The algorithm of shockable rhythms detection for automatic external defibrillator

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Introduction

Every year in Russia, about 300 000 people die from sudden cardiac arrest. In more than 80% of the cardiac arrest occurs outside the clinic. The one of the most effective method for saving life after cardiac arrest is passing through the chest of patient high-power electrical pulse with duration about few milliseconds (defibrillation). Every minute of defibrillation delay reduce the chance of survival for 7-10%. In this case automatic external defibrillator (AED) can be applied, because AED can be used in the absence of qualified persons. The main part of AED processor is the algorithm of shockable rhythms detection that automatically decides when shock is needed. The effective of defibrillation and accuracy of heart rhythm detection depends on parameters of the algorithm. In this article described method of finding optimal sensitivity-specificity ratio and given features of ECG analyzing in algorithm for AED.

Methods

The algorithm which integrates in processor of AED must have limited time for decision (up to 15 seconds [10]) and high parameters of sensitivity and specificity [1]. Usually, for making decision in the algorithm are used one or several different methods [2]. The choice of methods for detection of shockable heart rhythms base on the following criteria:

– variety of approaches for detection of shockable heart rhythms. Must be considered: form of ECG signal, frequency of peaks, power spectrum, amplitude, etc.;

– complexity of the algorithm. Although modern processors have high efficiency, the time of data processing is limit the total number of methods have been considered.

For each method parameter or a set of parameters must be defined. AED make decision according with that parameters, i.e. if the defined parameter can change from 0 to 1, and threshold value, for example 0.5, all values are above 0.5 correspond to the rhythm that requires defibrillation.

If threshold value changes, the total parameters of sensitivity and specificity have to be changed too. If sensitivity has increased the specificity always reduced or not changed. The main point in algorithm is find optimal sensitivity-specificity ratio. In that paper optimal ratio determined as a coefficient of efficiency:

$$Eff = \frac{Se * Sp^2}{10000},$$

where Se – sensitivity, Sp – specificity in percentages. The choice of that coefficient based on idea that chance of false defibrillation must be minimal. The value 10000 used for better visualization of Eff.

In algorithm used six different methods based on principles described above.

Below described how coefficient of efficiency used for finding optimal sensitivity-specificity ratio in method – the frequency of a signal out of inform interval.

The inform interval of ECG signal amplitudes $(-0.2 \cdot Max; 0.2 \cdot Max)$ can be used for detection of signal type, Max – maximum value of ECG amplitude in analyzed time window [6]. In method counted amount of values with amplitude out from interval $(-0.2 \cdot Max; 0.2 \cdot Max)$. Defined parameter calculated as:

$$W = \frac{N_1}{N_1 + N_2},$$

where N_1 – amount of counts with amplitude out from inform interval, N_2 – amount of counts with amplitude in inform interval. If W above than threshold value (wp) the heart rhythms will be detected as shockable. The algorithm analyzed on ECG signals 8201 – 8210 of AHA data base [9], that signals chosen because each of them have intervals with and without shockable rhythms of heart. On figure 1 and 2 presents sensitivity, specificity, and coefficient of efficiency in method. The optimal wp=*0,3*, because that value of Eff maximum.

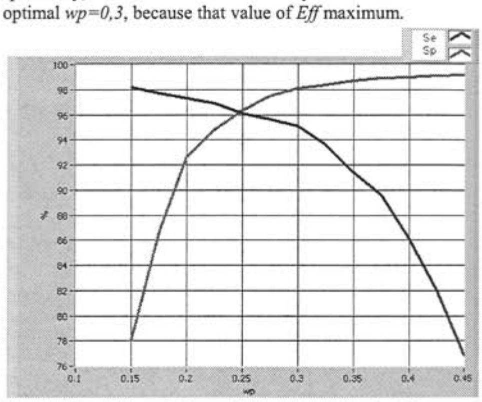

Fig. 1: Sensitivity and specificity in method of the frequency of a signal out of inform interval

According with that example were fond optimal threshold values for other five methods from the algorithm. Those methods described below.

Modified VF Filter

The mean period of a fixed length of data is obtained from equation:

$$T = 2\pi \sum_{i=1}^{m} |V_i| (\sum_{i=1}^{m} |V_i - V_{i-1}|)^{-1},$$

where V_i – signal samples, m – number of data points on analyze time window. The narrow band-stop filter is simulated by combining the ECG data with a copy of the data shifted by half a period. The VF-filter leakage (L) is computed as [7]:

$$L = \sum_{i=1}^{m} |V_i + V_{i-(T/2)}| * \left[\sum_{i=1}^{m} (|V_i| + |V_{i-(T/2)}|) \right]^{-1}.$$

Shockable heart rhythm was detected if parameter L <threshold value (*l=0,7*) on more than 80% of time window.

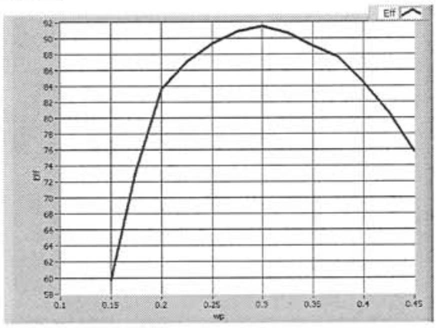

Fig. 2: Coefficient of efficiency in method of the frequency of a signal out of inform interval

Modified waveform factor

In method provides a running average of the ECG signal amplitude normalized to the R-wave amplitude [8]. For each QRS-complex, which detected as in [4], the instant *FFi* is calculated:

$$FFi = \frac{100 * \sum_{1}^{N} abs(A_n)}{N * abs(A_r)},$$

where N – total number of samples between the current and the previous R-wave, A_n – value of the nth amplitude of the ECG, A_r – value of the current R-wave peak.

Shockable heart rhythm was detected if parameter *FFi*>threshold value (*fp=16*) on more than 70% of time window.

Peaks Count Method

Method based on the fact that shockable heart rhythm is usually chaotic contractions of myocardium ventricles and this phenomenon is registered on ECG. The number of peaks (N) on the ECG signal whose amplitude is greater than some specified level from the time window, can be used as parameter for shockable rhythm detection. The specified level calculated as:

$$A_n = \begin{cases} 0{,}3 \max |X_n|, & if \max |X_n| < 3\,mV; \\ A_{n-1}, & if \max |X_n| \geq 3\,mV, \end{cases}$$

где X_n – array of the signal data on nth time window. Shockable heart rhythm was detected if *N*>threshold value (*np=5*).

Spectral Method

Method based on fact that the main power spectrum of the ECG signals during shockable rhythm is concentrated at frequencies up to 9 Hz [3], whereas the normal sinus rhythm may have the power spectrum at frequencies more than 9 Hz. Thus, the division of the absolute power spectrum (*Pw*) of the signal minus the frequency ranges from 0 to 9 Hz in positive harmonics (Pw_0^9) on the absolute spectral power of the signal at the selected time window can be used for shockable rhythms detection:

$$S = \frac{Pw - Pw_0^9}{Pw}.$$

Shockable heart rhythm was detected if *S*<threshold value (*sp=0.53*).

Power spectrum for a discrete signal is defined as:

$$Pw = \left| \sum_{n=0}^{tN} f_n e^{-i\omega n} \right|^2,$$

where f_n – discrete representation of the signal, t – time interval in seconds, N – sample rate.

Method of Maximum Signal Rising

Initially, the signal was passed through a bandpass filter with a bandwidth 14.5 and 23.5 Hz, after filtration only a narrow band present in the ECG spectrum, which corresponds to QRS-complex [5]. The absence of the QRS-complexes in some cases can be interpreted as shockable rhythm of heart.

This algorithm based on in ECG signal after filtration the QRS-complex has a greater slope than in shockable heart rhythm. The criterion for the method is:

$$Y = \max |x_{(i)n} - x_{(i-2)n}|,$$

Shockable heart rhythm was detected if parameter Y <threshold value (*yp=0.255*) on more than 30% of time window.

Results

The optimal parameters for described above methods correspond to time window in 2 seconds. For each time window will be individual optimal parameters. The six methods with optimal parameters were combined in algorithm. Table 1 shows the results of described algorithm on databases of ECG signals [11].

Table 1: Sensitivity and specificity on databases of ECG signals

DB	Se(%)	Sp(%)
AHA	97,2	99,9
MIT	90,0	99,9
CU	83,2	88,4
Total results	90,3	98,7

Also algorithm was analyzed on ECG signals of pigs, because cardiac anatomy of the pig it is similar to that of man. In experiment used five animals, through the chests of pig passed alternating current with duration about 1-2 seconds, what caused shockable rhythm of heard. Time of shockable rhythm for each animal was approximately 10 minutes. That time used because time between sudden cardiac arrest and first impulse of defibrillation usually several minutes, during that time amplitude-frequency characteristic of signal can significantly changed. Behavior of algorithm during shockable rhythm was analyzed. Table 2 shows the results of algorithm on animals ECG.

Table 2: Sensitivity and specificity on animals ECG

	Se (%)	Sp (%)
Pig 1	99,7	99,1
Pig 2	98,8	97,0
Pig 3	99,6	93,7
Pig 4	99,3	98,4
Pig 5	99,7	98,4
Total results	99,4	97,3

Conclusion

Described algorithm has high sensitivity and specificity, what allow use it in AED.

Using of coefficient of efficiency allow find optimal parameters for each method from algorithm.

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