Detection of Shockable and Non-Shockable Rhythms in Presence of CPR Artifacts by Time-Frequency ECG Analysis

JP Didon[1], I Dotsinsky[2], I Jekova[2], V Krasteva[2]

[1]Schiller Medical SAS, 4 rue L Pasteur, F-67160, Wissembourg, France
[2]Centre of Biomedical Engineering - Bulgarian Academy of Sciences, Acad GBonchev Str Bl 105, 1113, Sofia, Bulgaria

Abstract

Time-frequency domain features of chest compression (CC) artefacts, non-shockable (NShR) and shockable (ShR) rhythms were investigated. The aim was to provide reliable shock advisory analysis during CC by single channel electrocardiogram (ECG) processing. Three frequency bands were suggested to enhance specific components of the CC artefacts, NShR and ShR rhythms: (i) 2-3 Hz to emphasize the similarity of the basic wave of CC Artefacts; (ii) 4-7 Hz to highlight the irregularity of the fibrillation waves in ShR; (iii) 10-20 Hz to support the presence of QRS complexes in NShR. Based on our studies in the defined frequency bands, an automatic shock-advisory system (SAS) for detection of NShR and ShR in CC-contaminated ECGs was built. SAS assessed with ECGs from a testing dataset provided Se=94.2% for ShR, Sp=87% for NShR, Sp=83.7% for asystoles.

1. Introduction

Early defibrillation and continuous cardiopulmonary resuscitation (CPR) with minimal 'hands-off' intervals are advised to improve the survival rate in out-of-hospital cardiac arrests (OHCA) [1]. To support such life-saving practice, the shock-advisory systems of automated external defibrillators (AEDs) should be capable to reliably analyse the heart rhythm even if it is corrupted by the mechanical activity of the chest compressions (CC).

Different filtering techniques have been proposed in the literature mostly with adaptive schemes managed by reference signals from CC frequency [2-4], or acquired via outer sensors for thoracic impedance, accelerometer, 'ECG common' signal, arterial blood pressure [5-7]. However, any sensor different from defibrillation pads could be considered as an obstacle for an easy AED use.

ECG time-frequency study was applied aiming at reliable shock advisory analysis of CC contaminated arrhythmias by single channel ECG processing.

2. Methods

2.1. ECG data

Recordings of 168 OHCA interventions with AEDs (FredEasy, Schiller Medical SAS, France) collected by the emergency medical service in the region of Nancy (SDIS54 July-December, 2006) were retrospectively processed. They provided large excerpt of CC artefacts induced on human ECG via defi-pads. We hypothesized that the process governing the artefact morphology is non-ergodic due to change of the underlying ECG rhythm (shock delivery, drug injection), as well as to change of the CC features over time (fatigue of the rescuer, swap of rescuer, switching from human to machine compression). This consideration supported the use of several CC-contaminated episodes extracted from one intervention as independent strips included in the ECG dataset.

Two independent reviewers annotated the noise-free ECG rhythm seen during the AED analysis periods. The following rhythm annotations were accepted:

(i) NShR: Non-shockable rhythms, including normal sinus rhythms, ventricular ectopic beats, atrial flutter/fibrillation, bundle branch blocks, bradycardias and supraventricular tachycardias;
(ii) ShR: Shockable rhythms, containing ventricular fibrillations and rapid ventricular tachycardias;
(iii) ASYS: Asystoles with peak-to-peak amplitude below 100 uV for at least 3 seconds.

The CC-contaminated episodes were taken just before the AED analysis periods. They inherited the rhythm annotation of the adjacent AED analysis with the assumption that the ECG rhythm does not change during the last 10 seconds of CC. The following CC artefacts in the ECG channel were considered:

(i) CC-Artefacts: pure CC-artefacts on ASYS;
(ii) CC-artefacts contaminating NShR;
(iii) CC-artefacts contaminating ShR.

All OHCA signals were sampled at 500 Hz, 8-bit.

2.1.1. Training set

Three groups of signals were included in the training set, as follows: (i) 100 strips of pure CC Artefacts on ASYS; (ii) 100 strips of NShR (noise-free); (iii) 100 strips of ShR (noise-free). Each strip was 10 s in duration.

2.1.2. Testing set

The testing set included CC-contaminated episodes classified in the following groups: (i) 386 strips of pure CC Artefacts on ASYS; (ii) 284 strips of CC-contaminated NShR; (iii) 155 strips of CC-contaminated ShR. Each strip was 10 seconds in duration and represented the CC artefact and rhythm distributions reflecting those found in the 168 patients.

2.2. ECG signal processing

All procedures for time-frequency domain analysis and statistics were implemented in Matlab 7.0.

2.2.1. Spectral analysis

The first part of the study aimed to define the spectral bands in which the most outstanding frequency components of pure CC-Artefatcs and ECG arrhythmias (NShR and ShR) were distributed. Fourier transform was applied on 1-second strips taken from all signals of each group in the training dataset. Thus a total number of 100x10x1-second strips were analyzed to obtain the averaged PSD for each group - see Figure 1.

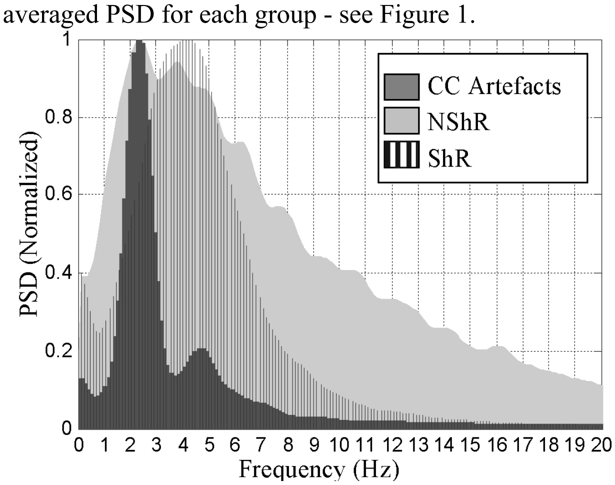

Figure 1. Normalized PSDs calculated for the 3 groups x 100 signals, as defined in the training dataset.

2.2.2. Time-domain analysis in freq. bands

Based on the observed PSDs in Figure 1, three frequency bands were suggested to enhance some specific components: (i) 2-3 Hz for the basic wave of CC-Artefacts; (ii) 4-7 Hz for the fibrillation waves in ShR; (iii) 10-20 Hz for the QRS complexes in NShR.

Three examples, showing CC-Artefact (Figure 2), NShR (Figure 3) and ShR (Figure 4) are provided to illustrate the specific behavior at each frequency band. Different features were assessed to derive quantitative measures of the outstanding components.

(2-3) Hz frequency band was simulated at the output of a band-pass digital filter (Butterworth, cutoff frequencies 2 and 3 Hz (-3 dB), 1st order).

The CC-Artefact within 2-3 Hz band (Figure 2, 2nd trace) resembled a sequence of high-amplitude and periodic waves, named basic CC waves. Our interest was to measure the level of similarity between the basic CC waves, outstanding the usual cases of sustained cardiac massage. Cross-correlation method was applied to estimate the periodicity of the signal waves, as follows:

1) The analyzed episode of 10 seconds was divided into 10 x 1-second strips;

2) Each 1-second strip was compared to the other 9 strips by calculation of 9 cross-correlation functions.

3) Correlation coefficient (CORR) was estimated as an average of all cross-correlation functions maxima.

The similarity of the 1-second strips is illustrated in Figure 5. Maximal CORR is estimated for CC-Artefacts (0.88), followed by NShR (0.66), and ShR (0.56).

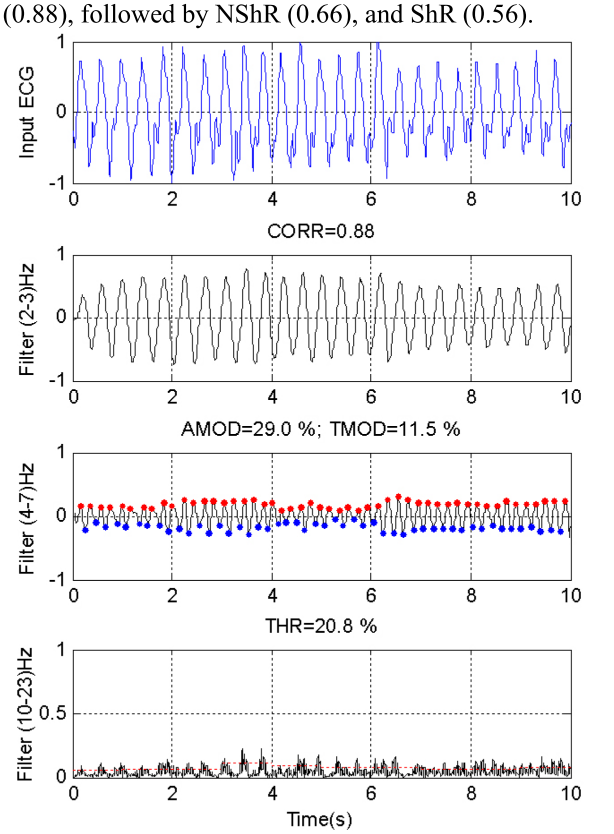

Figure 2. CC-Artefact on ASYS.
The input signal (1st trace) is band pass filtered at 2-3 Hz (2nd trace), 4-7 Hz (3rd trace) and 10-23 Hz (4th trace).

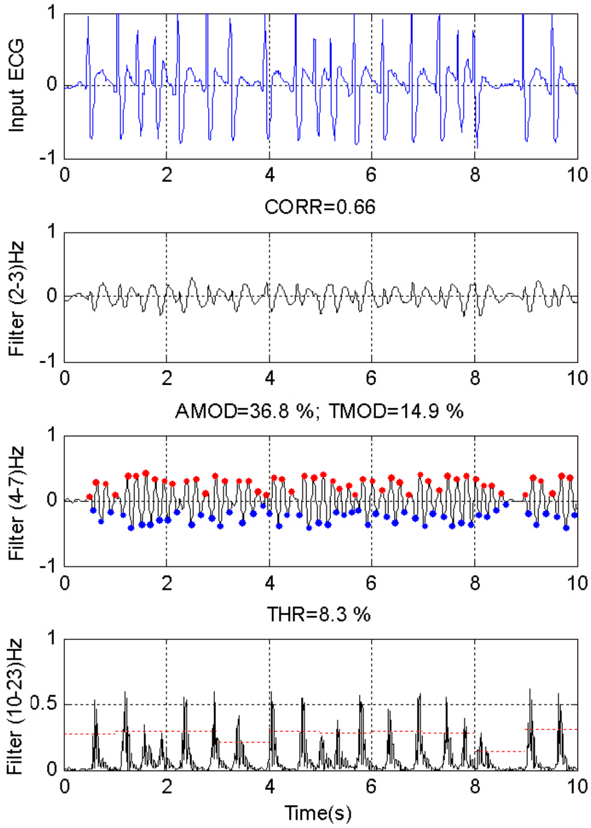

Figure 3. Noise-free NShR strip of 10 seconds.

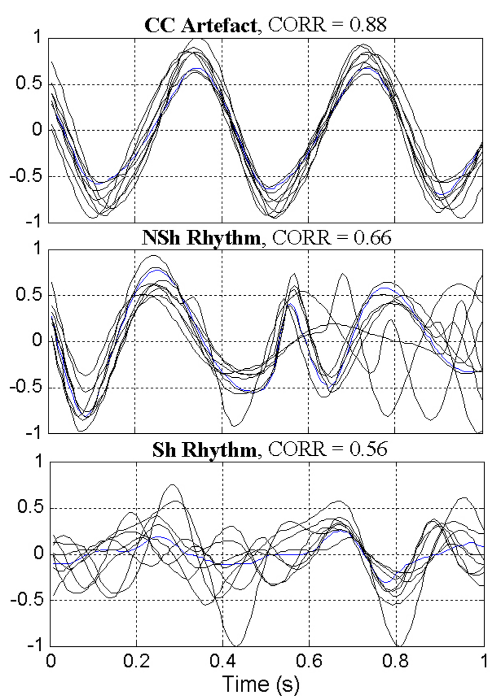

Figure 5. (2-3) Hz band pass normalized 1-second strips, shifted to maximal CORR. The full-length 10-second signals are depicted in Figures 2,3,4 (2nd trace).

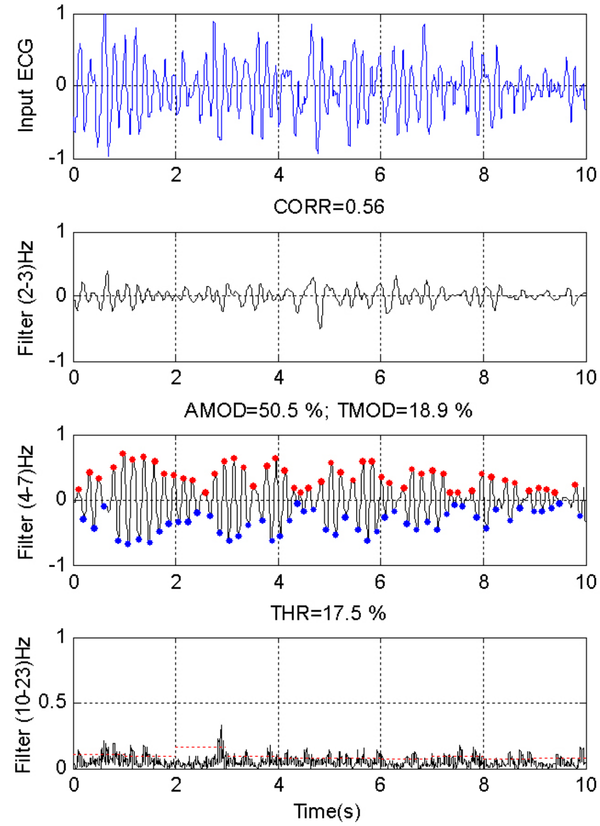

Figure 4. Noise-free ShR strip of 10 seconds.

(4-7) frequency band was simulated at the output of a band-pass digital filter (Butterworth, cutoff frequencies 4 and 7 Hz (-3 dB), 2nd order).

Amplitude and temporal deviation of the signal extrema was studied to assess the level of modulation. AMOD and TMOD parameters were calculated as:

AMOD = 100*std(ExtrAmpl)/mean(ExtrAmpl) (%);

TMOD = 100*std(ExtrTime)/mean(ExtrTime) (%),

where ExtrAmpl is the extrema amplitude and ExtrTime is the inter-extrema time distance.

In the particular examples, ShR (Figure 4, 3rd trace) showed high AMOD of about 50 % and TMOD of 19 %, due to the strong influence of chaotic fibrillation waves. Waves of NShR (Figure 3, 3rd trace) were also present at 4-7 Hz, but with less amplitude and time modulation (37 % and 15 %). Expectedly, the periodic CC-Artefacts were quite suppressed at 4-7 Hz with the lowest level of modulation (29 % and 11.5 %) (Figure 2, 3rd trace).

(10-20) Hz frequency band was simulated at the output of a band-pass digital filter (Butterworth, cutoff frequencies 10 - 23 Hz (-3 dB), 2nd order). The absolute value of the signal was considered. Bursts under QRS complexes were visible for NShR (Figure 3, 4th trace), while ShR and CC-Artefacts produced low-amplitude, uniform output (Figures 2, 4, 4th trace). The THR parameter was introduced to count the number of samples crossing a threshold (50 % from the maximum in 1-second strips). THR was low for NShR (8 %), but high for ShR (17.5 %) and CC-Artefacts (21 %).

2.2.3. Shock advisory system

In the second part of the study, a shock-advisory system (SAS) was designed to analyze CC-contaminated signals in order to classify the underlying ECG rhythm as NShR or ShR. This system is based on the results from our studies in the defined above frequency bands.

3. Results

The accuracy of SAS was first tested with the signals from the training dataset. For this purpose, the 100 strips of pure CC Artefacts on ASYS were considered as an additive noise superimposed to the 100xNShR and 100xShR strips at different signal-to-noise ratios (SNR). The achieved specificity (Sp) and sensitivity (Se) are presented in Table 1.

Table 1. Sp and Se calculated for two unfavourable SNR: CC artefact is equal or twice the amplitude of ECG.

SNR	NShR (Sp)	ShR (Se)
1	**92.0 %** (9199/10000)	**96.4 %** (9638/10000)
0.5	**82.3 %** (8233/10000)	**92.2 %** (9215/10000)

Second, the SAS accuracy was tested with CC contaminated signals as recorded on human ECG defined in the testing dataset (Table 2).

Table 2. Sp and Se calculated for the CC-contaminated OHCA signals from the testing dataset.

ASYS (Sp)	NShR (Sp)	ShR (Se)
83.7 % (323/386)	**87 %** (247/284)	**94.2 %** (146/155)

4. Discussion and conclusions

The considerable spectral overlap between CC artefacts and ECG arrhythmia (Figure 1) makes inadmissible the fixed-band filtering of CC artefacts with no affect on the ECG waves. Therefore, we suggested three frequency bands for best enhancement of some specific components that feature the CC artefacts (2-3 Hz), ShR (4-7 Hz) and NShR (10-20 Hz). We also applied specific analyses to derive quantitative measures of the outstanding artefact and rhythm behavior (Figures 2-4), such as cross-correlation in 2-3 Hz to estimate the CC artefact periodicity, the level of modulation (amplitude and time) in 4-7 Hz to highlight ShR chaotic waves, the peak threshold crossing in 10-20 Hz to detect the presence of QRS complexes in NShR.

We tested the potential of a simple time-frequency approach to work on a SAS during CC by analysis of a single channel ECG. The training was applied on artificially mixed ECG and CC-artefact signals (Table 1). The testing is based on OHCA signals during CC maneuvers (Table 2). The Se for ShR is 94 %, the Sp ranges between 84-87 %, (87% for NShR, 84 % for Asystole). The Se (ShR) meets the AHA performance goal for AEDs (>90 %). The accuracies for NShR and Asystole are lower, but equivalent to what is reported in literature. It is important to note that the AED embedding this SAS would confirm the result using an additional process that works on noise-free signals. High accuracy is provided for such shock advisory analysis on noise-free signals [8], however such accuracy is not required for the presented SAS that would only advise to stop CPR.

References

[1] Handley AJ, Koster R, Monsieurs K, Perkins GD, Davies S, Bossaert L. European Resuscitation Council Guidelines for Resuscitation 2005 – Section 2. Adult basic life support and use of automated external defibrillators. Resuscitation 2005; 76: S7-23.

[2] Aramendi E, de Gauna SR, Irusta U, Ruiz J, Arcocha MF, Ormaetxe JM. Detection of ventricular fibrillation in the presence of cardiopulmonary resuscitation artefacts. Resuscitation 2007; 72: 115-23.

[3] de Gauna SR, Ruiz J, Irusta U, Aramendi E, Eftestol T, Kramer-Johansen J. A method to remove CPR artefacts from human ECG using only the recorded ECG. Resuscitation 2008; 76: 271-8.

[4] Irusta U, Ruiz J, Ruiz de Gauna S, Eftestøl T, Kramer-Johansen J. A least mean square filter for the estimation of the cardiopulmonary resuscitation artifact based on the frequency of the compressions. IEEE Trans.Biomed.Eng. 2009; 56: 1052-62.

[5] Rheinberger K, Steinberger T, Unterkofler K, Baubin M, Klotz A, Amann A. Removal of CPR artefacts from the ventricular fibrillation ECG by adaptive regression on lagged reference signals. IEEE Trans Biomed Eng 2008; 45: 553-62.

[6] Husoy JH, Eilevstjonn J, Eftestol T, Aase SO, Myklebust H, Steen PA. Removal of cardiopulmonary resuscitation artefacts from human ECG using an efficient matching pursuit-like algorithm. IEEE Trans Biomed Eng 2002; 49:1287-98.

[7] Aase SO, Eftestol T, Husoy JH, Sunde K, Steen PA. CPR artefact removal from human ECG using optimal multichannel filtering. IEEE Trans Biomed Eng 2000; 47(11):1440-9.

[8] Jekova I, Krasteva V, Ménétré S, Stoyanov T, Christov I, Fleischhackl R, Schmid JJ, Didon JP. Bench study of the accuracy of a commercial AED arrhythmia analysis algorithm in the presence of electromagnetic interferences. Physiol. Meas. 2009; 30: 695-705.

Address for correspondence

Jean-Philippe Didon
Schiller Medical SAS, 4 rue L. Pasteur, F-67160, Wissembourg, France, jean-philippe.didon@schiller.fr.