ARTEFACT SUPPRESSION IN NERVE EVOKED SIGNALS USING ADAPTIVE FILTERING

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Summary: *Adaptive filtering to suppress the artefact in nerve evoked signals is applied. Scanned records are digitized and processed by means of the software package MATLAB. Artefacts are extracted and slightly modified to simulate those obtained by double, off-nerve, subthreshold or biphasic stimulation. They are used as reference input signals. The experiments show that the influence of the non-linear relation between them and true artefacts on the output of the adaptive filter is considerably limited.*

Introduction

The evoked nerve signals acquired by surface electrodes are usually contaminated by an artefact. It is caused by the electrical stimulus and consists of an initial spike and a longer lasting tail. This artefact does not hamper simple analysis like the measurement of conduction velocity. However, more sophisticated knowledge about compound action potentials, such as estimation of the fiber velocity distribution, may be gained by preprocessing of highly accurate response waveforms only.

The artefact amplitude depends on the electrode configuration, the stimulus intensity, the type of the stimulator output stage and the properties of the amplifier input stage.

Some guidelines have been recommended to suppress the artefacts [5, 6, 7, 8]:

1. Stimuli isolation using screened transformer, radio frequency modulation or optical coupling.
2. Electrode impedance reduction by skin abrasion.
3. Positioning the recording electrodes on a equipotential line if possible.
4. Placement of a large grounding electrode near to the recording electrodes.

Knaflitz and Merletti (1988) proposed a hybrid stimulator [5]. Its output stage is switched from constant current mode during the pulses to constant voltage mode between them, thus providing for a faster discharge of the electrodes and tissue capacitances.

Minzly et al. (1993) designed an artefact suppressor [7]. The amplifier input remains inhibited until an additional channel detects the stimulation pulse. An additional delay of 1 ms is generated expecting to cover the depolarization artefact, then a measuring window of 43 ms allows the evoked signal to be recorded.

The problem with the artefact may be considerably reduced with the use of a DC amplifier [1, 7].

Nilson et al. (1988) reported on biphasic stimulation [8]. The second pulse is generated after a short delay in the refractory period thus evoking an artefact only. The two opposite directed artefacts are mutually compensated to some extent, limited by their time-shift and the difference between the cathode and anode voltages even with generation of identical stimuli.

Many signal processing methods are also used for artefact cancellation [6]. The double-stimulus method is similar to the biphasic stimulation. The responses of a single pulse and two closely delayed monophasic pulses are recorded. The double pulse artefact is assumed to be a superposition of two equal single pulse artefacts. The responses are subtracted to yield an estimate of the single pulse artefact, which is aligned with and subtracted from the contaminated single pulse response. The inconvenience is that in fact the second artefact may differ considerably from the first.

The off-nerve stimulation uses a second pair of recording electrodes positioned away from the nerve to record a pure artefact. Nevertheless, the two artefacts are not linearly related and the nerve response is usually estimated by some kind of weighting function. Moreover, it is very difficult to find an electrode location for the second recording that may be completely free of evoked signal.

Another way to obtain a free of artefact evoked signal is to record from the same electrode configuration once the contaminated evoked signal and then the pure artefact by reducing the stimulus intensity below the threshold of the nerve excitation. Since the subthreshold artefact is very small, many stimuli are required to average out the noise. To cancel the artefact, the averaged signal should be scaled before subtraction from the contaminated signal. However, the artefact waveforms are slightly different and require some kind of sophisticated scaling.

Recently some successful results were reported on adaptive cancellation of the respiratory artefact in electrogastrogram signals [4] and of the main interference [2] and drift [3] in electrocardiogram signals.

We applied adaptive filtering to study the possibilities for canceling artefacts in a sequence of nerve evoked signals.

Materials, method and results

Recordings of nerve evoked signals are scanned with 300 pixels/inch and resampled with 75 kHz and 0,3 μV/bit. Sequences of selected repetitive signals are organized in files.

Casual and non-casual adaptive filters are applied. The essential part of the program written for MATLAB is given in the Appendix.

Experiments with sequences of stimulus pulses taken as reference signals **R** are carried out using different sets of parameters. The step-sizes controlling the convergence and stability μ were chosen by means of $\mu<1/(R^2N)$. The number of coefficients **N** was taken among 2, 4,...,1024. The primary contaminated signal **P** was delayed with **D**=**N**/**2**. In case of casual filter, **D**=**0**. Two filtered signals **F** are

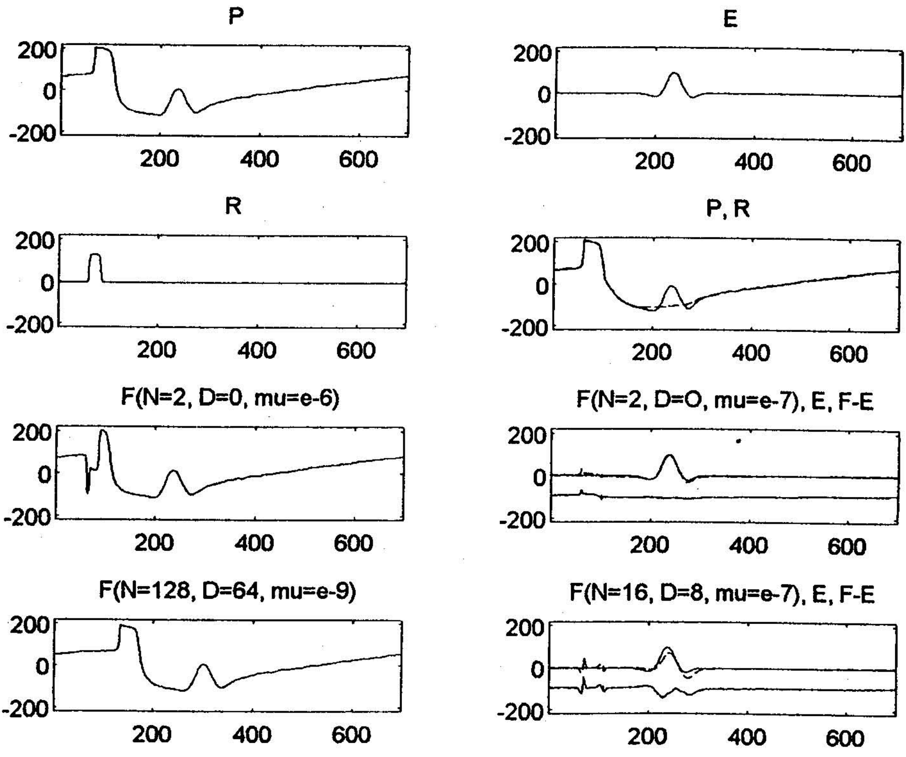
P
E
R
P, R
F(N=2, D=0, mu=e-6)
F(N=2, D=O, mu=e-7), E, F-E
F(N=128, D=64, mu=e-9)
F(N=16, D=8, mu=e-7), E, F-E
200
0
-200
200
400
600

Fig. 1

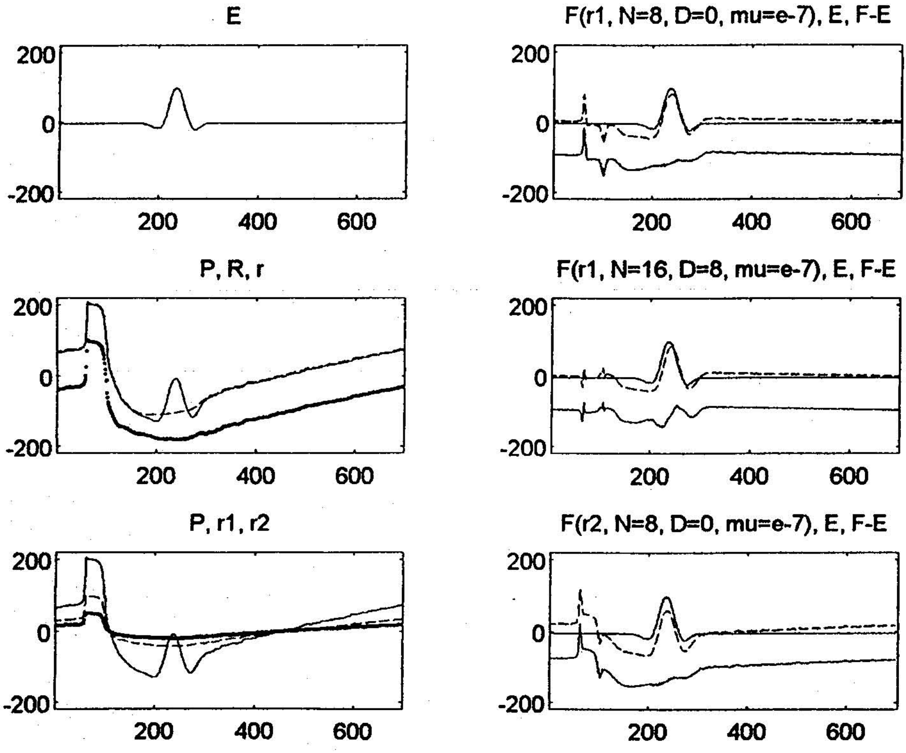
E
F(r1, N=8, D=0, mu=e-7), E, F-E
P, R, r
F(r1, N=16, D=8, mu=e-7), E, F-E
P, r1, r2
F(r2, N=8, D=0, mu=e-7), E, F-E
200
0
-200
200
400
600

Fig. 2

shown in the left lower part of Fig. 1. The initial adaptive period is skipped. As it can be seen, the artefact is practically not suppressed.

We extracted the response **E** and the artefact **R** (plotted with dashed line) from the recording. Then **E** and **R** were mixed to obtain **P** (right upper part of the Fig. 1). The two diagrams including **F** (dashed line), **E** and the errors **F-E** (shifted down in the diagrams) show that the casual filters are more efficient than the non-casual ones.

Further the same primary signal **P** was used, while reference signals were **r1=r/2** and **r2=r/4** respectively (Fig. 2). Here **r** (dotted line) differs slightly from **R**, thereby simulating artefacts **r1** (dashed line) and **r2** (dotted line) obtained by double, off-nerve, subthreshold or biphasic stimuli. **F**, **E** and **F-E** are plotted as in Fig. 1. In the case of **r1** both casual and non-casual filters were used.

Conclusions

The extracted signals allow a deterministic assessment of the errors in filtering a sequence of identical **P**, instead of the statistical attempt usually applied with adaptive cancellation. A higher number of N affects the response waveform. Obviously, the non-casual filter gives rise of not tolerable distortions in these signals because of the shift involved (**D≠0**). However, an efficient artefact suppression could be obtained using convenient parameters. The results obtained with **r1**, **r2** and **D=0** prove the adaptive filtering is a successful tool for dealing with the non-linearities between the evoked signals and reference artefacts even assuming a great difference in amplitude as between **P** and **r2**.

Appendix

Essential part of the program written for MATLAB adaptive filtering

```
% P->primary input, R->reference input, OUT->error output, F->filter output
% iteration number=length(R)+1=length(OUT)
    W=zeros(1,N);                    % initial FIR coefficients definition
    for i=N:length(R);
        FIR=0;
        for j=1:N; FIR=FIR+R(i-j+1)*W(j);
        end;
        ERR=P(i)-FIR; OUT(i-N+1)=ERR; F(i-N+1)=FIR;
        for j=1:N; W(j)=W(j)+2*MU*R(i-j+1)*ERR;
        end;
    end;
```

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