Algorithm for life-threatening arrhythmias detection with reduced false alarms

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Abstract

With the increasing quality and costs of health services a lot of attention is put to provide excellent care on the ICU. However, the amount of false alarms of cardiac episodes still outnumbers the true ones significantly. The advanced analysis of multiple signals registered by monitoring system might enable reduction of the false alarms.

We analyzed 750 multi-channel recordings from the PhysioNet Challenge 2015 labeled either 'true alarm' or 'false alarm'. In our algorithm there are multiple methods enabling to determine the location of R peaks in ECG signal, basing mostly on RS slopes. Similar slope detection method is performed for other channels provided. In case of signals where it is not possible to detect QRS complexes direct signal morphology assessment is used. These steps allowed us to obtain information needed to verify if the alarm was true or false.

The final scores of PhysioNet Challenge 2015 were: 57.72 for Real-time event and 63.69 for the Retrospective one.

1. Introduction

With the increasing quality and costs of health services a lot of stress is put to provide excellent care on the ICU, where patients are in the most demanding condition and need reliable monitoring. However, the amount of false alarms of cardiac episodes still outnumbers the true ones significantly. These situations might result from the poor quality or loss of the signals which prevent from proper analysis. The advanced analysis of multiple signals such as electrocardiogram (ECG), blood pressure (BP) and photoplethysmogram (PLETH) registered by monitoring system might allow reduction of the false alarms and improve its performance.

We analyzed 750 multi-channel recordings with the sampling rate of 250 Hz from the PhysioNet Challenge 2015 training set, which contains 2 types of signals: real-time with the length of 5 minutes recorded before the alarm and retrospective with additional 30 s after alarm. Each alarm was labeled either 'true' or 'false'. Our task was to reduce number of false alarms, while avoiding the suppression of true ones. Each recording contained two ECG leads and at least one additional pulsatile waveform (e.g. blood pressure, photoplethysomogram).

In our algorithm there are multiple methods enabling do determine the location of R peaks in ECG signal, such as one which concentrates on RS slopes, the most prominent part of a QRS complex. Similar slope detection method is performed for other channels provided. In case of signals recorded during Ventricular Flutter and Fibrillation, where it is not possible to detect QRS complexes direct signal morphology assessment is used. In Ventricular Tachycardia alarms we combine analysis of annotations with those of signal morphology.

Based on obtained annotations algorithm verifies whether the alarm was true for following arrhythmic events: Asystole, Bradycardia and Tachycardia, using criteria given in the Challenge. That was the task in PhysioNet/Computing in Cardiology Challenge 2015.

2. Data

The methods presented in this paper were trained on PhysioNet Challenge 2015 data set that came from three largest intensive care monitoring manufacturers' bedside units. The whole base of recordings was divided into two sets – training and test one. Each of them was divided into subsets - "real time" and "retrospective". Training data set was available at every step of the challenge and contained of 750 recordings. Test set, which includes 500 recordings, was unavailable for public and our algorithm was scored based on tests performed on it. No more than three alarms of each of the five categories (Asystole, Bradycardia, Tachycardia, Ventricular Tachycardia and Ventricular Flutter/Fibrillation) are used from any given patient. Arrhythmias were annotated by set of professional annotators. In each recording alarm was triggered 5 minutes from the beginning. Exact time of alarm may vary between the cases, but it the onset of the event must have been between 4:50 and 5:00 of the record. In the "real-time" subset, each record is exactly five minutes long, and the "retrospective" recordings have additive 30 seconds.

All signals in the data set have been resampled to 12 bit and 250 Hz frequency. FIR band pass filter and mains notch filters have been used to remove noise from the

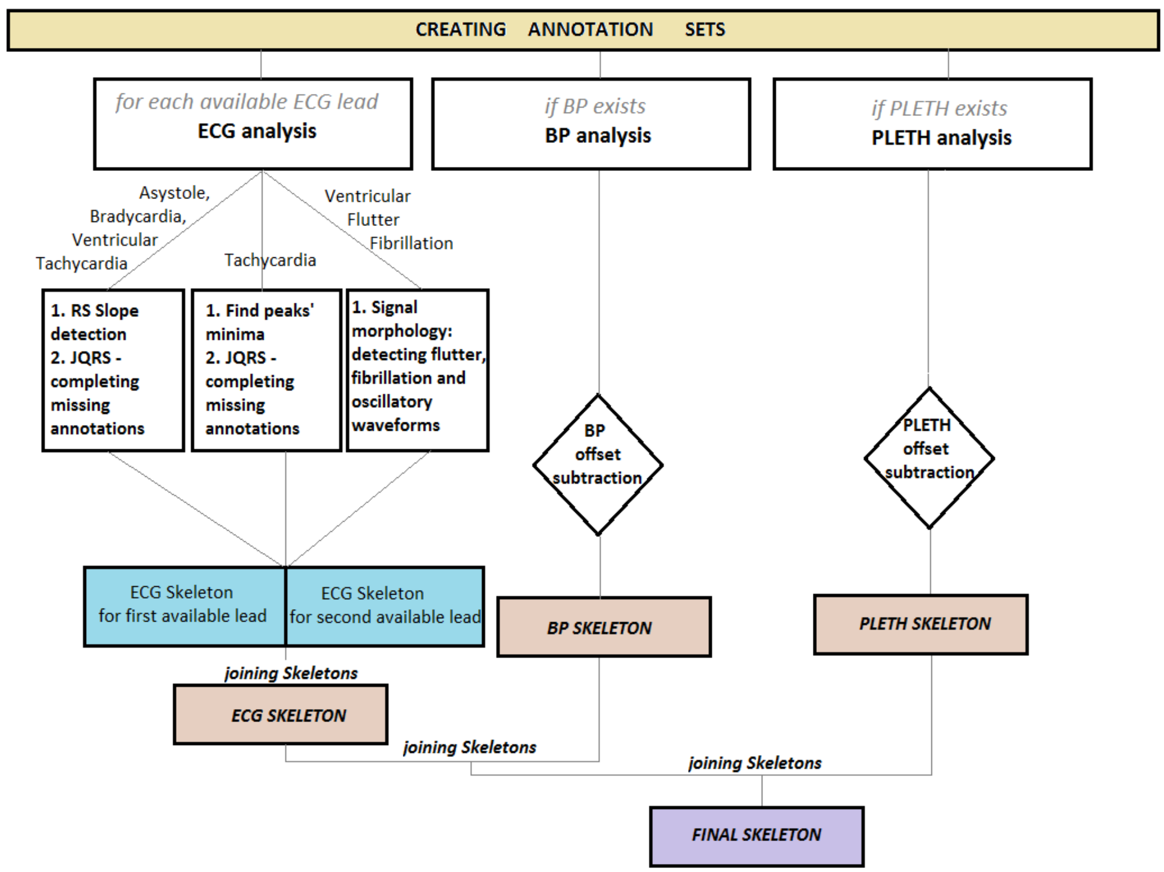

Figure 1. Flow chart of creating annotation set. The algorithm uses all available signals and various methods of detection.

recordings. For every patient two channels of ECG and up to two pulsatile waveforms were available. In available ECG leads may or may not be the one that have triggered the alarm. Moreover, in this recordings pacemaker and other noise components may occur. The movement artefacts, sensor disconnect and other events can exist in pulsatile waveforms.

3. Methods and results

3.1. Preparation and analysis of the signals

As was noted before, our algorithm is based on ECG, BP and PLETH signal analysis. Before the start of proper analysis, signals had to be adequately prepared. For this purpose all of the recordings were denoised using eighth-order Butterworth zero-phase low pass filter with the 40 Hz threshold frequency. Then a non-causal median filter with 250 ms sliding window was applied to detrend ECG channels and to detrend pulsatile signals a non-causal mean filter with window length of 350 ms was used.

3.2. Annotation sets

After signal preparation we started creating set of annotations (see Figure 1) containing location of R peaks for every recording, in order to compute the heart rate in final step of the algorithm as one of the most important criteria in the Challenge. First step was the analysis of ECG leads. To improve efficiency of this part we use two R peak detection algorithms: RS slope detection [1] and JQRS [2]-[3]. RS slope detection determines the locations of R peaks based on the longest, decreasing slopes in the signal. The ECG Skeleton of annotations is made. Then we apply JQRS algorithm and complete skeleton if there were missing annotations. In case of 'Tachycardia' alarm type, instead of RS Slope algorithm, we find minimum peaks in the ECG signal. This method tends to be less sensitive, but it helps with locating missed annotations and combined with JQRS method, creates ECG Skeleton of annotations without missing any of them, what is extremely important in this type of arrhythmia. We determine minimum interval length of the distance between annotations obtained from separate

ECG leads which designate the same heart beats, and in each pair of annotations fulfilling that condition we leave only one annotation, obtaining final ECG Skeleton. Only in Ventricular Flutter/Fibrillation RS Slope detection and JQRS are not used, because it that case it is not possible to find QRS complexes. ECG Skeleton in this category is created based on direct signal morphology assessment.

Then the BP signal is analysed. We use the same algorithm as for adaptive RS Slope detection. However in this step BP signal is reversed in time to detect the pressure rise with a downward-slope detection algorithm. For the physiological reasons the offset between ECG and BP signals occurs, which we compute basing on the ECG record. We determine mean value of the distance between annotations obtained from ECG and BP signals, which designate the same heart beats. Subtracting the offset provides the BP Skeleton [4].

Then PLETH analysis if performed. Signal is divided into two parts by the horizontal axis. We calculate average of upper (above zero) and lower (below zero) part of the signal, and find maxima in the part with higher average. As in the previous step, we compute the offset basing on ECG record, and after subtracting the offset we get PLETH Skeleton.

ECG signal will always be considered as the most important one, because of its precision in registering heart rate variability. Secondly, BP signal will be examined and finally PLETH record will be included. In that order the annotation sets are joined, giving Final Skeleton, but they still need to meet physiological requirements to prevent duplication of detected annotations.

However, to determine whether the alarm was true or false we did not use only the Last Skeleton. Separate annotations sets obtained from ECG, BP and PLETH analysis, as well as raw ECG signal, were also employed on checking alarm conditions of particular alarms. The usage of signals varied between the types of alarm.

3.3 Detecting true and false alarms

ASYSTOLE Firstly, we analyze final annotation set (Last Skeleton) and the check for the basic condition for Asystole is performed. If there is not any interval longer than 4s, than we assigned tested signal as the true alarm. However, in case of small number of annotations in ECG, we additionally examine the longest RR interval from ECG Skeleton and we check the quality of appropriate part of PLETH or BP (if any of this exist). If chosen part of the signal is irregular (what we check using standard deviation), we assume that it cannot detect annotation correctly, co we consider the alarm as true. In the final part of Asystole Detection, the check is performed, whether PLETH or BP signal is very regular for 30 seconds. In this case, we assume that alarm is false, despite of previous analysis (see Figure 2).

BRADYCARDIA In case of Bradycardia, we assume that very close annotations are impossible, so we remove one of annotations in every pair of two that are closer than 140 ms. Then we examine RR of the maximal length, found using Final Annotation Set, and corresponding part of PLETH and BP signal. If this part is very irregular, than we consider only ECG Skeleton in Bradycardia detection. Than for Last Skeleton or ECG Skeleton we check condition for Bradycardia: heart rate lower than 40 BPM for 5 consecutive beats.

TACHYCARDIA In Tachycardia detection, we always choose Final Skeleton, considering all found annotations for available signals. Than for Last Skeleton we check condition for Tachycardia: heart rate faster than 140 BPM for 17 consecutive beats.

VENTRICULAR TACHYCARDIA Our conditions for Ventricular Tachycardia alarms does not really need the annotations of R peaks from the ECG, what is convenient considering that with morphology changes locations of R peaks might be difficult to determine. However, usually changes in morphology of QRS complexes cause also the difference in the signal amplitude, and that is the property on which our algorithm focuses. As in the previous alarm types, we analyze last 30 seconds before the alarm of each signal, but this time with moving window of length 3 s with step of 1 s. In every window the signal we split into two parts by the horizontal axis. The absolute value of sum of the samples in upper (above zero) and lower (below zero) part of the signal is being calculated and added to the appropriate array. In the next step, position of the median, maximum and minimum for both signal parts are determined. Then a verification is performed whether in the upper part of the signal the maximal sum of samples is bigger than median multiplied by 2.5 or if the minimal value is smaller than 0.25 median, and in the same way for the lower part of the signal. If any of that terms was fulfilled and the annotation set of PLETH signal exists and is not very regular (what we check by standard deviation), we set the alarm result as 1.

VENTRICULAR FLUTTER/FIBRILLATION In Ventricular flatter/fibrillation alarm detection is based on two terms. First of them is adequate to detect all the flutter, fibrillation and oscillatory waveform, which do not contain typical QRS complexes. Applied function detects all of the zero crossing points, where signal changes sign from positive to negative. Than distances between them are counted and their standard deviation is determined. Basing on that we verify whether the annotations are sufficiently regular. In this case we classify the alarm as true, because we assume that the signal is a waveform. If standard deviation is too high, it means that the annotations are placed in some random spots, and alarm type is set to zero. The complementary condition checks whether the skeleton obtained after BP or PLETH analysis is extremely regular in full, 30 second

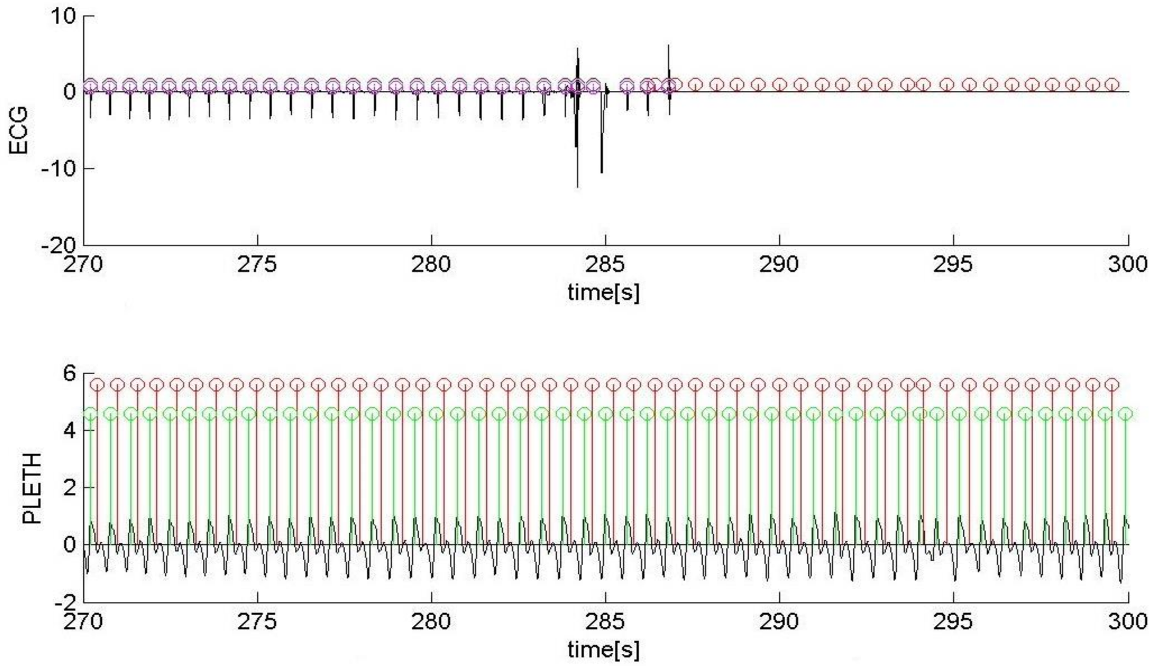

Figure 2. Basing only on ECG signal (pink annotations in the top figure) we would detect Asystole in this case, but after considering annotations from PLETH and creating Final Skeleton (red annotations in the top figure) we correctly assign the alarm to false.

fragment we are analyzing. If the answer is positive, the alarm result is set to zero.

4. Results

The final scores of PhysioNet Challenge 2015 were 57.72 for Real-time event and 63.69 for the Retrospective one.

5. Discussion and conclusions

In our algorithm we do not use highly advanced methods of calculation, however in Asystole and Tachycardia detection this approach gave satisfactory results (above 80%). Our method was based mostly on ECG signal and localization of QRS complexes, and therefore in Ventricular Flutter/Fibrillation, where R peaks detection algorithm was replaced only with performing the check of signal regularity with SD, it gave a bit lower result (62%). The main problem we had in case of recordings which were labeled as another alarm type than it really occurred in this recording, as for Tachycardia and Ventricular Tachycardia (for VT the result was almost 50%). We cannot assess directly why result for Bradycardia (also almost 50%) was low, because in the test set was not many records of this type of alarm, and for them we obtained much higher result (about 75%).

For each type of alarm another detection method was more successful. For this reason in each type we used various versions of our algorithm, and we took different signals into account. Although our simple in concept approach in many cases turned out to be most effective, it still requires further study.

6. References

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