SUPPRESSION OF AC RAILWAY POWER-LINE INTERFERENCE IN ECG SIGNALS RECORDED BY PUBLIC ACCESS DEFIBRILLATORS

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The public access defibrillators (PADs) are introduced on the market for more efficient treatment of out-of-hospital sudden cardiac arrests. PADs are used normally by untrained people at streets, sports centers, airports, and other public scenes. Therefore, the automatic fibrillation detection is of high importance. Special case represents the railway stations. Some countries use 16.7 Hz AC power-line, which introduces largely frequency-varying interference that may corrupt the fibrillation detection. Moving signal averaging is often applied for 50/60 Hz interference suppression if the affect on the ECG spectrum has no importance (no morphological analysis is performed). This approach may be also applied on the railway interference if its frequency is ongoing detected to synchronize the analog-to-digital conversion (ADC) for introducing of variable inter-sample intervals. A better solution consists of rated ADC, frequency measuring, internal irregular re-sampling according to the interference frequency, moving averaging over constant sample number followed by regular back re-sampling.

Keywords: public access defibrillator, railway interference suppression

1. INTRODUCTION

The public access defibrillators (PADs) are suggested, designed and introduced on the market for more efficient treatment of out-of-hospital sudden cardiac arrests [1, 2]. They are hardly recommended by ILCOR Guidelines [3]. PADs are used normally by untrained people at streets, theaters, sports centers, airports, and other public scenes. Therefore, the automatic fibrillation detection is of high importance. Recently [4-6], special attention is paid to the susceptibility of PADs to the electromagnetic field generated by the train overhead lines at railway platforms in countries using 16.7 Hz AC power-line, e.g. Switzerland, Germany, Austria, Norway and Sweden [4, 5, 7]. The induced interference may corrupt the fibrillation detection [8, 9] and increase the risk of lethal exit of the incident.

Effective suppression of the railway interference is impeded by its large frequency band. The Official Journal of the European Communities [10] reported for possible deviations from 15.69 through 17.36 Hz. No data about the rate of frequency changes are available. Christov and Iliev [6] assume a modulation of 20% around 16.7 Hz per 10 s.

Another difficulty derives from the almost total overlap between the spectra of QRS complexes and interference.

No papers on railway interference suppression are available, except for the publication of Christov and Iliev [6]. They apply adaptive filtration based on possible use of special antenna within the PAD to feed the reference input of the filter. The authors present good results of simulated experiments with normal ECG signals, tachycardia and ventricular fibrillation. No signal distortions can be observed. However, the absence of really embedded antenna is an important disadvantage of the method proposed.

2. MATERIALS AND METHODS

The study was carried out in a MATLAB environment. ECG recordings were taken from the AHA database. Sinusoidal interferences were synthesized and the mixed signals were processed. The interference suppression as well as the differences between input and processed signal are assessed. The developed algorithm and program have a structure that simulates real-time going procedure.

3. ASSESSMENT OF SOME TRADITIONAL FILTRATIONS APPLIED FOR RAILWAY INTERFERENCE SUPPRESSION

The railway interference may be suppressed by appropriate notch filter, moving averaging (comb filtering with linear phase characteristic) or other relatively simple techniques. They have the common disadvantage to affect the ECG spectrum and especially to reduce the amplitude mostly of high and steep QRS complexes. However, hardly such shape diversions may cause failure of the algorithms for fibrillation detection. The reason is that the variety of the ECG signal population is immense and consequently, each processed signal may be assumed to be equal or very close to some non-processed signal (generation) of the population.

Therefore, only the extent of interference suppression is further assessed.

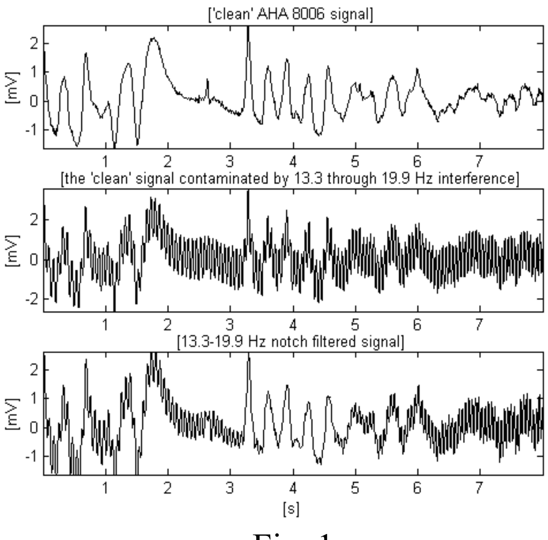

Fig. 1

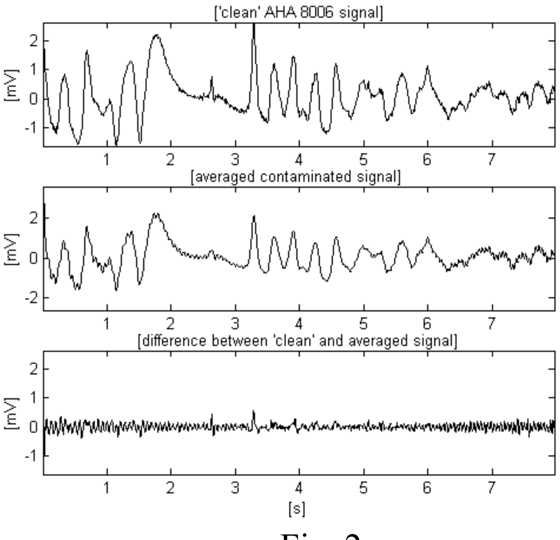

Fig. 2

The first trace of Fig. 1 shows an 8 second epoch of the AHA 8006 signal. It is assumed to be ‘clean’ input signal, which is mixed by interference with ±1 mV amplitude and variable frequency from 13.3 trough 19.9 Hz (second trace). As can be seen, the residual interference after notch filtration may disturb the fibrillation detection. No difference between input and processed signal is shown, as it is obviously high and does not contribute to assess other approaches.

The same input signal is used for moving averaging estimation (Fig.2). The processed signal (second trace) shows improved interference suppression mainly in the middle part of the epoch where the interference frequency coincides with the first zero of the comb filter. The third trace includes partially eliminated interference together with clipped peaks of some sharp complexes.

Adaptive and non-adaptive filters [11, 12] are not considered because of their unacceptably long transient time appearing every time the ECG signal course changes.

4. PROPOSED APPROACH

The second trace of Fig. 2 suggests that good suppression can be obtained if the comb filter zero follows the interference frequency change. As the number of averaged values is integer, the inter-sample intervals has to be modified by dynamic sampling rate of the analog-to-digital conversion (ADC). This approach has been developed and implemented for 50/60 Hz interference cancellation [13, 14]. However, sometimes the hardware synchronization is not suitable. Recently, another solution is proposed [15]. It consists of rated ADC, software frequency measuring, internal irregular re-sampling according to the interference frequency, moving averaging over constant sample number followed by regular back re-sampling. This method is modified for railway interference cancellation. Its features may be assessed in Fig. 3, where no residual noise is observed.

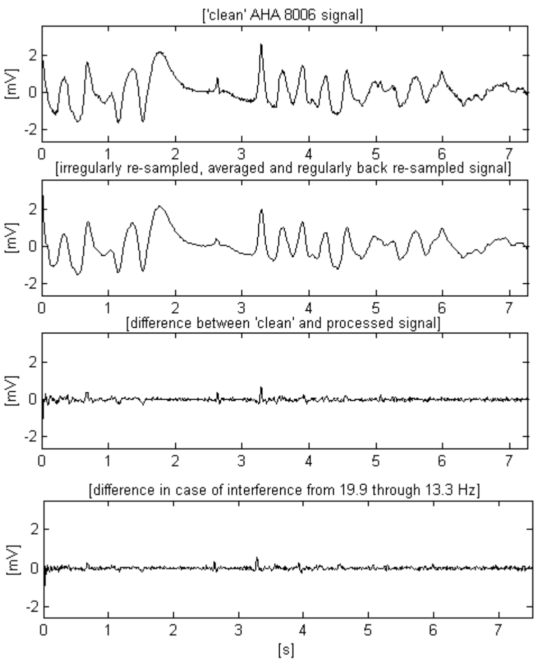

Fig. 3

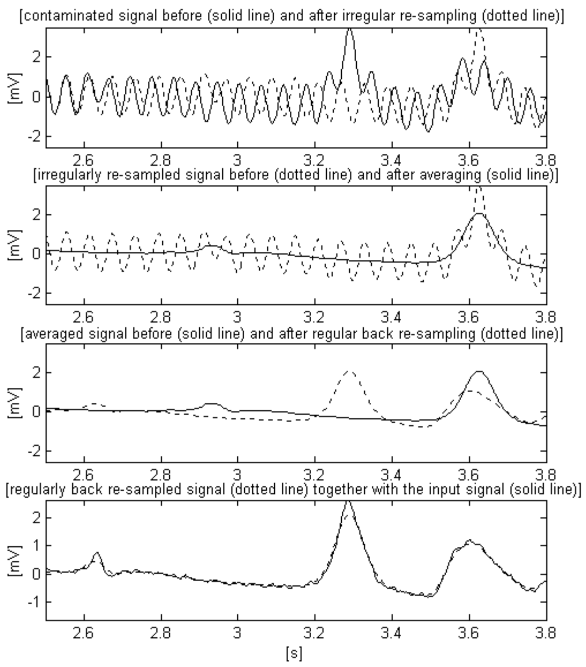

Fig. 4

The four steps of the two-way re-sampling are illustrated in Fig. 4. For a better observation, the signal is limited inside 2.5 and 3.8 s. Both re-samplings are done by linear interpolation, which seems to be simple procedure. However, since the program written in MATLAB language simulates real time going process, each cycle begins with ongoing sample of the input signal and the sequence of non-alternatively right and back interpolations requires more sophisticated coordination of steps. The possible cases are presented in Fig. 5. A pointer P_r is assigned to the regular ADC positions marked by ‘X’. Two other pointers, P_f and P_s control the locations ‘O’ and ‘⊗’ for first and second re-sampling, respectively. The pointers are incremented at the beginning of the cycles.

```
                first re-sampling
                X      O      X
X      O        X             X
                X             X      O      X
                X             X      O

               second re-sampling
                O      ⊗      O
O      ⊗        O             O
                O             O      ⊗      O
```

Fig. 5

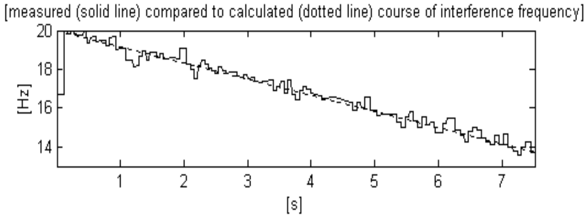

Fig. 6

The first line in Fig. 5 presents the simplest case of interpolation. If the last ‘O’ address of P_f (second line, second column) is on the left hand to the interval defined by two consecutive ‘X’ addresses of P_r (second line, third and fifth columns), this pointer is decremented before the interpolation is accomplished. Further, two cases show the last P_f address on the right hand to the interval. P_r is incremented before the interpolation, if possible (third line). Otherwise, P_f is decremented without interpolation to hold the address inside the interval in the next cycle (forth line). The second re-sampling follows the same rules (fifth trough seventh lines), except for the last case shown with the first re-sampling. It is unrealistic because the program begins after a certain delay of P_f and P_s in respect to P_r is reached.

The interference frequency is software measured using recently published method [15, 16]. The contaminated signal is band-pass filtered at –3 dB from 13 through 20 Hz. The amplitudes of two adjacent samples on a positive-going slope of the interference signal, located below and above the zero line, are measured. Then the crossing point of the interference with the zero line is determined by interpolation. It is used to calculate the ongoing fluctuation of the interference period of repetition,

In fact, the contaminated signal is filtered over the interpolated one. This way the accuracy of following the interference frequency fluctuations increases considerably. In contrast to the software measurement of 50/60 Hz interference [15, 16], the influence of large and high QRS complexes is in order of magnitude higher. It is reduced by clipping the calculated inter-sample intervals beyond a level defined as percentage of the average sum of the two last intervals, thus adapting better the expected reasonable frequency fluctuation to the current interference frequency. The efficiency of the approach can be seen in Fig. 6, where the dotted line represents the preliminary calculated course of the synthesized interference while the solid line is for the measured frequency.

5. RESULTS

The proposed method results in a total railway interference cancellation (second trace of Fig. 3) together with suppression of inherent input signal noise while the peak amplitudes of two sharp complexes are reduced (third and forth traces in Fig. 3, forth trace in Fig. 4). The last two traces in Fig. 3 show the independency of the method with respect to the interference frequency course.

Two other signals AHA chosen to present the transition from normal heart activity to fibrillation can be observed in Fig. 7 and 8. The second signal, which includes high and steep QRS complexes, is superimposed by interference with lower amplitude, which is the worst case of using the software interference frequency measurement [16].

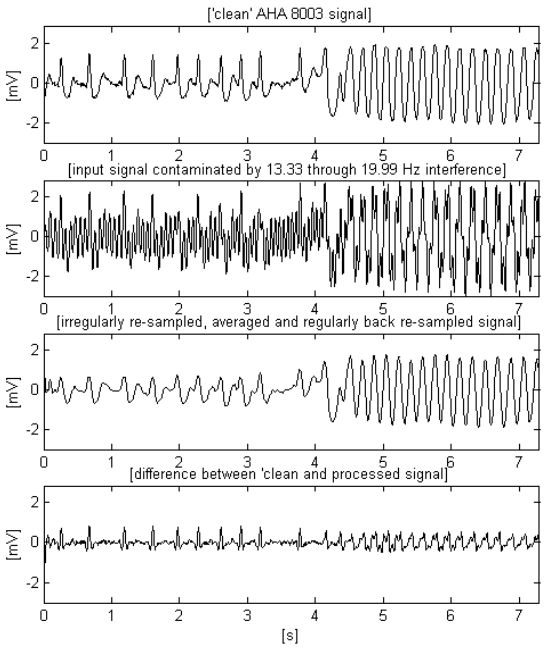

Fig. 7

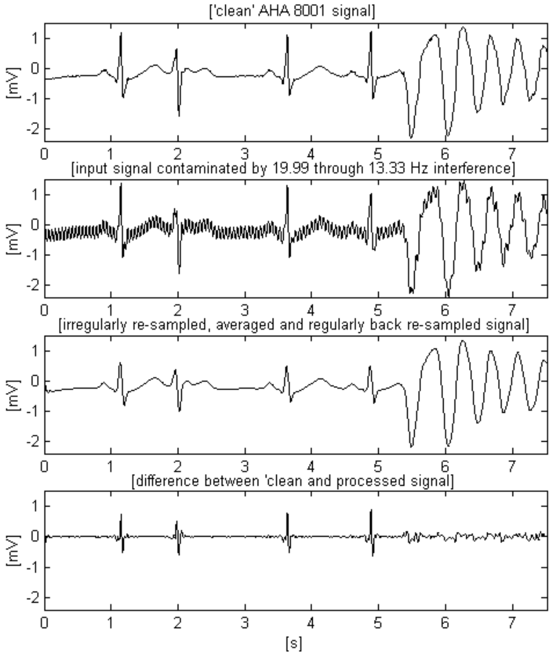

Fig. 8

6. DISCUSSIONS AND CONCLUSION

Shape diversions accompanying averaging procedures applied on contaminated by railway interference are assumed to be negligible to accurate fibrillation detection. In this study good results are obtained by comb filter. It is run over constant number of samples with variable intervals. The samples are interpolated according to software measured interference frequency. The influence of large and high QRS complexes is reduced. Then the averaged samples are re-sampled with the rated SR.

The developed method, algorithm and program written in MATLAB language are a useful tool for real time railway interference suppression.

7. ACKNOWLEDGEMENT

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