,3, and 4 would have already been scanned. As we are proceeding in the counter clockwise direction, we cannot consider pixel 5. A careful analysis of figure (13) with all the ECG contour would reveal that there is no way that pixel 8 can be white when 'p' is the starting pixel. So, we are now left with only two pixels 6 and 7. From figure (12), their directivities can be found to be 5 and 4 respectively. By explicitly proceeding in the directions 4 or 5, the next pixel in the contour can be identified.

The coordinates of the starting pixel and the next pixel in the contour from first two rows of the chain code matrix with 'n' rows and 2 columns. The number 'n' denotes the number of pixels in the contour. Unlike the case for the second pixel in the contour, for all other pixels, there are five directions in which the chain code can proceed.

In figure 13 (b) consider that the pixel 6 is white which implies that the chain code moves in direction 5. The figure 13 (c) has been structured assuming such a possibility.

The old pixel numbers are depicted within brackets. The pixel 3 in figure13 (c) is the pixel 'p' in figure13 (b). So, in figure13 (c) it can be rightly that the chain coding has proceeding from pixel 3 to pixel 'p'.

Now, to determine the next pixel direction in the chain code, it is enough if we scan through five pixels namely 1,4,6,7 and 8 as shown in figure13 (c). It is only in there directions the chain coding can advance. The other three pixels 2, 3, and 5 needs into account as the chain code came to pixel 'p' from 3.

Similarly, for all other directions also, it is sufficient to consider only 5 pixels instead of 8. This chain coding proceeds until the Q, S, and T pixels are reached after making a full traversal through the outer contour. After detecting every successive pixel in the 3 ECG wave contour, it's Q, S, and T pixels coordinates have to be displayed as result see figure (14).

Q-Detection	At the three points below (X, Y)					(a)
	31	39	325	39	180	39
T-Detection	At the three points below (X, Y)					(b)
	96	36	338	39	245	36
S-Detection						(c)
	58	37	338	39	207	36

Figure (14) the coordinates of:

- (a) Three Q-peak coordinates detected
- (b) Three S-peak coordinates detected
- (c) Three T-peak coordinates detected

### 3.2.1- Q – peak S – peak and T – peak detection

After R – peak pixel was obtained, the Q, S, and T – peaks or pixels detected by following ECG boundary in the chain code until reach the pixel that illustrated the following:

For Q – peak conditions:

- 1- This pixel is on the baseline.
- 2- This pixel is at the left of R – peak.
- 3- This pixel is satisfied one of the threshold mask as shown in figure (15).

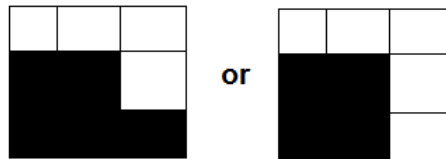


Figure (15) threshold mask for Q-peak detection

For S – peak conditions:

- 1- This pixel is at the right of R – peak.
- 2- This pixel is the most less x-axis coordinates pixel under the base line on the contour.
- 3- This pixel is satisfied one of the threshold mask as shown in figure (16).
- 4- If this pixel is on the baseline then flag=1.

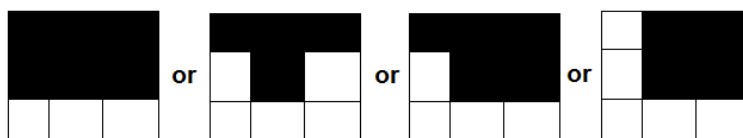


Figure (16) threshold mask for S – peak or T – peak detection

For T – peak conditions:

- 1- This pixel is at the right of S – peak.
- 2- If this pixel is the most less x-axis coordinates pixel under the baseline then:
  - a) flag = (-)
  - b) This pixel is satisfied one of the threshold mask as shown in figure (16).
- 3- If this pixel is the most maximum x-axis coordinates pixel upper the baseline then:
  - a) flag = (+)
  - b) This pixel is satisfied one of the threshold mask as shown in figure (17).

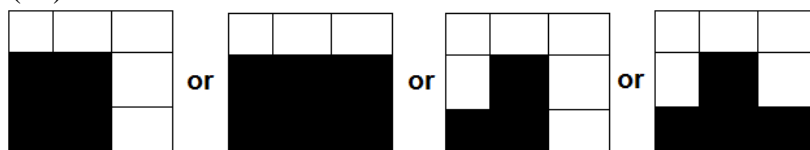


Figure (17) threshold mask for T-peak detection with flag (+)

#### 4- Experimental results

A number of experiments were preformed to test and evaluate the performance of the proposed software. It has shown the ability to process binary ECG wave image features extraction of image of size 396 x 60 pixels with in less than 4 seconds on average.

The algorithm was tested on most known recorded normal ECG images. It was found that the acceptable results on a good noise free binary images; the proposed software gives the solution to reach the optimal processing by:

- 1- A group of enhancement filters with it's undo result see figure (6).
- 2- Use the enlarging technique (1x4) to figure, detect and increase human vision to solve the problems that may appear in some noise ECG images see figure (5).

By taken the opinion of some doctors they found that, it is a very good step for automated ECG wave to give a good support to reduce errors and increases the human visual system experts.

## **5- Conclusion**

This paper presents a normal binary ECG image features extraction method based on the histogram run length encoding generation and contour detection method. The proposed software based on spatial domain techniques. The complexity and difficulty of detecting normal ECG wave image features Q, R, S, and T – peaks has been solved.

Experiment results prove the segmentation of ECG wave features can be detected efficiently after a good enhancement and noise remove.

Binary ECG image features extraction Q, R, S, and T – peaks has been reached.

## **6- Future works**

Several suggestions can be recommended for future works maybe given as follows:

- 1- Using the same technique to extract another feature such as P – peak and u – peak.
- 2- P – R interval, P – R segment, QRS interval, S – T interval, S – T segment, and Q – T interval can be combined in order to increase the performance of process.

There are numerous of ECG characteristic point detection. These works are still in progress and we hope to contribute significantly in the field of ECG signal processing by using the work presented here.

## References

- [1] Scott , E. Umbaugh, "Computer Vision and Image Processing", 1998, prentice Hall PTR.
- [2] Rafal G. Gonzalez , Richard. EWoods , "Digital Image Processing", Addison – Wesley publishing company. Inc, 2000.
- [3] C. Li, C. Zheng (1993) Pro C. Annual Int. Conf, IEE Eng. In Med. & Biol. SOC., SanDiego , California , 33033i .
- [4] C. Li, C. Zheng C. Tai (1995), IEEE Trans. Biomed. Eng. 42 21-28
- [5] Kiri Wagstaff, Claire Cardie Seth Rogers and Stefan Schroedl, "Constrained K – means Clustering with Background Knowledge", Cornell University, USA, 2001.
- [6] M. B-Velasco, B. Weng, and K. E. Barner. 'ECG Signal Denoising and Base-line Wander Correction Based on the Empirical mode Decomposition". Comput. Bio. Med.,38:1-13,2008 .
- [7] Yong. Rui and Thomas S. Huang, Shih-Fu Change, "Image Retrieval: Current Techniques. Promising Directions, and Open Issues" Journal of visual communication and image representation Vol. 10, PP.39-62, 1999.
- [8] "The Clinical Value of the ECG in Non Cardiac Conditions', Chest 2004; 125(4): 1516-76. PMID 15078775.
- [9] " ECG – Simplified . Aswini Kumar M. D. " Life Hugger. <http://ph.lifehugger.Com/doc/120/ecg/-100-steps> :Retrieved 2010-02-11 .
- [10] "American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care, 2005 part 8 : Stablization of the Patient with Acute Coronary Syndromes" Circulation 2005; 112;112 : IV-89-IV-110 .
- [11] Braun wald E. (Editor), Heart Disease : A textbook of cardiorascular medicine , fifth edition, P. 108 , Philadelphia, W.B. Saunders Co., 1997. ISBN 0-7216-5666-8.
- [12] Kenneth .R. Castleman, Translated by ZHU zhigang etc. "DIGITAL IMAGE PROCESSING"[M].Beijing: Electronic and Industrial Press, 1998.
- [13] Ruan qiuqi. "DIGITAL IMAGE PROCESSING"[M].Beijing: Electronic and Industrial Press , 2001.
- [14] Keiji Taniguchi. "DIGITAL IMAGE PROCESSING"[M].Beijing: Science Press and Kyoritsu Shuppan Co., Ltd ,2002.