Detection of P Wave in Electrocardiogram

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Abstract

The aim of this paper is to discuss a new algorithm to detect P wave in the resting electrocardiogram (ECG). The independent ECG leads were acquired simultaneously; the sampling rate was 500 Hz. A moving average bandpass filter and a notch filter were applied to the ECG. All the QRS-T complexes were detected and removed from de original signal. A new lead was constructed as the sum of the independent lead, sample by sample. The Teager Energy Operator was applied to the new constructed lead to get an auxiliary function where high energy zones were emphasized. A threshold was computed, based on the maximum value of the auxiliary function, to identify atrial activity. When this activity was detected, the onset and offset of the atrial wave were identified in the original leads using slope criterion. The proposed algorithm was tested with 300 ECGs from adults patients; the sensitivity for P wave detection reached 96,47 %; false positive were not produce.

1. Introduction

The ECG is a non-invasive and simple cardiac test which provides valuable information for the diagnosis of heart disease [1]. Despite the great advances made in medical technology in recent decades, the rest electrocardiogram (ECG) remains the most widely used test in the world. Example of such statement is more than 300 million ECGs made in USA annually [2].

Nowadays, automatic identification and measuring of ECG events is vey important to cardiac disease diagnosis. In a clinical setting, such intensive care unit, it is essential for automated systems to accurately detect and classify ECG components. The correct performance of these systems depends on several important factors, including the quality of the signal and the knowledge represented and applied to get a diagnostic. The algorithms and methods developed for this purpose have become a very useful tool because of their effectiveness.

The P wave is caused by atrial depolarization. Its duration is normally not greater than 120 ms, but it can be changed by atrial disturbances. Automatic P wave detection is a complex process because of the characteristics of such a wave, being a low-amplitude and low-frequency component of the ECG which can be coupled to the QRS complex or not. Over the last years, the P wave detection and measuring problem has been addressed using different approaches [3-6]. The thresholding technique has been applied intensively, but scientists are still working to improve existing solutions. More sophisticated techniques have been used, but failures have been reported for different situations [7]. Also, researchers have to keep a compromise between the performance and the computing power needed for real applications.

The aim of this paper is to explain an algorithm, developed and tested by the authors, to detect and to measure P waves in the rest ECG. It is an off-line algorithm designed to study atrial activity. The algorithm has been preliminary tested with real ECGs.

2. Materials and methods

The proposed algorithm can be broken down in the following stages:

ECG acquisition: Independent leads (I, II, V1, V2, V3, V4, V5 and V6) have to be acquired simultaneously. The sampling rate must be 500 Hz or higher according to the standard IEC 60601-2-51 [8]. The intrinsic noise of each channel of the ECG amplifier must not exceed 30 microvolts because this is the limit set by international standards for resting ECG [8,9]. Leads III, aVR, aVL and aVF were computed according to classic expressions based upon leads I and II.

Digital filtering: Two filters in cascade were applied to the ECG in order to remove noise. A digital moving average filter proposed by Ligtenberg and Kunt [10] was used because it is very easy to implement in real-time. This filter is defined as shown in the expression 1.

$$y(k)=\frac{1}{K^2}\sum_{m=k-K+1}^{k}\sum_{n=m-K+1}^{m}x(n)-\frac{1}{L^2}\sum_{m=k-L+1}^{k}\sum_{n=m-K+1}^{m}x(n) \quad (1)$$

where:

x(n): input signal

y(k): filtered signal at time k

K, L: filter constants

The notch filter is used to cancel 60 Hz interference; but it could be substituted by a 50 Hz notch filter. The main goal of this step is to minimize the noise because of the low amplitude of P wave.

The authors implemented a second order IIR filter with a linear phase distortion in the studied frequency band. This filter is defined as shown in the expression 2.

$$y(k) = x(k) - 1.458x(k-1) + x(k-2) + 1.094y(k-1) - y(k-2) \quad (2)$$

where
x(n): input signal
y(k): filtered signal at time k

QRS complex detection: An algorithm developed and used successfully by the authors previously was used [11]. This algorithm was based on the Function of Spatial Velocity (FSV) which was computed sample by sample applyng the expression 3.

$$y(k) = \sum_{i=1}^{C} [x(i,k) - x(i,k+1)]^2 \quad (3)$$

where,
y(k): Function of Spatial Velocity
x(i,k): k-sample for lead i
C: number of independent leads

The algorithm is so easy to implement because only integer arithmetic amd simple rules are used. The quadratic differences emphasize high-energy zones of the ECG and these zones always are the QRS complexes.

A frontier was set to identify candidate zones to be a QRS complex; this frontier or threshold was defined as the 20% of the maximum value of FSV. When the auxiliary function values were over this frontier during more than 16 ms, a QRS complex was detected. After this condition was reached, the algorithm search for the 90% of the maximum value of FSV and this point was considered as the end of the region associated to the QRS complex.

Several heuristic rules were applied to confirm the detection. QRS with duration below 30 ms or a voltage level less than 15 µV were rejected. The presence of pacemaker must be detected before to apply this algorithm. More details were published previously [11, 12]; an example of the FSV is shown in Figure 2.

A nine-point derivative function is used to identify the onset and offset of each QRS complex detected. This kind of derivative function reduced the noise influence. This derivative function is shown in expression 3.

$$y(k) = \sum_{i=-4}^{4} i * x(k-i) \quad (4)$$

where
x(n): input signal
y(k): derivative values

The maximum slope of the ECG was detected inside the region delineated with the FSV; this sample was used as start point in order to look for the QRS complex onset and offset. A search back and search forward processes were made to identify these points. A set of heuristic criteria, based on previous experiences, were applied to stop this processes.

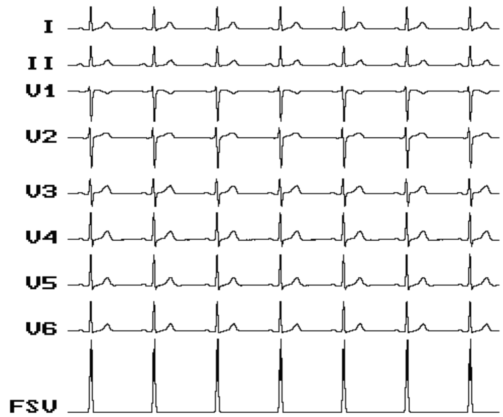

Figure 1. Function of Spatial Velocity.

T wave offset was defined as the interception between the ECG baseline and a tangential line to the second branch of the studied wave. It is ilustraded on figure 2. Two samples of the second branch of this wave are used to compute the slope of the tangential line. Previously, the T wave peak is identified according to a procedure described in a previous research [12]. When T wave amplitud is less than 0,2 mV the algorithm described does not have a good accuracy and a correction is needed.

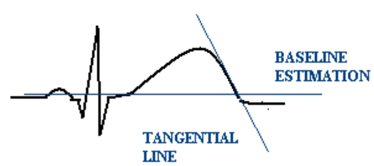

Figure 2. Definition of T wave offset.

The baseline estimation is computed as the average of the samples corresponding to the 20 ms previous to the QRS complex onset.

QRS-T complex removing: The QRS-T complexes represent the ventricular activity in the ECG and they will be cancelled to simplify the signal to analyze. The proposed algorithm is focused in detection of P wave coupled or not to the QRS complex, but only P waves present in TQ intervals. This is the reason to remove all the QRS-T complexes detected.

Samples of the QRS-T complexes were replaced by the mean value between the voltages corresponding to the QRS complex onset and the T wave offset detected in the previous step of the proposed algorithm. These complexes become in isoelectric regions. Thus, all the independent leads are converted into new signals representing only the electrical activity associated with TQ intervals. For each of these intervals, the minimum value of voltage is detected and its value is subtracted from each of the samples.

Creation of a new lead: The atrial activity is present in all leads at the same time because these signals were acquired simultaneously. A unique signal is constructed with all the leads in order to detect the ECG zones considered as candidate to be a P wave in any lead. The new signal is obtained by the sum of the absolute values, sample by sample, of all independent leads.

Computing an auxiliary function: Teager Energy Operator is defined as shown in expression 4.

$$y(k) = x(k)^2 - \left[x(k-1) * x(k+1)\right] \tag{4}$$

where,
x(n): input signal
y(k): Teager Energy Operator

The auxiliary function was defined as a collector of the Teager Energy Operator. 100 ms-duration moving window vas applied across each TQ segment to sum the corresponding values of the operator. This collector allows emphasizing the ECG sections with major energy as candidates to be P wave regions. This operator has been used in QRS complex detection with good results reported [14], but never has been reported its application in atrial wave's identification processes.

P wave detection: The proposed algorithm was designed to identify ECG zones which can be considered as candidates to be a P wave. After that, the delineation of the waves is made lead by lead.

The maximum value of the auxiliary function was located for any TQ interval and the 15 % of its value was used as a wave identification theshold. If the maximum value did not reach a value specified by the authors, no P waves are identified in the studied TQ interval. When the auxiliary functions values remain over the threshold during 16 ms, a P wave zone was located and the waves were delineated lead by lead. To delineate the waves, onset and offset were detected using a nine-point derivative function and some criteria set previously. The maximum value of the ECG was searched inside the P wave zone and it was used to compute the wave amplitude. When the wave amplitud was less than 0,15 mV, a wave did not exist. Also, if duration is less than 20 ms, the algorithm arrived to the same conclusion.

3. Results

Two evaluations were made with different data. A set of fifty ECGs from CSE database, MO1 serie, were used for a laboratory test and the proposed algorithm was implemented in a digital electrocardiograph in order to make a test in real conditions, including factor like patient movement, skin impedance, electrode poor contact, etc. The name of the ECG from CSE database including in the evaluation are shown in Table I.

All the QRS complexes present in the ECG from CSE database files were detected without false positives. It is very important for the proposed algorithm because the QRS-T complexes are the reference to define the TQ intervals. The presence of false positives could introduce a negative influence in the algorithm performance because TQ samples could be cancelled erroneously.

Table 1. CSE data set for testing of the algorithm.

ECGs from MA1_ series				
002	027	047	075	098
003	030	048	076	099
007	031	049	077	101
008	033	051	078	102
009	034	060	079	104
012	037	061	080	105
013	038	062	081	106
014	040	063	085	110
019	042	064	086	112
021	043	066	090	114

All P wave zones were detected, but eleven false positives were taken as real waves. The majority of these errors were near the end of T wave because of the incorrect identification of this event. If the performance of the T offset algorithm is improved, this error will be reduced.

When the algorithm identified and measured P waves in the leads, the same performance was reached independent of the wave morphology. The algorithm was prone to detect real positives, but aproximately 2% of real waves were not identified because of the rules applied about amplitude and duration. The authors consider more important the absence of false positives.

A second evaluation was made with 300 ten-second electrocardiograms acquired in three hospitals in Havana, Cuba. Three CARDIOCID electrocardiographs, manufactured by COMBIOMED in Cuba, were used to acquire and store the signals [xx]. All patients were adults between 22 and 81 years old. The studied population grouped by age is shown in Table 1.

Table 2. Age groups of patients studied.

Age group	Female	Male
20 to 29 years old	6	14
30 to 39 years old	27	20
40 to 49 years old	42	36
50 to 59 years old	19	30
60 to 69 years old	22	12
70 to 79 years old	18	28
80 to 89 years old	7	19
Total	141	159

The proposed method was applied to patients with sinus arrhythmia, atrial fibrillation, intraventricular block, unspecific disorders of the T wave, ST segment deviations, isolated VPCs and normal ECGs. The ECG distribution according to pathologies can be seen in Table II. Three cardiologists, with more than then years making ECG interpretation, identified 2738 P wave zones in the studied ECGs. They did not know the results obtained by the proposed algorithms when they were checked the ECGs.

Table 3. ECG according to pathologies.

ECG type	Quantity
sinus arrhythmia	6
atrial fibrillation	4
intraventricular block	10
unspecific disorders of the T wave	22
ST segment deviations	31
isolated VPCs	69
normal ECGs	159
Total	300

It is remarkable that three ECGs with atrial fibrillation were studied and the algorithm did not detect any P wave in these signals. The fibrillations waves were not detected because this kind of wave did not reach the amplitude and duration rules set by the proposed algorithm. This result can be useful for the atrial fibrillation diagnosis because this pathology can be described as ¨ an ECG with RR interval irregular and P wave absence¨.

The algorithm performance was not influenced by the other pathologies. The performance was similar for normal or not normal ECGs.

4. Conclusions

The proposed algorithm seems to be a powerful tool to detect P wave in rest ECG, but its performance should be improved. The authors will work in order to get better results in T wave offset identification.

The auxiliary function was easy to implement and very useful. It is very important to ensure a minimal noise contaminating the ECG studied in order to get the best performance.

The implementation of the algorithm is simple for any microprocessor or microcontroller because only integer arithmetic is used.

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