A Novel Method for the Detection of QRS Complex Using Vectorcardiographic Octants

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Abstract

Electrocardiogram (ECG) is currently the most widely used in clinical practice for the diagnosis of heart disease. However, there is a vectorcardiography (VCG) method that in certain cases can detect some pathologies with higher accuracy than a 12 lead ECG. In this work, we present a new method of QRS complex detection based on the octant theory introduced by Laufberger. The presented algorithm is based on the principle of numerical sequence analysis. This search algorithm consists of three main parts: Window search in number series, Modification of window search in number series due to a longer search window, and modification of number series due to a shorter search window. These individual parts form one whole of the whole algorithm. The accuracy of the presented algorithm was tested on 80 physiological records from the PTB database by calculating accuracy, sensitivity and specificity. The percentage accuracy for healthy records was 98.28% sensitivity 98.2% and specificity 98.1%.This algorithm has low computational complexity and can be a useful tool to simplify the work of cardiologists in the analysis of long records.

1. Introduction

Electrocardiogram (ECG) is currently the most commonly used method in clinical practice to measure the electrical activity of the heart. This method most often measures potentials from electrodes placed on the patient's body. The most commonly used ECG system is a 12-lead ECG. This system monitors basic cardiac electrical activity from 12 different measurement angles.

In addition to the ECG, there is an alternative in the form of Vectorcardiography (VCG). This method consists in measuring the electrical activity of the heart in three planes (sagittal, horizontal and transversal), which are perpendicular to each other. The heart acts as a dipole from which it is possible to analyze changes in the dipole moment over time. Thus, it is possible to convert one-dimensional information from each of the three leads to three coordinates in an orthogonal coordinate system [1–3]. The vectorcardiogram is presented in three-dimensional space and has the shape of a three-dimensional curve defined by the movement of the dipole in time. The most commonly used lead system for measuring VCG is Frank's lead system. In some cases, VCG achieves better results in the detection of certain arrhythmias. For example, in paper [4, 5] dealing with atrial dilation and right ventricular hypertrophy, a higher sensitivity in VCG detection was found. The authors suggested increasing the frequency of VCG use in clinical practice.

The above work was preceded by the work of Professor Laufberger dealing with octant theory. Professor Laufberger published a series of articles in 1980-1982, in which he analyzed the distribution of the VCG curve in the cardioelectric space. The Cartesian coordinate system was divided into eight subspaces called octants. These octants divide the spatial vectorcardiographic curve into individual parts. In the abstract model, the real heart space can be represented by a cube, which consists of eight fields or octants, which are numbered according to the rule in Table 1.

Table 1. Rule distribution for dividing the VCG curve into octants

	Lead		
Octant No	X	Y	Z
1	+	+	+
2	+	+	-
3	-	+	-
4	-	+	+
5	+	-	+
6	+	-	-
7	-	-	-
8	-	-	+

In his work, Laufberger analyzed the sequence of octants and defined patterns of octant numbers for the QRS complex. He dealt with the variability of the passage of the

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QRS complex through individual octants and defined some patterns of the QRS sequence for healthy and pathological records [6–9].

This work is based on the analysis of the sequence of octant numbers defined by Professor Laufberger in order to create an algorithm for automated detection of the QRS complex. This new number series processing algorithm is intended to provide a new perspective on existing and more complex QRS detectors.

2. Material and Methods

2.1. Study population

VCG records from the Physikalisch - Technische Bundesanstalt diagnostic database, which contains records from healthy volunteers and patients with various heart diseases, were used in this study. The individual records of this database consist of 15 simultaneously recorded signals, namely a 12-lead ECG and a 3-lead VCG. Signals were acquired for 2 minutes with a 16-bit resolution in the range of ± 16.384 mV and sampled at a sampling frequency of 1 kHz. A total of 80 healthy (HC) subjects were used for this study.

2.2. Data Preprocessing

Due to the fact that these are biological data, interfering components are also measured together with the required signal. The biggest interfering component in the signal that significantly affects the analysis of octant numbers is the fluctuation on the isoelectric line. To remove this interfering component, a Savitz - Golay filter with order 2 and a window length of 1200 was used. This value of the window length was based mainly on the sampling frequency and signal length. The result of this filter is the detection of fluctuations, which are removed from the desired signal afterwards.

2.3. Research approach

In the first step, it was necessary to divide the VCG loop into individual octants according to the rule in Table 1. Figure 1 shows an example of the lead X divided into octants according to the color rule given in Table 2. From this distribution we get a vector of numerical values (1 to 8) corresponding to individual octants.

After dividing into individual octants, there was a problem with very short octant numbers. There may be situations where, for example, in some QRS complexes there is a very short part of the octant number that does not occur in other ORS complexes of the same record. These short numbers can only have a maximum of 3 samples at a sampling frequency of 1 kHz. This short number can

Table 2. Color marking of individual octants

Octant No	Color
1	Red
2	Green
3	Blue
4	Yellow
5	Black
6	Cyan
7	Magenta
8	Gray

be a problem in the QRS complex search algorithm. This problem is mainly due to the high sampling frequency and these numbers are mainly a disturbing component in our number series. For this reason, short octant numbers were ”filtered”. Filtration was performed by detecting octant numbers that lasted less than 6 samples. This degree of filtration was chosen mainly because in such a short interval at a sampling frequency of 1 kHz there will be no significant cardiac changes.

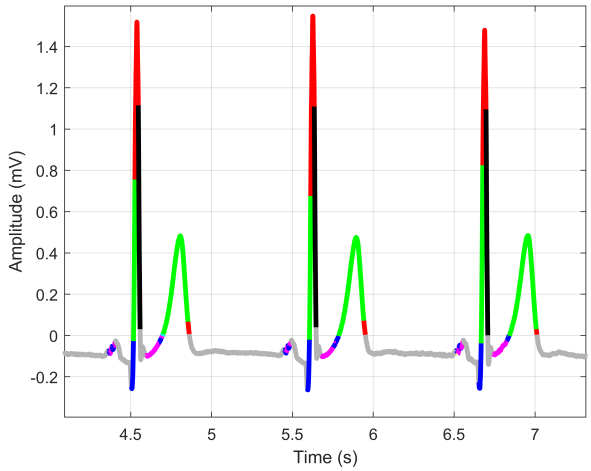

Figure 1. Distribution the record into individual octants with the appropriate color coding

After adjusting the sequence of octant numbers by filtering, the first significant point of the QRS complex, peak R, was detected. Assuming that R peak has the highest amplitude in the whole record, the cyclic algorithm searches for the maximum in each octant number then compare with the maximum detected in the next octant until the next maximum is smaller than the previous one. The maximum detected value is taken as the R peak.

The detected R peaks then serve as starting points for the detection of peaks Q and S. In the case of peak Q, the search algorithm searches from peak R for the mini-

mum in individual octants that are before peak R. Once the minimum is detected, this minimum is compared with the minimum in the next previous octant. This procedure is repeated until the detected minimum in the respective octant is greater than the minimum of the previous octant. The smallest detected minimum is as peak Q. The same principle is used to detect peak S, except that the minima are sought after point R. The detected peaks can be seen in Figure 2.

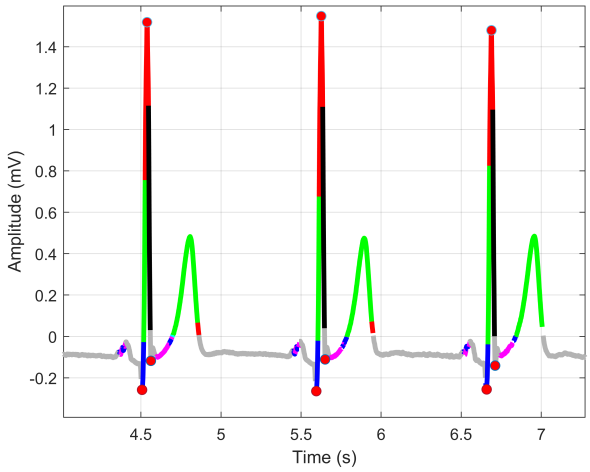

Figure 2. Detection of Q, R and S peaks using octants - 2D visualization

From the detected QRS peaks, the QRS sequence was subsequently defined as the octant interval between the Q and S peaks.

The next step is automatic QRS detection based on the defined QRS section (QRSosn). Proposed search algorithm consists of three steps. In the first step, the algorithm works on the principle of searching for detected QRSosn in the whole sequence of octant numbers of the given record. Figure 3 shows the detected search QRSosn in the red box and the sequence of octant numbers. QRSosn "slides" along a series of numbers and detects the QRS complex if it encounters the same sequence as in the search window (red numbers in a numerical sequence).

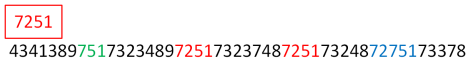

Figure 3. Search for patterns according to the defined window - Detection of only red patterns

This method of detection is not very reliable, despite the applied filter of short octant numbers. In some records, the QRSosn is slightly different for QRS throughout the record. This may be due to insufficient filtering of short octant numbers, which in some cases have one more sample than the filter rule used. For this reason, the second part of the algorithm is to modify the sequence of octant numbers. In this part, the algorithm finds the first position of the potential QRS complex in the octant series and looks at the following positions in the window and the number sequence. If the i-th position in the number series does not match the i-th position of the window, the algorithm skips this position in the number series. It then compares the i-th position of the window with the i+1-th in the numerical series. These numbers already match, and the algorithm continues to compare numbers along the entire length of the search box.

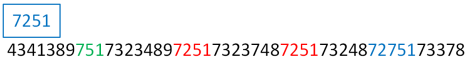

Figure 4. Modification of the octant series sequence by tracking the i+1-th octant number in the potential QRS - Extension of the detection by the blue part in the pattern

Similarly, QRSosn may be composed of more numbers than potential QRS in a sequence of octant numbers. Therefore, the third part of the algorithm finds the first position of the potential QRS complex and looks at the following positions in the window and the number sequence. Here the algorithm detects the difference between the window and the sequence, see Figure 5. Therefore, the algorithm skips the mismatched position and compares the i+1-th position of the search window with the i-th position in the octant sequence. Here the number of octants agrees and the algorithm continues along the entire length of the window.

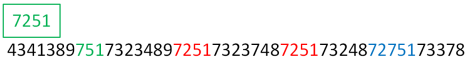

Figure 5. Modifying the search window by tracking the i+1-th octant number in the defined window - Extending the detection by the green part in the pattern

2.4. Evaluation parameters

The described algorithm for QRS complex detection was tested on 80 patient records from the PhysioNet PTB database. The success of the algorithm was analyzed by calculating the percentage accuracy of detection, sensitivity and specificity.

$$Acc = \frac{Number\ Of\ Detected\ QRS}{Total\ Number\ Of\ QRS} \cdot 100 \qquad (1)$$

$$Sens = \frac{TP}{TP + FN} \qquad (2)$$

$$Spec = \frac{TN}{TN + FP} \tag{3}$$

where TP (True Positive) indicates QRS complexes correctly detected, FN (False Negative) are QRS complexes that were not correctly detected, FP (False Positive) indicates inaccurately detected QRS complexes and TN (True Negative) indicates correctly undetected QRS complexes.

3. Result analysis

For healthy records, the algorithm achieved a percentage accuracy of 98.28% according to Equation 1. Figure 6 shows an example of detected QRS complexes with the beginning of the QRS complex defined by the first octant of QRSosn.

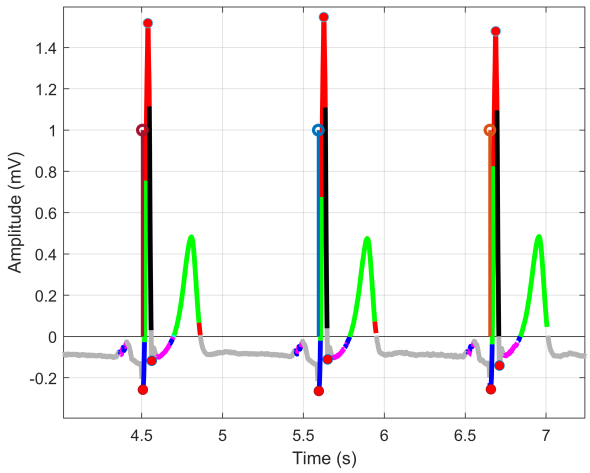

Figure 6. Detected QRS peaks indicating the beginning of the QRS complex, which is defined by the appropriate octant number

Based on the formulas (2) and (3), the specificity of the presented algorithm for healthy records is 0.981 and the sensitivity is 0.982.

4. Conclusion

We have introduced a new possibility of QRS detection based on a sequence of octant numbers defined by Professor Laufberger. This proposed algorithm consists of three main parts: searching for the same QRSosn patterns in the number series, modifying the QRSosn due to the occurrence of shorter QRS sequences in the number series, and modifying the number series due to the occurrence of shorter QRSosn. The main benefit of the proposed algorithm is low computational complexity. Vectorardiography has been placed in the background in the last century due to its complexity of interpretation. Nowadays, with more advanced technologies, more and more work is dealing with VCG analysis. The result of this work is a new QRS complex algorithm, which was analyzed on healthy records with a detection accuracy of 98.28%, a sensitivity of 0.982 and a specificity of 0.981. Further work in this area is the possibility of improving the algorithm for pathological records, detection of extrasystoles by subtraction analysis and analysis of suspicious findings.

Acknowledgments

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