

False Alarms in Intensive Care Unit Monitors: Detection of Life-threatening Arrhythmias Using Elementary Algebra, Descriptive Statistics and Fuzzy Logic

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Abstract

Aims: A false alarm ratio of up to 86 % has been reported in Intensive Care Unit (ICU) monitors. Such a high value can lead to reduced staff attention and patient deprivation. We present a method for detection of specific arrhythmias – asystole, extreme bradycardia, extreme tachycardia, ventricular tachycardia and ventricular flutter / fibrillation – in accordance with the “2015 Physionet/CinC Challenge”.

Data: The method was trained with the use of 750 records and tested on 500 records from ICUs provided by Physionet.

Method: Invalid data segments are detected in each of the channels. Next, QRS complexes and RR intervals are found in all signals using a different QRS detection approach according to the signal source. The RR series obtained are tested for regular heart activity; if this fails, an arrhythmia-specific test is processed. Tests for individual arrhythmias are based on examination of QRS temporal distribution, comparison of heart rate (HR) with known limits, and observation of low-frequency ECG activities.

Results: Training-set sensitivity and specificity of 96 % and 89 % were achieved. A hidden test set resulted in a score of 81.39 (real-time event) and 84.96 (retrospective event).

1. Introduction

Arrhythmias are abnormalities in heart function. Some are present even in healthy subjects (as sparse ventricle beats or junctional escape beats), while others are seriously dangerous, even life-threatening. Intensive care units (ICU) are, for this reason, usually equipped with monitors able to detect life-threatening arrhythmias as asystole (missing beats for more than 4 s), bradycardia (HR < 40 bpm), tachycardia (HR > 140 bpm), ventricular tachycardia (a sequence of ventricle beats at HR > 100 bpm) and ventricular flutter/fibrillation (oscillatory waveform for more than 4 s).

The mentioned arrhythmias may lead to death in an extremely short time, for which reason the reaction delay of ICU monitors must be within 10 seconds of event onset, as defined in AAMI guidelines [1]. It is not acceptable to miss any life-threatening arrhythmias and it seems reasonable to sound the alarm whenever practically anything suspicious occurs in order to save a life. On the other hand, however, if we include the whole range of noises (produced by patient movement/manipulation, defective wiring, staff manipulation of equipment or wrong device settings, etc.), the false alarm ratio may amount to as much as 86 % [2] which is reflected in the decreased sensitivity of personnel to monitor warnings [3] and the mental deprivation of patients [4].

The task set by the Physionet “CinC Challenge 2015” [5] was to develop an algorithm to decrease the false alarm ratio of life-threatening arrhythmias.

2. Method

The goal of the proposed method is to process a multimodal record and state whether the arrhythmia alarm reported by the ICU monitor is true or false.

Data channels are first independently searched for invalid blocks (Fig. 1A) and QRS complexes (Fig. 1B). Using the QRS distribution and derived R-R information, each channel in the record is tested for regular heart activity (Fig. 1C). If any of the channels passes this test, a false alarm is reported and the process ends. If this is not the case, a specific arrhythmia test is executed (Fig. 1D).

2.1. Method input

The input for the proposed method is a 5-minute-long record from the ICU monitor at 250 Hz, containing two ECG channels and one or two pressure channels with arterial blood pressure (ABP) and/or photoplethysmograph (PPG). In view of the expected arrhythmia presence in the last ten seconds of each record (in correspondence with AAMI guidelines [1]), only the last 14 seconds are loaded and examined.

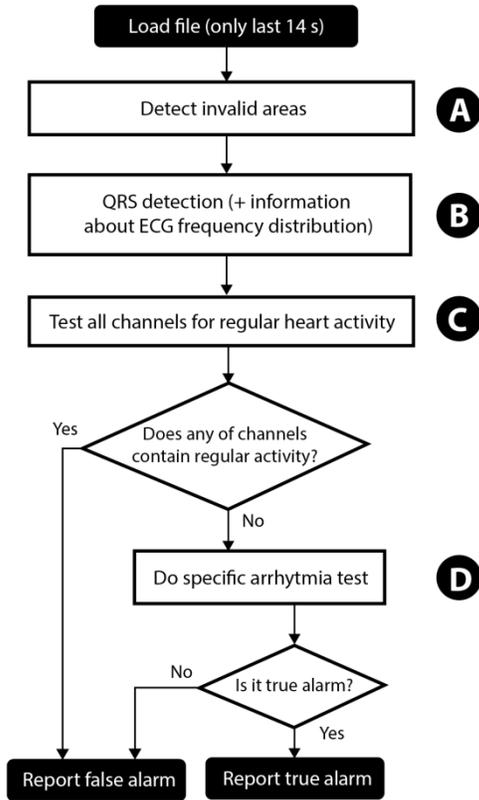


Fig. 1 – Method flowchart

2.2. Invalid data detection

After loading, areas with possibly invalid data are detected (Fig. 1A). Each signal is searched in 2-second blocks, and the minimal/maximal range, standard deviation and value limits are compared to limits defined separately for each signal type.

To identify areas with high-frequency noise, the amplitude envelope of the signal (at a frequency range of 70–90 Hz) is tested to check whether it falls within the permitted range.

In training records, signal saturation often occurs as a consequence of overloading monitor inputs and can raise false alarms. To find saturated areas, a histogram (10 bins) is computed and the amplitude of the first and last bin compared to the sum of the remaining bins.

Every following step ignores data marked as “Invalid”.

2.3. QRS detection from ECG

Detection of QRS complexes is based on amplitude envelopes of the ECG signal (Fig. 2 and 3). Amplitude envelopes in three frequency ranges are computed using Fourier and Hilbert transform – LF (1–8 Hz), MF (5–25 Hz) and HF (50–70 Hz). Local maxima above the zero level are found by subtraction: MF – HF. Descriptive

statistics is used to decide whether each maximum is or is not a QRS. Comparing the amplitude of LF and MF envelopes in the place of QRS is used to state a “Group” of QRS – ventricle beats usually have a higher amplitude at a low frequency than regular beats. This information is useful for ventricular tachycardia detection. Also, the maximum length of block (LF_{MAX}) when LF is higher than MF is stored for use with a ventricular fibrillation test.

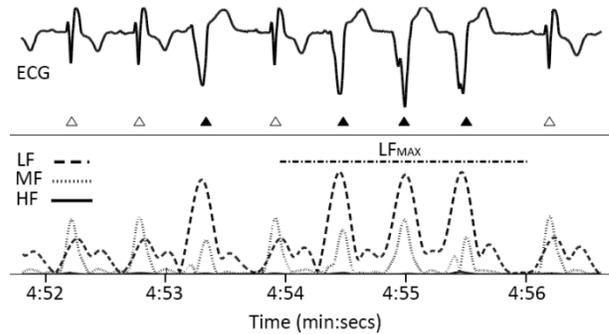


Fig. 2 – QRS detection. Top: raw ECG signal with detected QRS. White triangles are regular beats – Group 1, black triangles are ventricular beats – Group 2. Bottom: three amplitude envelopes for frequencies 1–8 Hz (LF), 5–25 Hz (MF) and 50–70 Hz (HF). The LF_{MAX} line marks the area with non-interrupted LF dominance (record “v532s”).

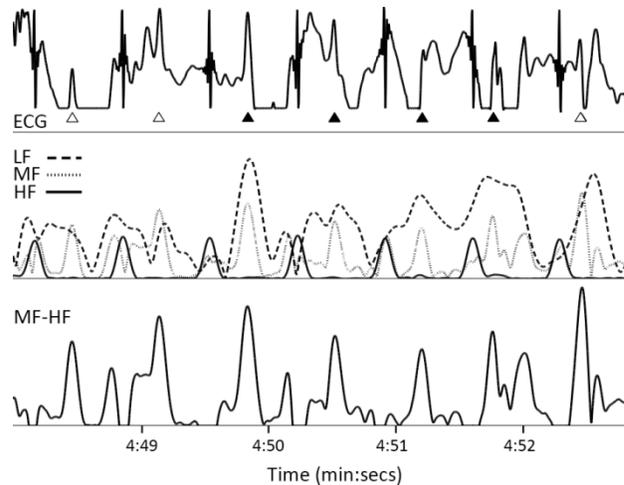


Fig. 3 – QRS detection, patient with pacemaker. Top: raw, damaged ECG. Middle: Frequency envelopes. Bottom: subtraction MF – HF, preventing detector from raising false QRS complexes by pacemaker stimuli. Detected QRS are shown at the top as white and black triangles, although in the case of a seriously damaged signal the distinction between regular and ventricular beats is not reliable (record “v5851”).

2.4. QRS detection from ABP

Diastole detection is usually used to detect heart beats from the ABP channel. This may become unsatisfactory in patients in which locating diastole is complicated (as in record “v830s”). Therefore, we convert the signal to a variation range using a window 150 ms wide, accepting only values for which the mean of the right half is greater than the values in the left half of the window and where the variation range is greater than the limit. Heart-beat positions are found in local maxima of the smoothed (low-pass, 3 Hz) variation range signal.

2.5. QRS detection from PPG

QRS complexes are derived from a photoplethysmograph signal using interpolation lines from small blocks. The PPG signal is filtered (low-pass, 20 Hz), differentiated and all local, rightmost minima are found. Next, each minimum is tested as QRS as follows: two time windows are defined (0.1 s long from the tested minimum to the right and 0.2 s long from the minimum to the left). The signal in both windows is linearly interpolated and the slopes of the resultant lines are tested for the correct range.

2.6. Regular activity test

When a QRS sequence for each channel in the record is obtained, it is tested for regular heart activity (Fig. 1C). During this test, the minimal and maximal heart rate, summation and standard deviation of RRs and absence of invalid samples are compared to the limits.

In this way, only beat series with a reasonable QRS distribution throughout most of the signal length, in similar intervals and from channels without any invalid data, can pass. If any of the channels passes the regular activity test, a false alarm is reported and the process ends. This block is capable of revealing 35 % of false alarms in the training set.

2.7. Arrhythmia tests

If the regular activity test is not passed, then a specific arrhythmia test is executed. Each arrhythmia test begins with a more specific form of the regular activity test to prevent more false alarms.

2.7.1. Asystole test

The asystole test algorithm (Fig. 4) searches signals with a 3.2-second-wide window and tests all channels for QRS presence. The score (1 for QRS present, -1 for no QRS) is weighted by the average invalid rate in the window and added to result vector R . Therefore, channels

with a higher ratio of invalid data have a weaker influence on the result vector. Channels with QRS present in the window decrease values in vector R while channels without QRSs increase them.

Finally, if the vector R contains any value greater than zero, the asystole test is finished as a true alarm.

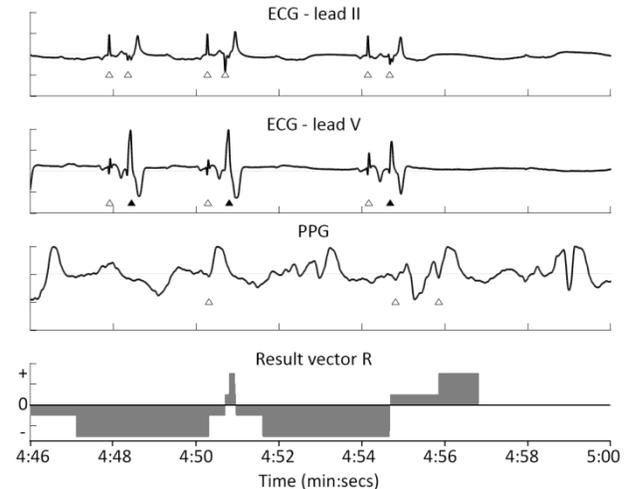


Fig. 4 – Asystole test. From the top: two ECG signals, plethysmograph channel and result vector R , revealing asystole true alarm (record “a449I”) when values in result vector $R > 0$. Triangles show detected QRS complexes.

2.7.2 Bradycardia test

A bradycardia test is processed only on the most reliable signal in the record (decided using descriptive statistics on QRS temporal distribution).

QRSs from the selected channel are searched to find a QRS sequence of 3 members with $HR < 46$ bpm. If such a sequence is found, a bradycardia alarm is reported.

2.7.3. Tachycardia test

QRS complexes from the most reliable channel (as in the bradycardia test) are searched for a sequence of 12 beats with $HR > 130$ bpm to confirm or deny a tachycardia alarm.

2.7.4. Ventricular tachycardia test

Values for result vector R are collected from all channels, though in this case different algorithms are used depending on the channel type.

For ECG channels, we have information about a “Group” for each QRS (Fig. 2) which is 1 for short beats and 2 for longer beats (determined in ECG detection). We can therefore find a sequence of 3 beats from Group 2 (i.e. ventricle beats) with $HR > 95$ bpm and add a score to result vector R in the corresponding time range.

In the case of an ABP channel, we do not have information about a QRS group. The variation range of the ABP signal is found and searched in a 3-second window for significantly decreased activity, computed as a local variation range. When this decreases below the limits, the score is added to the result vector R . If it contains any value greater than zero, a true ventricular tachycardia alarm is reported. In this test, the PPG signal is not used (except “Regular activity test”).

2.7.5. Ventricular fibrillation/flutter test

This algorithm consists of several consecutive steps which prove or deny a fibrillation alarm. Vent. fibrillation in ECG is characterized as an intense, continuous low-frequency activity, for which reason the first step looks into ECG detection results. If $LF_{MAX} > 3$ s, the result vector R is filled with ones.

If the result is still false alarm, additional information can be acquired from the ABP channel, searched in a 3-second-long window. It is scored using standard deviation, weighted by signal validity and added to result vector R .

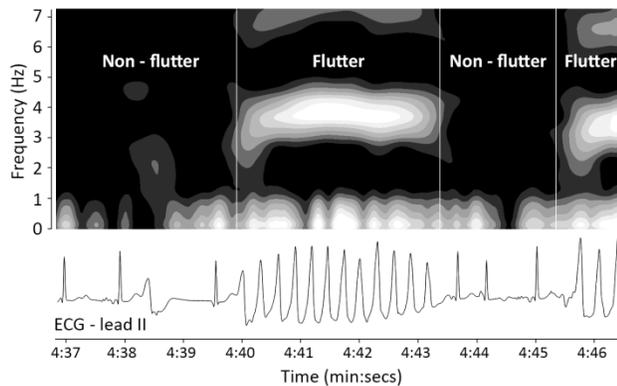


Fig. 5 – Time-frequency analysis of ventricular fibrillation epoch shows clearly visible high amplitudes in frequencies above 2 Hz in comparison to non-fibrillation epochs (record “f563l”).

To suppress false alarms, blocks of regular activity (using QRS temporal distribution) are searched in a 2-second-long window; results define the vector A . It is used in the last block which may deny a positive result of the fibrillation test. This is based on the fact that in fibrillation records the prevailing frequency (in true alarm records from the training set) lies above 1.5–2 Hz (Fig. 5). Both ECG channels are searched in two-second window W for frequency maxims using the Fast Fourier Transform. FFT maxima vector M is weighted by data validity and is set to zero for samples where $A_w > 0$. Mean values of vector M are compared to limits, the result added to vector R , and the ventricular fibrillation test returns a true alarm if it contains any positive values.

3. Results

The method was evaluated with the training set (750 records) and hidden test set (500 records). The results for the test set are presented in Table 1.

Table 1. Test set results. TPR – true positive ratio, TNR – true negative ratio. Individual arrhythmia results are followed by overall results for both challenge events.

Arrhythmia type	TPR [%]	TNR [%]	Score -
Asystole	100	97	97.42
Bradycardia	100	72	83.51
Tachycardia	97	100	87.80
Ventricular fibrillation	67	100	78.57
Ventricular tachycardia	85	84	75.07
Real-time (Event I)	92	88	81.39
Retrospective (Event II)	95	88	84.96

Using the proposed method we achieved score of 81.39 for real-time and 84.96 for retrospective event in “CinC Challenge 2015” official phase.

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