DETECTION OF P WAVE DURING SECOND-DEGREE ATRIOVENTRICULAR BLOCK IN ECG SIGNALS

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Abstract: Automatic detection of P wave during the second-degree AV block is the main condition for automatic detection of this pathology. This work deals with developing of the algorithm for P wave detection. The algorithm is appropriate for ECG signals with AV block as well as signals with other rhythm types (it does not produce false positive P wave detections). For P wave detection, the phasor transform is applied and several innovative rules are created. These rules are based on knowledge of heart manifestation during both physiological and pathological heart function. The proposed algorithm consists of four parts – filtration, QRS complex detection, application of rules, and P wave detection. The accuracy of the P wave detection algorithm is 99.74 % for signals with AV block, and 99.82 % for signals without any pathologies.

Keywords: ECG, second-degree AV block, P wave detection, phasor transform

1. INTRODUCTION

Atrioventricular (AV) block is a type of cardiac rhythm disorder. It is caused by disorder in conduction between atria and ventricles (AV junction). The contractions of atria and ventricles are not coordinated and it can cause various health problems. AV block manifests in electrocardiogram (ECG) as a P wave, which is not followed by QRS complex. For automatic identification of this pathology, all P waves should be correctly detected using automatic algorithm [1]. Commonly used algorithms for P wave detection fail on the ECG signals with AV block [2]. Majority of P wave detection algorithms search for the P wave before QRS complex, which is true for physiological ECG. Also the testing of these algorithms is problematic, because freely available standard databases do not include many signals with AV block. Even if they include some signals, these signals are not usually correctly annotated. Many algorithms do not count with this pathology (AV block). Majority of P wave detection algorithms reach good accuracy, unfortunately they are tested only on signals with normal rhythm. Algorithms described in [2] and [3] reached the accuracy of 99.70 % and 99.76 %, respectively, but they were tested on signals with mainly normal rhythm – QT Database (QTDB) [4]. If these algorithms were tested on signal no. 231 from MIT-BIH Arrhythmia Database (MITADB) with second-degree AV block, the accuracy of P wave detection was only 84.08 % and 66.40 %, in [2] and [3] respectively. The MITADB does not include publicly available annotations of P wave. The authors of [2] provided their own annotations as well as we did.

2. METHODS

For P wave detection, the phasor transform (PT) is used together with several innovative rules. These rules are based on knowledge of heart manifestation during both normal and pathological heart functions. The proposed algorithm consists of four parts – filtration, QRS complex and T wave detection, application of rules, and P wave detection. The overall process is shown in Figure 1. Each block is described in the next subchapters in detail.

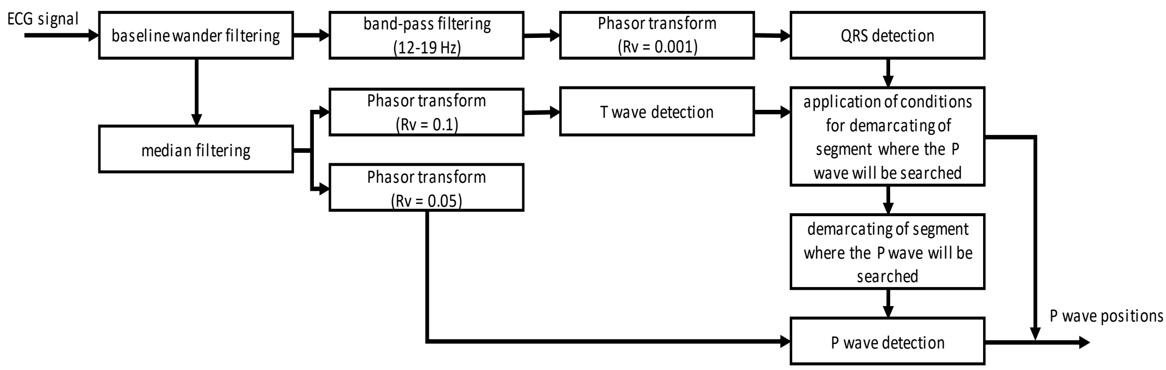

Figure 1: Block diagram of P wave detection using phasor transform.

2.1. PREPROCESSING

ECG signal is firstly filtered using the spectral lines resetting with cutoff frequency of 0.67 Hz to eliminate baseline wander and DC component. For QRS detection, signal is filtered by band-pass filter with cutoff frequencies of 12 Hz and 19 Hz for suppressing P and T wave. For P and T wave detection, the ECG signal is smoothed by nonlinear median filter. The length of the median filter window was set to 40 ms for two reasons: a) to smooth the signal properly, b) to avoid suppression of P wave (its duration is usually 100 ms). This setting proved the best results.

2.2. PHASOR TRANSFORM

PT transforms each sample of the signal into a complex number preserving the signal information. Transformation of each ECG sample into a phasor signal enhances changes of the waves in the ECG signal. Thus, considering instantaneous phase variation in consecutive samples of the transformed ECG, the slight variations provoked by P waves and T waves in the original signal are maximized. It can be observed in Figure 2. Therefore, PT makes their detection and delineation noticeably easier [5]. For detection of ECG waves, the PT was firstly used in [5].
Phasor transform is defined as

$$y(n) = R_V + jx(n), \tag{1}$$

where $y(n)$ is the complex signal, R_V is a constant value and $x(n)$ is the original signal. The magnitude $M(n)$ is computed as

$$M(n) = \sqrt{R_V^2 + x(n)^2} \tag{2}$$

and phase (phasor signal) $\varphi(n)$ is computed as

$$\varphi(n) = tan^{-1}\left(\frac{x(n)}{R_V}\right). \tag{3}$$

The degree with which ECG waves are enhanced in phasor signal is determined by the value of R_V. The value of R_V is always within the interval <0, 1>. In case of R_V = 1, the phasor signal is the same as the original signal. The only difference is normalization of phasor signal to the interval <0, $\frac{\pi}{2}$>. If R_V = 0, the phasor signal contains only two values: 0 and $\frac{\pi}{2}$. A constant value of R_V is considered as a real part of transformation, whereas the imaginary component of the transformation is the original value of the ECG sample. In this work, the values of *Rv* were determined heuristically.
The example of phasor signal $\varphi(n)$ of ECG signal is shown in Figure 2.

2.3. QRS DETECTION

In case of QRS detection, phasor transform of ECG signal with R_V = 0.001 is performed. In such preprocessed signal $\varphi(n)$, we search for maxima in sliding window of 300 ms size. The next step is

to check, whether the found maxima are higher than the adaptive threshold. The value of the adaptive threshold is derived from the standard deviation of phasor signal calculated in moving window of 2 s size. Threshold is established as a double of standard deviation in a given window. The positions of such maxima are considered as positions of QRS complexes (R waves).
Finally, it is checked, whether the interval between two subsequent QRS complexes (RR interval) is not 1.75× (or more) longer than the previous one. If it is longer, backward searching is performed. In this case, it is searched for the maximum in the given segment in the magnitude signal $M(n)$. A new threshold is established as 0.3× amplitude of previously detected R wave and the position of maximum is considered as the position of QRS complex.

2.4. T WAVE DETECTION

QRS complex as a reference is used for T wave detection. The area after actual QRS complex $R(i)$ is selected as $R(i)+0.16\times RR(i+1)$ to $R(i)+0.57\times RR(i+1)$. In the next step, phasor transform with $R_V = 0.1$ is applied only for this segment. The maximum of phase variation in demarcated segment is considered as a position of T wave.

2.5. P WAVE DETECTION

For P wave detection, the QRS complex as a reference is used. The area before QRS complex is demarcated in median filtered signal (as mentioned in chapter 2.1.) with respect to the length of $RR(i)$. The area for searching P wave is demarcated from $R(i)-0.7\times RR(i)$ to $R(i)-0.07\times RR(i)$ before actual R wave. PT with $R_V = 0.05$ is performed only for this segment. The example of PT output of ECG signal for detection of P wave is shown in Figure 2. The P waves (which are not visible in the original signal) are in phasor signal significantly enhanced and therefore easier detectable.

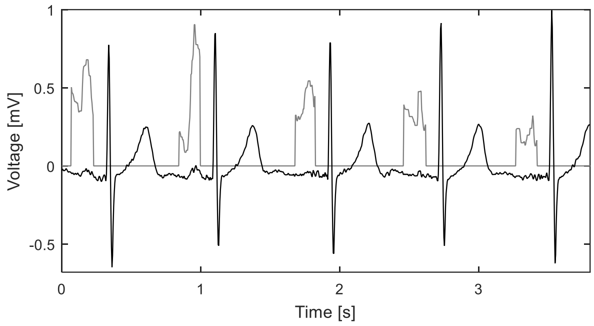

Figure 2: The example of phasor signal (grey curve). It was computed only from the relevant segment (from $R(i)-0.7\times RR(i)$ to $R(i)-0.07\times RR(i)$) of the original ECG signal (black curve).

In demarcated P wave segment in phasor signal, the maximum is found and this is considered as a potential P wave. Thereafter it is verified, whether the position of currently detected P wave is located after the position of T wave from previous heartbeat. If this criterion is not met it means, that instead of P wave, the T wave from the previous heartbeat was detected. The P wave is probably not present in actual heartbeat or it is hidden in previous T wave. In this case, the position of such P wave is deleted.
The second criterion is that the current heartbeat is not premature ventricular contraction. The validation of this criterion is performed by calculating the area under the curve (AUC) of QRS complex. The onset and offset of QRS complex is set 60 ms before and after the detected R wave, respectively. If the AUC of the current QRS complex is at least 1.2× larger than the average AUC of all previous QRS complexes, the heartbeat is considered as the premature ventricular contraction. In this case, the P wave of current heartbeat (if it is detected) is deleted.
The third criterion checks, whether the current $RR(i)$ interval is not 1.6× (or more) longer than the previous one. If it is longer, the dissociated P wave is searched. The P wave is then searched in segment that begins 200 ms after previous T wave and ends 200 ms before currently detected P wave.

In this segment, PT is applied with the same conditions as in the case of searching normal P wave (before QRS). The maximum detected in this segment is considered as a potential P wave.
Situation, when the current *RR*(*i*) is at least 1.6× longer than the previous one can arise as well in case, when the supraventricular extrasystole appears in the signal. In this case, it is important to avoid searching for the dissociated P wave, because it is not present. Therefore, the parameter *RR*(*i*-1) + *RR*(*i*) (the sum of the previous and current RR interval) is calculated. It is checked, whether the value of the parameter lies within the interval <1.8×*RR*(*i*-2), 2.2×*RR*(*i*-2)>. If it does, we suppose that the current *RR*(*i*) interval is prolonged due to the presence of supraventricular extrasystole and thus, the dissociated P wave is not searched.
Finally, the last condition is applied. The voltage of the P wave must be higher than the value computed as 0.1× voltage of actual R wave. To precise the position of P wave peak, the maximum is searched in the original signal 20 ms before and after the maximum detected in the phasor signal.

3. RESULTS

3.1. DETECTION OF P WAVE DURING THE SECOND-DEGREE AV BLOCK

Proposed algorithm for P wave detection was tested on the whole signal no. 231 from the MITADB, which contains the second-degree AV block. The authors of [2] used the same signal for testing their P wave detection algorithm. The MITADB does not contain annotations of P wave. The authors of [2] provided their own annotations as well as we did. Nevertheless, they used only a part of the signal for testing purposes and they did not specify which one (the only available information is that testing was done on 838 P waves). Therefore it is not possible to test all P wave detection algorithms on the same data. They reached accuracy Acc = 84.08 % (sensitivity Se = 72.79 % and positive predictivity PP = 99.51 %) as is shown in Table I. In this article, very popular algorithm for ECG component detection (ecgpuwave [3]) was tested on the same signal with Acc = 66.40 % (Se = 49.76 % and PP = 99.76 %).

Method	Acc [%]	Se [%]	PP [%]
This work	99.84	99.94	99.74
Ecgpuwave [3]	66.40	49.76	99.76
PP rhythm tracking [2]	84.08	72.79	99.51
PT [6]	88.52	78.06	98.98

Table 1: Performance of the P wave detection.

The proposed method was also compared with our previously published algorithm [6]. This algorithm was tested on the whole signal no. 231 with Acc = 88.52 % (Se = 78.06 % and PP = 98.98 %). This result is better than the results of authors mentioned above. The algorithm achieved higher accuracy and it was tested on the whole signal (not just on any part). It is worth noting, that the signal includes segments which are not considered as AV block.
Although the proposed algorithm was tested on the whole signal no. 231, the achieved results are

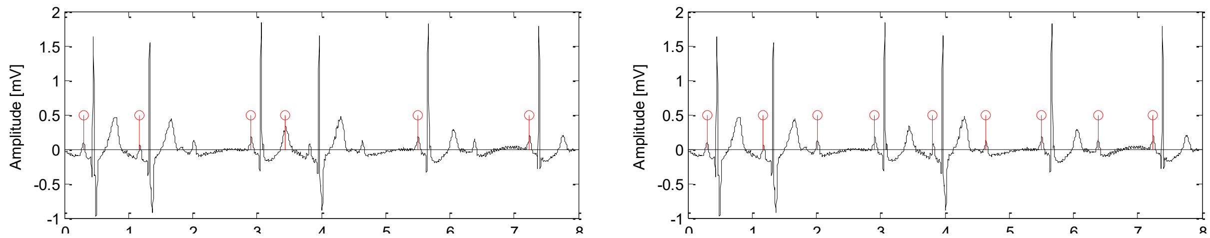

Figure 3: The results of P wave detection using algorithm [4] (left) and proposed algorithm (right).

Acc = 99.84 % (Se = 99.94 % and PP = 99.74 %). Only 6 out of 1,994 P waves were detected incorrectly. It means, that even if these mistakes were present in the segment of the signal used for testing by authors of [2] (838 heartbeats), the accuracy of our algorithm would be 98.66 %. This result is still much better, than the result achieved in [2]. The examples of results of the proposed algorithm and algorithm [6] are shown in Figure 3.

3.2. DETECTION OF P WAVE DURING PHYSIOLOGICAL RHYTHM

For validation that the proposed algorithm is functional also for signals with physiological rhythm, it was tested on the freely available standard QTDB [4] (it contains around 3,600 beats). The results are summarized in Table 2. The results of P wave detection using the proposed algorithm are better than the results presented in other works. These results confirmed, that the proposed algorithm can be used for detection of P waves in signals with second-degree AV block as well as signals with physiological rhythm. The algorithm does not produce false positive P wave detections.

Method	**Acc [%]**	**Se [%]**	**PP [%]**
This work	99.85	99.88	99.82
PT [2]	99.52	99.28	99.75
Wavelet transform [1]	95.01	98.87	91.03

Table 2: The results of P wave detection in QTDB.

4. CONCLUSION

In the article, highly effective algorithm for P wave detection is proposed. The algorithm can detect P wave in normal ECG signals (tested on QTDB) as well as in signals including second-degree AV block. The algorithm is based on PT and use of newly introduced rules, which comes from knowledge about heart manifestation. These rules enable to find P wave in the right location. The results of P wave detection using proposed algorithms outperform the results of other authors for both pathological and physiological signals. Using QTDB for testing, the accuracy of detection is 99.85 % (Se = 99.88 % and PP = 99.82 %). Testing the algorithm on signal no. 231 (with second-degree AV block) from MITADB, the accuracy of P wave detection is 99.84 % (Se = 99.94 % and PP = 99.74 %). This algorithm is appropriate for automatic detection of second-degree AV block, which is conditioned by correct detection of P wave.

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