Communication

High-pass filtering of the electrogastrogram

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Abstract—*The recording and processing of an electrogastrogram require adequate band-pass filtering, to suppress unwanted artefacts but preserve the original signal waveform. High-pass filtering of various types, of different time constants τ, filter order, analogue and digital implementation, have been used to obtain higher baseline stability and faster signal recovery after strong artefacts. Special attention should be given to possible signal amplitude and phase distortions due to high-pass filtering, which can strongly influence accurate amplitude measurements or studies of signal propagation from multichannel recordings. Synthesised and original signals are used to demonstrate the effect of high-pass filtering. The use of a first-order filter with $\tau = 5$ s is recommended for EGG studies if not especially directed to investigation of bradygastria. In the opposite case, $\tau = 15$ s should be used, and with backward filtering a full restoration of the original signal can be obtained. The same is valid for recording the electrical activity of the colon. Lower time constants ($\tau = 5$ s or less) can be applied to acquire signals from the small intestines. A radical solution is the use of a DC amplifier with controllable subtraction of the DC component.*

Keywords—*Electrogastrogram, High-pass filtering, Low-frequency distortions, Time constant*

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1 Introduction

THE ELECTRICAL activity of the stomach recorded non-invasively by cutaneous electrodes, or the electrogastrogram (EGG), is a signal of low amplitude (about 100–400 μV) and frequencies of about 3 cycles min^{-1}, to about 9 and occasionally up to 12 cycles min^{-1}, corresponding to a bandwidth of 0.05–0.2 Hz.

Recording and processing the EGG require adequate amplification and band-pass filtering to suppress unwanted artefacts but also to preserve the original signal. Many authors accept a first-order high-frequency filter with a cutoff of 0.03 Hz (ABELL and MALAGELADA, 1988; COENEN *et al.*, 1992; LIN and CHEN, 1994). CHEN and MCCALLUM prefer to use 0.02 Hz (CHEN and MCCALLUM, 1991*a*,*b*) and warn about possible bradycardia of 0.0166 Hz (1 cycle min^{-1}). Therefore, they suggest a filter time constant $\tau = 10$ s or more, if bradycardia is to be studied or expected (CHEN and MCCALLUM, 1991*a*). Normally they accept time constants of 3 or 5 s (0.053 or 0.032 Hz). In some cases $\tau = 8$ s (CHEN and MCCALLUM, 1993) and even $\tau = 10$ s (0.016 Hz) are used (BRUIJS *et al.*, 1991), but the high-order filter proposed by the latter (24 dB oct^{-1}) might create slow oscillations when attacked by high slew rate waves or artefacts.

Using a lower time constant leads to a reduction of electrode potentials drift and to transient periods of shorter duration after amplifier saturation. These advantages are to be considered in view of the fact that the lowest frequency components of the ECG are prone to distortion by incorrect selection of the high-pass filter time constant.

We are faced with the problem of building a portable EGG recorder, where the compromise between stable baseline recording and preservation of the signal shape is of the utmost importance. The selection of a lowest possible filter time constant leading to acceptable low-frequency signal waveforms is necessary. Therefore, we study low-frequency component distortions due to different filter time constants using sets of simulated and real signals.

2 Method

We obtain electrogastrograms from 26 healthy volunteers and patients with motility disorders in fasting and fed states. We use parts of these recordings as examples in this study. We place cutaneous electrodes (conventional disposable electrocardiographic stick-on type) on the upper abdomen over the projected stomach position (ATANASSOVA *et al.*, 1995). We use a two-channel EGG recorder with a high-pass filter time constant of 5 s. Its microprocessor system is programmed to eliminate 50 Hz interference and electrocardiogram artefacts (DASKALOV *et al.*, 1995). We thus obtain a high-quality EGG

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signal and transfer it to a personal computer for further processing. We obtain several EGG records through a DC amplifier (DOTSINSKY *et al.*, 1991).

We synthesise artificial signals with sinusoidal bursts of typical EGG frequency of about three cycles min^{-1} or 0.05 Hz and of a bradygastric frequency of 1 cycle min^{-1} (0.0166 Hz).

The large variety of EGG signals that we collect allow us to select different epochs with bradygastric, tachygastric and mixed waves to test possible lower-frequency component distortions.

We apply digital filtering (equivalent to the application of a first-order analogue high-pass filter with different time constants) forward and backward to the artificial and real signal epochs. We test backward filtering with the same time constant that was used for signal acquisition, to assess possible restoration of the original waveforms.

We use a well-known high-pass digital filter (BOGNER and CONSTANTINIDIS, 1975).

$$Y_n = A(X_n - X_{n-1}) + BY_{n-1}$$

where

$$A = \frac{1}{1 + \tan(\pi F_c T)} \text{ and } B = \frac{1 - \tan(\pi F_c T)}{1 + \tan(\pi F_c T)}$$

$F_c = 1/2\pi\tau$ is the cutoff frequency (Hz), T is the sampling period (s) and τ is the time constant (s).

Here $X_1, X_2, \ldots, X_z$ are the original signal samples and $Y_1, Y_2, \ldots, Y_z$ are the filtered samples. We apply this filtering procedure to the digitised signal in the forward direction, starting with samples X_0, $X_1, \ldots$ We apply the backward filtering in the same way, but starting with the last sample: X_z, $X_{z-1}, X_{z-2}, \ldots$

3 Results

Fig. 1*a* shows a test signal of four sinusoidal waves with a period of 25 s, corresponding to an EGG wave of 2.4 cycles min^{-1}. After high-pass first-order filtering with $\tau = 5$ s, there is a 29% reduction in amplitude of the first wave and 20% of the remaining waves (Fig. 1*b*). The backward filtering with the same time constant (Fig. 1*c*) leads to further amplitude reduction of 37% with respect to the original signal. It could be surmised that normal EGG waves of 2.4 cycles min^{-1} and more are not considerably distorted by a $\tau = 5$ s filter (except for the artefact at the end of the burst due to the abrupt transition from sinusoid to baseline). As for the wave amplitudes, the initial wave reduction is substantial and the remaining waves suffer a 20% loss. As for backward filtering for restoration of the original signal, we can see that this approach is inappropriate in the case of $\tau = 5$ s.

Therefore, we may suggest that the $\tau = 5$ s filter is acceptable for EGG signal acquisition, provided that bradygastria is not considered, and with an awareness about possible relatively abrupt transients in amplitude, that are practically improbable.

The same test signal is subjected to filtering with $\tau = 10$ s and $\tau = 15$ s. Figs. 1*e* and *f* and Figs. 1*h* and *i* show that the amplitude reductions are about 6% with $\tau = 10$ s and only 2% with $\tau = 15$ s. The backward filtering with $\tau = 15$ s shows an acceptably restored waveform.

We deduce that in the rare cases of investigations involving waveform analysis or precise amplitude measurements, time constants of 10 or 15 s are recommended. Backward filtering with $\tau = 15$ s can almost completely restore the original waveform.

We perform similar experiments using a test signal of 1 cycles min^{-1}. The results presented in Fig. 2 show that

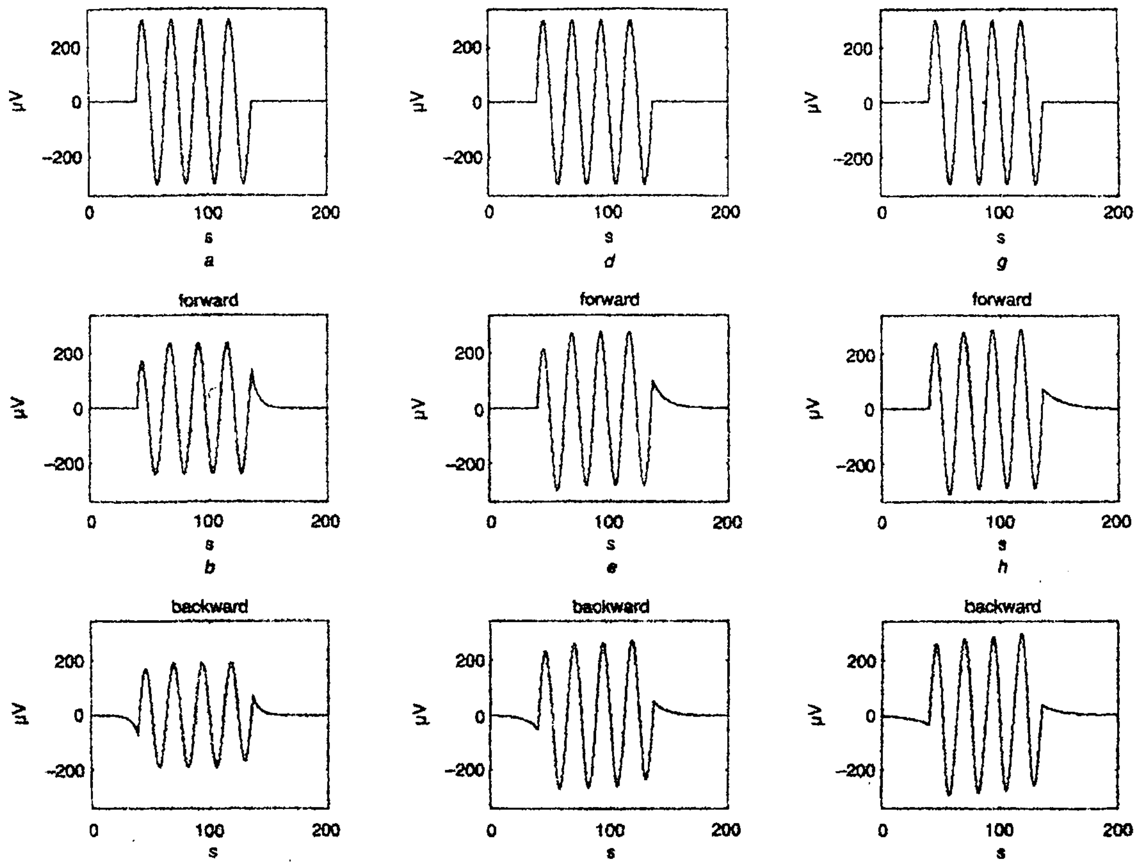

Fig. 1 *Sinusoidal test signal of 3 cycles min^{-1} subjected to forward and backward filtering with a time constant of (a, b, c) 5 s, (d, e, f) 10 s and (g, h, i) 15 s*

using $\tau = 5$ s is totally unacceptable for studying bradygastria, with $\tau = 10$ s (Fig. 2*e*), an amplitude reduction of 23% can be seen and $\tau = 15$ s leads to an acceptable 12% loss. We also see that backward filtering (Fig. 2*f*, *i*) cannot restore the original signal.

We apply the above procedure to some original EGG signals, to better present possible distortions.

An EGG signal, obtained with a DC amplifier, is shown in Fig. 3*a* (solid line), with a frequency of about 3 cycles min^{-1}. The signal filtered with $\tau = 5$ s is shown by a dotted line. We observe amplitude and phase distortions, but judge these as acceptable for most cases of clinical EGG investigations.

The same signal, filtered with $\tau = 10$ s (Fig. 3*b*) is considerably less distorted. The $\tau = 15$ s filtering (Fig. 4*a*) leads to further reduction of the distortions. In this case the backward filtering (Fig. 4*b*) practically restores the original signal.

A signal composed of slow and fast components, shown in Fig. 5, is subjected to forward filtering with $T = 5$ s. We observe that the slower waves (time segments 0–40 s, 80–100 s and 175–200 s) are distorted in amplitude and phase, and the faster waves (40–80 s, 100–170 s) are well preserved. This result is expected, but we show it here to recall that in studies involving assessment of wave propagation, meaning phase comparison between EGG signals, special attention should be paid to the signal frequency components and the high-pass filtering used.

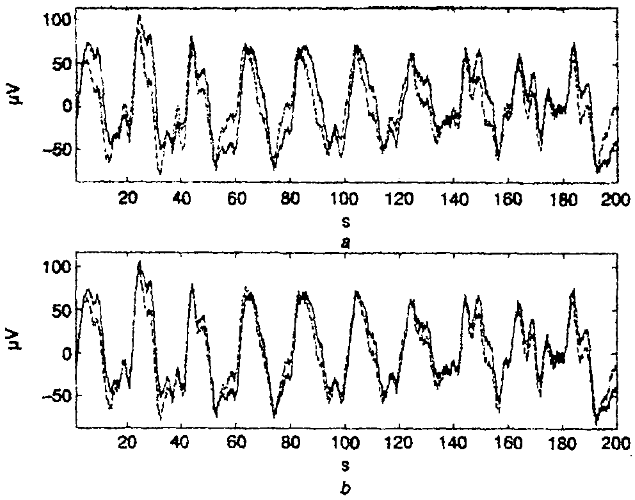

Fig. 3 *EGG signal of about 3 cycles min^{-1} obtained by a DC amplifier (solid line) and high-pass filtered (dotted line) with a time constant of (a) 5 s and (b) 10 s*

4 Discussion and conclusion

It is well known that large time constants lead to slow baseline restoration after strong artefacts, eventually leading to amplifier saturation. In such cases the amplifier may remain blocked for as much as 4–5 times τ, e.g. for more than 1 min with $\tau = 15$ s. A compromise is the use of a saturation detector driving a switch for fast discharging of the filter capacitor. A radical solution is the use of DC amplifiers with controllable subtraction of the DC component, as proposed for ECG and EEG acquisition (DOTSINSKY *et al.*, 1991) and used for experimental EGG recording in the present investigation.

The use of high-pass filtering in the acquisition of EGG signals is an accepted procedure, but the selection of the filter cut-off frequency or the time constant should be considered

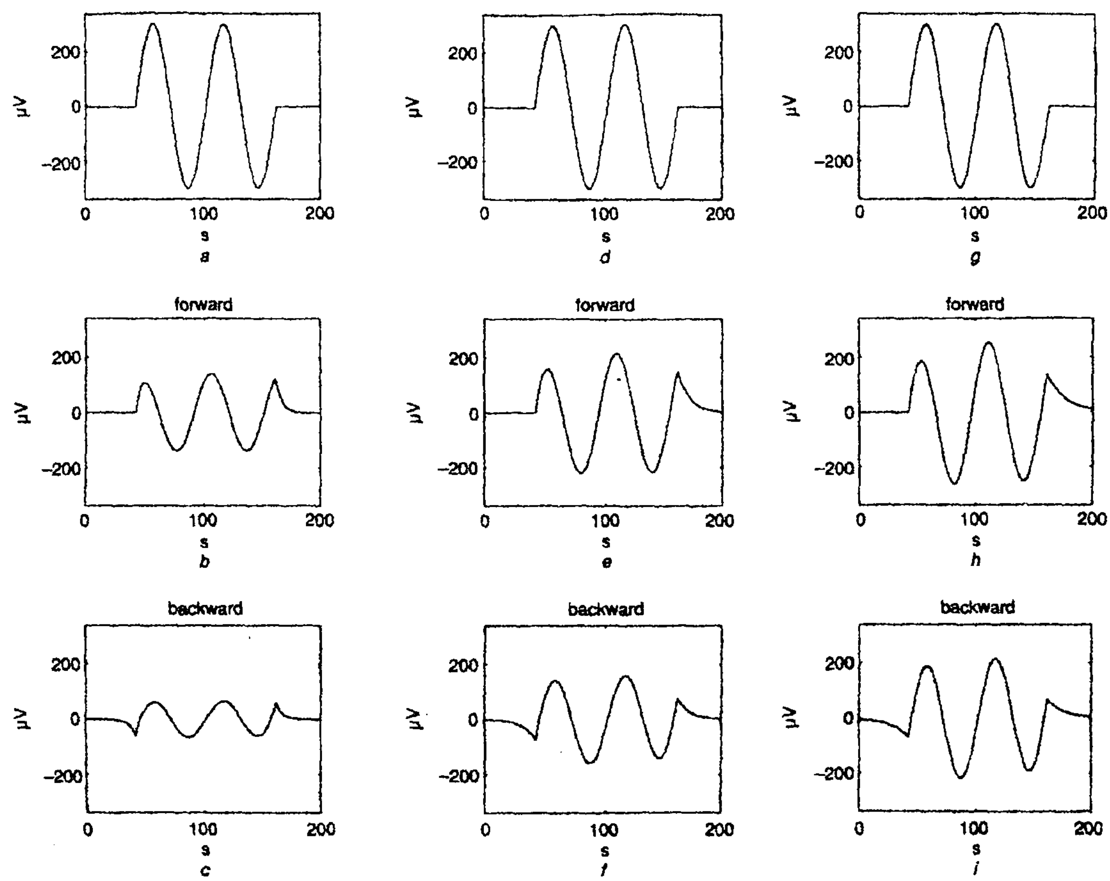

Fig. 2 *Sinusoidal test signal of 1 cycles min^{-1} subjected to forward and backward filtering with a time constant of (a, b, c) 5 s, (d, e, f) 10 s and (g, h, i) 15 s*

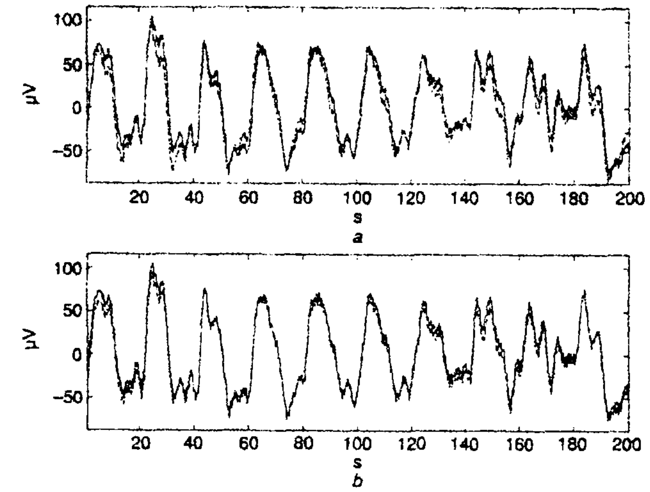

Fig. 4 *(a) EGG signal of about 3 cycles min^{-1}, obtained by a DC amplifier (solid line) and high-pass filtered (dotted line) with a time constant of 15 s; (b) restored by backward filtering (dotted line)*

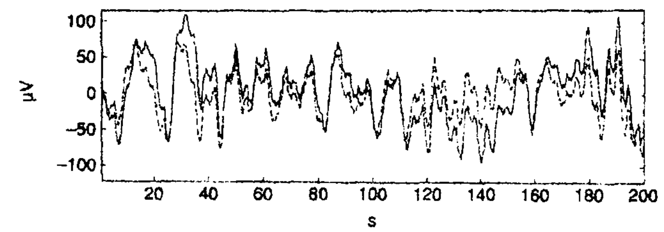

Fig. 5 *EGG signal, obtained by a DC amplifier (solid line), filtered by a 5 s time constant, where slower waves are distorted in amplitude and phase and faster waves remain undistorted*

with care, depending on the specific investigation. A time constant of 5 s is an acceptable compromise between electrode polarisation changes suppression and preservation of EGG signal amplitude, provided that frequencies lower than about 2.5 cycles min^{-1} are not expected and are not of interest, meaning that bradygastria is excluded. We may use similar or even lower time constants to record electrical activity in the small intestine.

The original EGG signal waveform can be obtained by a higher time constant, for example 15 s, and backward filtering. Of course, we cannot do this in real time.

In cases in which lower frequency components are of interest (bradycardia, electrical activity of the colon), lower filter time constants (10 s or 15 s) are to be used. Obviously, a better solution is the use of a DC amplifier, especially if combined with a high resolution (16 bit or more) analogue-to-digital converter.

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References

ABELL, T. L., and MALAGELADA, J. R. (1988): 'Electrogastrography: current assessment and future perspectives', *Dig. Dis. Sci.*, **33**, pp. 982–992

ATANASSOVA, E., DASKALOV, I., DOTSINSKY, I., CHRISTOV, I., and ATANASSOVA, A. (1995): 'Non-invasive electrogastrography. Part 2: Human electrogastrogram', *Arch. Phys. Biochem.*, **103** (4), pp. 436–441

BOGNER, R. E., and CONSTANTINIDIS, A. G. (Eds.) (1975): 'Introduction to digital filtering' (John Wiley and Sons, London, New York, Sydney, Toronto)

BRUIJS, P. P. M., VAN DER SCHEE, E. J., SMUR, A. J. P. M., AKKERMAN, L. M. A., and VAN STRIEN, H. L. C. J. (1991): 'Bedside system for cutaneous recording and analysis of gastric myoelectric and impedance signals', *Med. Biol. Eng. Comput.*, **29**, pp. 609–615

CHEN, J., and MCCALLUM, R. W. (1991a): 'Response of the electrical activity in the human stomach to water and solid meal', *Med. Biol. Eng. Comput.*, **29**, pp. 351–357

CHEN, J., and MCCALLUM, R. W. (1991b): 'Electrogastrography: measurement, analysis and prospective application', *Med. Biol. Eng. Comput.*, **29**, pp. 339–350

CHEN, J., and MCCALLUM, R. W. (1993): 'Frequency components of the electrogastrogram and their correlation with gastrointestinal contractions', *Med. Biol. Eng. Comput.*, **31**, pp. 60–67

COENEN, CH., THEUS, M., and THEUS, V. (1992): 'Anordnung zür Aufzeichnung und sofortigen Interpretation der myoelektrischen Aktivität des Magens—Elektrogastrographie', *Biomed. Technik*, **37**, pp. 99–105

DASKALOV, I., ATANASSOVA, E., DOTSINSKY, I., and CHRISTOV, I. (1995): 'Investigations in noninvasive electrogastrography', *Biomed. Tech.*, **40**, (2), pp. 161–163

DOTSINSKY, I., CHRISTOV, I., and DASKALOV, I. (1991): 'Multichannel DC amplifier for a microprocessor electroencephalograph', *Med. Biol. Eng. Comput.*, **29**, pp. 324–329

LIN, Z.-Y., and CHEN, J. DE Z. (1994): 'Time-frequency representation of the electrogastrogram—application of the exponential distribution', *IEEE Trans. Biomed. Eng.*, **41**, pp. 267–275