Ventricular fibrillation detection in automatic external defibrillators

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***Abstract*— Sensitivity and specificity of ventricular fibrillation detection algorithms should be nearly 100% in automatic external defibrillators. For achieving these values in the paper described method of algorithms combination based on the weights coefficients and coefficients of efficiency. The algorithm was tested on annotated databases of ECG signals (AHA, MIT, CU).**

Keywords: sensitivity, specificity, defibrillation, weights coefficients

I. INTRODUCTION

Every year in the world from sudden cardiac arrest died millions of people [1]. In more than 80% of sudden cardiac arrests occur outside the clinics. Automated external defibrillators (AEDs) used for resuscitation patients in case of sudden cardiac arrest both inside and outside the clinic and can be used not only qualified medical personnel. During defibrillation through the patient's chest passed power electric impulse with duration about few milliseconds. Each minute of defibrillation delay reduces chance for successful survival by 7-10%. The main element of AED software is algorithm of ventricular fibrillation (VF) detection. Sensitivity and specificity parameters of the VF detection algorithm define quality of ECG analysis and defibrillation effectively. There are a lot of VF detection algorithms [2, 3]. Development of computer technology allows using several algorithms in complex [4, 5]. The ability of several methods using in complex allows increasing sensitivity and specificity in VF detection algorithm. In this paper described method of algorithms combination for VF detection.

II. METHOD

The choice of methods for VF detection bases on the following criteria: 1. variety of approaches for detection of VF. Must be considered: form of ECG signal, frequency of peaks, power spectrum, amplitude, etc.; 2. complexity of the algorithm. Although modern processors have high efficiency, time of data processing is limit the total number of methods have been considered. In paper described 6 algorithms chosen according with principles described above. The algorithms were analyzed on ECG signals 8201 – 8210 of AHA data base [6], that signals chosen because each of them have intervals with and without VF.

1. Signal out frequency of inform interval. The inform interval of ECG signal amplitudes (-0.2*Max*; 0.2*Max*) can be used for detection of signal type, *Max* – maximum value of ECG amplitude in analyzed time gap [7]. In method counted amount of values with amplitude out from interval (-0.2*Max*; 0.2*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 VF.

2.Modified VF filter. The mean period of a fixed length of data is obtained from equation:

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

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 [8]:

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

VF was detected if parameter L <threshold value (l) on more than 80% of time gap.

3. Modified waveform factor. In method provides running average of the ECG signal amplitude normalized to the R-wave amplitude [3]. For each QRS-complex, which detected as in [9], 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. VF was detected if parameter *FFi*>threshold value (*fp*) on more than 70% of time gap.

4. Peaks count method.
Method based on the fact that VF 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 gap, can be used as parameter for VF detection. The specified level calculated as:

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

where X_n – array of the signal data on nth time gap. was detected if N>threshold value (*np*).

5. Spectral method. Method based on fact that the main power spectrum of the ECG signals during VF is concentrated at frequencies up to 9 Hz [10], 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 gap can be used for VF detection:

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

VF was detected if S<threshold value (*sp*).

6. 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 [11]. The absence of the QRS-complexes in some cases can be interpreted as VF.

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

$$Y = \max\left|X_{(i)n} - X_{(i-2)n}\right|,$$

VF was detected if parameter Y <threshold value (*yp*).

The main point in algorithm is found optimal sensitivity-specificity ratio. In that paper optimal ratio determined as a ***coefficient of efficiency***:

$$Eff(a) = \frac{Se(a) \cdot Sp(a)^2}{10000},$$

where *Se* – sensitivity, *Sp* – specificity in percentages, a – threshold value which separate VF and normal heart rhythm. The choice of that coefficient based on idea that chance of false defibrillation must be minimal. Influence of each algorithm on result decision based on weight coefficients:

$$Wk = \max\left[Eff(a)\right].$$

Algorithms combination. Final decision about presents or absents VF rhythm was made according with criterion:

$$\begin{cases} \sum_{i=1}^{j=6} Keff_i > 0,\ no\,VF, \\ \sum_{i=1}^{j=6} Keff_i \leq 0,\ VF, \end{cases}$$

where

$$Keff(a) = \begin{cases} -(Wk - Eff(a)),\ a > a_{\max}, \\ Wk - Eff(a),\ a \leq a_{\max}, \end{cases}$$

$a_{\max}$ – threshold value corresponding to *Wk*.

Se(a) and *Sp(a)* for each *Keff* was calculated, firstly experimentally and secondly mathematically in concordance with experimental points “Fig. 1” and demonstrated in Table 1.

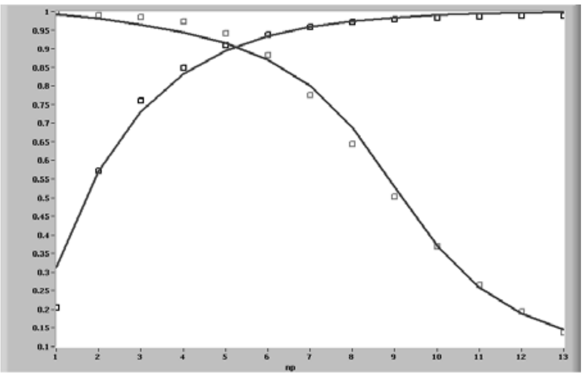

Figure 1. Sensitivity and Specificity in peaks count method

TABLE I. SENSETIVITY AND SPECIFICITY FOR EACH ALGOTIRHM

Method	Sensitivity and Specificity
Modified VF filter	$Se(a) = 0{,}4\arctan(7(a-0{,}6)) + 0{,}54$ $Sp(a) = 1 - 4{,}3\cdot 10^{-6}\exp(13{,}67a)$
Modified waveform factor	$Se(a) = -0{,}32\arctan(0{,}15(a-26)) + 0{,}57$ $Sp(a) = 1 - \exp(-0{,}16a)$
Spectral method	$Se(a) = 1 - 4{,}7\cdot 10^{8}\exp(-40a)$ $Sp(a) = -0{,}27\arctan(25(a-0{,}57)) + 0{,}71$
Frequency of a signal out of inform interval	$Se(a) = 1 - 0{,}0041\exp(8{,}8a)$ $Sp(a) = 1 - \exp(-12{,}5a)$
Peaks count method	$Se(a) = -0{,}35\cdot\arctan(0{,}49(a-9)) + 0{,}53$ $Sp(a) = 1 - 1{,}1\exp(-0{,}47a)$
Method of maximum signal rising	$Se(a) = 1 - 1{,}3\exp(-9a)$ $Sp(a) = -0{,}32\arctan(6(a-0{,}48)) + 0{,}41$

III. RESULTS

The optimal parameters for described above methods correspond to time gap in 2 seconds. For each time gap will be individual optimal parameters. Table 2 shows the results of described algorithm on databases of ECG signals [12].

TABLE II. SENSITIVITY AND SPECIFICITY ON DATABASES OF ECG SIGNALS

DB	Se(%)	Sp(%)
AHA	96,6	99,7
MIT	91,3	99,9
CU	84,0	81,3
Total	91,5	98,7

Standard databases of ECG signals used for VF detection algorithms have some shortcomings: 1. total time of VF in databases from table 2 about 3.5%; 2. Duration of each VF in described databases about few minutes.

So algorithm was analyzed on ECG signals of pigs, because cardiac anatomy of the pig is similar to that kind of human [13]. In experiment were used five animals, through the chests of pig passed alternating current with duration about 1-2 seconds, that caused VF rhythm of heard. Time of VF rhythm for each animal was approximately 10 minutes. That time used because time between sudden cardiac arrest and first impulse of defibrillation are usually several minutes, during that time amplitude-frequency characteristic of signal can significantly changed “Fig.2”. Behavior of algorithm during VF was analyzed. Table 3 shows the results of algorithm on animals ECG.

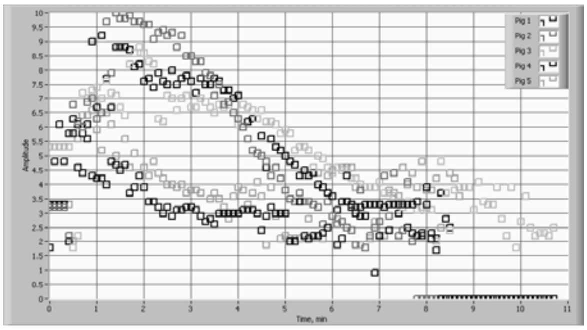

Figure 2. Maximum power spectrum changes during VF developing

TABLE III. SENSITIVITY AND SPECIFICITY ON ANIMALS ECG

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

IV. CONCLUSION

Developed VF detection algorithm has high sensitivity and specificity, and corresponded to requirements of standard [14], and can be used in AED.

The weighting coefficients allow to determine the significance of each algorithm in total decision and coefficients of efficiency adapts algorithms to changes in the ECG signal.

Presented method of algorithms combination, can be used for optimization automatic processing of medical data, where key parameters are sensitivity and specificity.

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