AUTOMATIC INDICATION OF HEART ATRIAL ENLARGEMENT BASED ON ECG SIGNAL PROCESSING

الاستدلال التلقائي لتضخم اذين القلب بالاعتماد على معالجة اشارة القلب

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ABSTRACT

The Electrocardiogram (ECG) is an important signal that reports the activity of the human heart, it is pretended to be a diagnostic source for different cardiac diseases. The Heart Atrial Enlargement (HAE) is one of the known heart diseases that it is diagnosed based on manual reading of ECG signal reports. The recording of ECG signal could be affected by different sources of noise that lead to non-accurate analysis of the recorded signal. In this research a new algorithm has been suggested to give an automatic indication to the HAE. The proposed algorithm using three stages of processing to achieved its job. The algorithm uses Savitzky Golay (SG) filter for noise cancellation to clean and smooth the ECG signal from any unwanted noise. MATLAB simulation has been used to build and test the suggested algorithm. The designed algorithm has been tested on ECG waves from the MIT-BIH MGH/MF waveform database. The proposed algorithm has achieved an overall matching performance of 88.235 %.

Keywords: Electrocardiogram (ECG), Savitzky Golay filter, Noise cancellation, Heart Atrial Enlargement (HAE).

الخلاصة

إن تخطيط القلب الكهربائي (ECG) يمثل إشارة مهمة توضح مدى نشاط القلب البشري، و تعتبر مصدرا تشخيصيا لأمراض القلب المختلفة. توسع اذين القلب هو واحد من أمراض القلب المعروفة التي يتم تشخيصها على أساس القراءة اليدوية لتقارير إشارة تخطيط القلب. تسجيل إشارة تخطيط القلب قد يتأثر بأنواع مختلفة من الضوضاء و التي تؤدي الى تحليل غير دقيق للإشارة المسجلة. في هذا البحث تم اقتراح خوارزمية جديدة لإعطاء استدلال تلقائي على توسع اذين القلب. الخوارزمية المقترحة تستخدم ثلاث مراحل من المعالجة لتحقيق وظيفتها. تستخدم الخوارزمية مرشح سافيتسكي غولاي كمفلتر لإشارة تخطيط القلب من أي ضجيج غير مرغوب فيه. وقد استخدمت أداة ماتلاب لمحاكاة واختبار الخوارزمية. تم اختبار الخوارزمية المصممة على موجات تخطيط القلب من قاعدة بيانات (MIT-BIH MGH/MF) وقد حققت الخوارزمية المقترحة أداء مطابقة شاملا بنسبة ٨٨.٢٣٥٪.

الكلمات المفتاحية: تخطيط القلب الكهربائي (ECG)، فلتر سافيتسكي غولاي، إلغاء الضوضاء، توسع أذين القلب (HAE).

1. INTRODUCTION

The Electrocardiogram (ECG) is an important signal that reports the activity of the human heart and it is pretended to be a diagnostic source for different cardiac diseases. Useful information regarding heart condition is stored in the waveforms of ECG signal. ECG signal is a periodic signal that has repeated cycles per time and the main waveforms that form one cycle of the ECG signal are P, Q, R, S, and T waveforms as it shown in Figure 1. Recording the ECG signal could be affected by different sources of noise that lead to non-accurate analysis of the signal. Major sources of noise affect the ECG signal are shown in table 1. The noises that comes from the power line interference and that is come from the baseline drift have the highest degree of effect on the ECG signal among other sources of noise [1, 2].

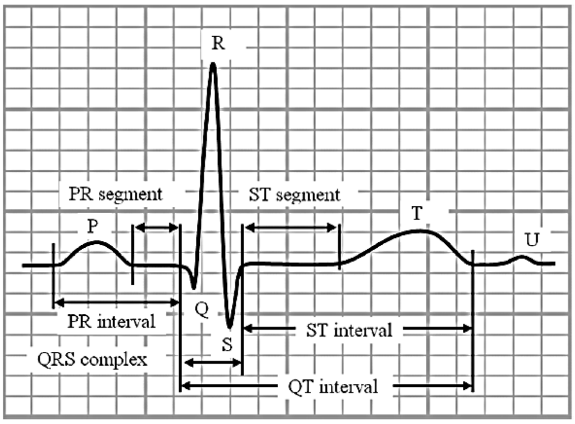


Figure 1: One cycle of standard ECG signal [3]

Table 1: Major sources of noise affect the ECG signal.

Type of noise source	Rang of frequencies
Power line interferences	50/60 Hz
Electrode pop or contact	Less than 0.5 Hz
Motion artifacts	approximately 0.014Hz
Muscle contraction	20 Hz – 1000 Hz
Baseline drift	0.15 Hz – 0.3 Hz

2. MANUAL DIAGNOSIS OF HAE

The HAE is one of the known heart diseases that appear as an enlargement in the atrial of the heart. Obesity has been proofed as the first cause of left atrial enlargement [4]. Right atrial could be also suffered from enlargement through different causes including (high pressure in the right ventricular, disease in the valves, the fibrillation of atrial and dilated cardiomyopathy) [5]. The manual diagnosis of the HAE through ECG signal report mainly depends on the Experience of the doctor or ECG expert in performing a correct and accurate interpretation to ECG signal report. The P waves are reflection to the statues of heart atrial. The shape and characteristics of P waves can give one of the following indications:

i. Diagnosis of Right Atrial Enlargement (RAE):

   1. The voltage of P wave is increased in the first part.

   2. The duration of P wave is constant.

ii. Diagnosis of Left Atrial Enlargement (LAE):

   1. The voltage of the second part of P wave may increase in rarely states.

   2. The duration of P wave is increased.

The manual procedure cannot be always accurate due to that the differences in amplitude and voltage of p waves could not be clear enough to be recognized by eyes due to the different types of noise affects the recording of ECG signal.

3. PROPOSED ALGORITHM

The aim of this research is to build an automatic computerized algorithm that give an automatic indication to the HAE and classify it to left or right HAE through the processing of ECG signal. The new algorithm is a computerized version of the manual procedure explained previously. Three stages of processing are used in the proposed algorithm which are preparing and smoothing ECG signal, peaks detection, and decision making stage. Figure 2 shows the general description of the algorithm proposed in this research.

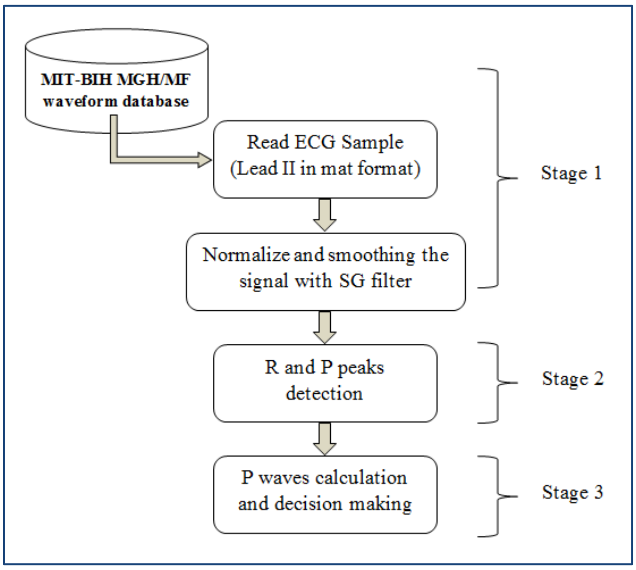


Figure 2: General block diagram of the proposed algorithm

Stage1: *preparing and smoothing ECG signal*

The job in this stage is to clean the ECG signal from noise and any unwanted signal to improve the accuracy of ECG signal processing. Among the different sources of noise mentioned in table 1, the noises that comes from the power line interference and that is come from the baseline drift have the highest degree of effect on the ECG signal among other sources of noise. Different techniques could be used to accomplish the job of this stage such as (Savitzky Golay filter, derivative smoothing function, wavelet filters, FIR filter, Butterworth filter, and etc.). Smoothing the ECG signal with Savitzky Golay filter (SG filter) is improved as one of the best noise cancelling filters that are used widely for signal processing in biomedical field [6]. SG filter has the ability of protecting the shape of ECG beat "including the peaks and valleys" when it compared with FIR filter [7]. SG filter is working according to the following equations [8, 9].

$$g_m = \sum_{k=-n_L}^{n_R} c_K + n_L \,.\, s_{m+K} \ldots (1)$$

s_{m+K}: the input signal

g_m: the output signal

$-n_L, n_R$: points in the left and right of a data point m respectivly

$c_K + n_L$: represents the coefficients of SG filter calculated with the following formula:

$$c_{M+n_L} = \left(A(A)^T . A)\right)^T \sum_{k=0}^{n} \binom{n}{k} x^k a^{n-k} \ldots (2)$$

Cleaning the ECG signal from noise and any unwanted signal has a significant role in the analysis of ECG signal in the next stages and make the processing easier and more accurate.

Stage2: *R and P waveforms detection stage*

The P wave is the first waveform in the ECG cycle and it is a reflection to the statues of heart atrial. R peak has the highest amplitude among the beats of ECG signal and detection it can be used in detection and analysis of all the other peaks in the ECG signal. Since the duration of P-

R is in a constant range in ECG signal, detecting R peak has a main contribution in detecting P waveform. The main characteristics and relations of P & R waveforms are shown in Table 2 below [10]:

Table 2: The main characteristics and relations of P & R waveforms

Normal Voltage (mV)	Duration Time (s)
R wave	
0.18 – 1.68	0.6 - 1.2 for (R – R)
P wave	
Not exceed 0.25	0.12 for (P duration) 0.12 – 0.20 for (P – R)

R detection algorithm

1. Read the filtered signal from stage 1 and convert it to digital signal and store it in a vector (ECG signal [n]).
2. Calculate the largest peak of R value in the vector (ECG signal [n]).
3. Based on the characteristics of R wave in table 2 above, any amplitude in (ECG signal [n]) vector is said to be one of the real R peaks when it satisfy with the following conditions.

0.18 * x <= signal [n] <= 1.68 * x… (3)
signal [n-1] <= signal [n]>= signal [n+1]… (4)
When x is the largest peak and signal [n] represents ECG signal [n] amplitude

0.6<= (signal [n] – signal [n-1]) <=1.2… (5)
When signal [n] represents ECG signal [n] time

4. Save the time of any value in (ECG signal [n]) vector that is satisfied with conditions in 3 in a new vector (R peaks [n]).

P detection algorithm

1. Calculate the real duration of R-R in (R peaks [n]) which is the difference in time between each two adjacent wave of R peaks.
2. Calculate the start, center, and end points of P wave according to their distance from R peak. Based on information in table 2, The three points will be calculated as follow.

Start point = 0.1 * (R – R duration)… (6)
Center point = 0.3 * (R – R duration)… (7)
End point = 0.5 * (R – R duration)… (8)

3. Calculate the amplitude and duration of each P wave using the following equations.

Amplitude of P wave = Amplitude of (ECG signal [n]) at n= centre point … (9)

Duration of P wave = End point – Start point … (10)

Stage3: *Decision making*

According to the calculations of stage 2, it is easy to test the P wave and decide which is normal or not. By comparing the amplitude of detected P waves with those related with HAE, we can decide and diagnose the statues of the heart and which it has left or right HAE.

1. The P wave is said to be abnormal when:

Amplitude of P wave > 0.25 … (11)
Or Duration of P wave >0.12 … (12)

2. The heart is said to be suffer from HAE when it's P wave has abnormal properties and it is classified as follow:

RAE diagnosis: *when amplitude of P wave is greater than 0.25 and the duration is normal.*

LAE diagnosis: *when amplitude of P wave is normal and the duration is greater than 0.12.*

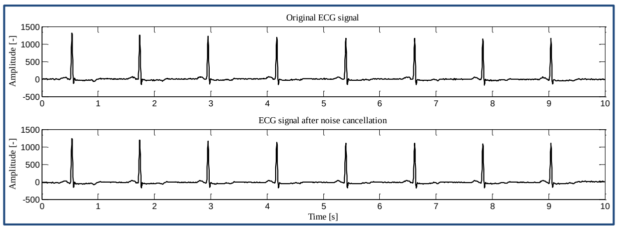
Table 3: The performance evaluation of the proposed algorithm

NO. of Samples	Database classificatin	algorithm classificatio	Matching	Overall Percentage of matching
17	13 LAE 4 RAE	11 LAE 6 RAE	15 out of 17	**88.235 %**
Ecg 1	**LAE**	**LAE**	**YES**	
Ecg 2	**LAE**	**LAE**	**YES**	
Ecg 3	**LAE**	**RAE**	**NO**	
Ecg 4	**RAE**	**RAE**	**YES**	
Ecg 5	**LAE**	**LAE**	**YES**	
Ecg 6	**LAE**	**LAE**	**YES**	
Ecg 7	**LAE**	**LAE**	**YES**	
Ecg 8	**LAE**	**LAE**	**YES**	
Ecg 9	**LAE**	**RAE**	**NO**	
Ecg 10	**RAE**	**RAE**	**YES**	
Ecg 11	**LAE**	**LAE**	**YES**	
Ecg 12	**LAE**	**LAE**	**YES**	
Ecg 13	**LAE**	**LAE**	**YES**	
Ecg 14	**LAE**	**LAE**	**YES**	
Ecg 15	**RAE**	**RAE**	**YES**	
Ecg 16	**LAE**	**LAE**	**YES**	
Ecg 17	**RAE**	**RAE**	**YES**	

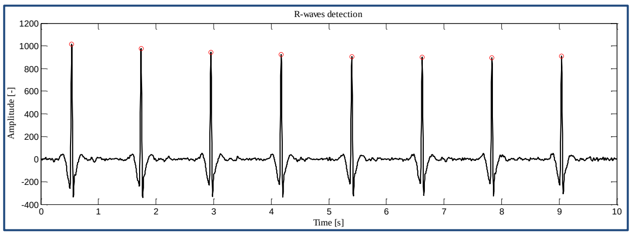
4. SIMULATION AND RESULTS

To build the proposed algorithm MATLAB tool has been selected to simulate and test the algorithm. The database used to test the proposed algorithm was obtained from the MIT-BIH MGH/MF waveform database provided in the Physionet website [11]. Lead II was selected among other leads of ECG signal due to the best occurrence of P waveform in this lead [12]. Seventeen different reports of ECG signals each of 10 seconds duration have been selected from the mentioned database to study the behavior of the proposed algorithm. The mat format provided by the database is used to deal with the signals as vectors in MATLAB tools. The sampling frequency used to sample the signals of the database is 360 Hz.

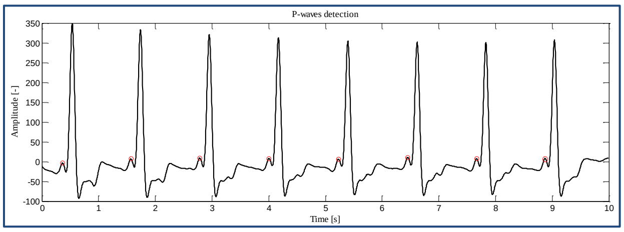
The three stages explained previously were built using MATLAB tools environment. The analysis of one of the selected ECG signals showing the main calculations done by the proposed algorithm is shown in Figure 3. Table 3 shows the percent of accuracy in classifying the ECG signal and determining the existence of HAE and indicating its type. The overall percent of matching between the indications of HAE calculated by the proposed algorithm and those provided with the by the database is 88.235%.



(A)



(B)



(C)

Figure 3: (A) ECG noise cancellation, **(B)** R-waves detection, and **(C)** P-waves detection

5. CONCLUSIONS AND FUTURE DIRECTIONS

The main job of this research was to use computer aided design to build an algorithm that is able to automatically indicate and classify the HAE. The suggested algorithm can effectively provide an indication about HAE and classify it to LAE and RAE. The results showed that the overall matching performance of the proposed algorithm is 88.235 %.

The proposed algorithm accomplish the high percent of matching value through several factors i.e., by using SG filter in cleaning and smoothing the ECG signal in preparing stage, and by using an easy and straightforward procedure to detect R and P components of ECG signal. For the future development, the proposed algorithm could be tested with different sources of ECG databases and developed to detect BI-HAE in which an advanced processing of different leads of ECG is included.

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