Technical note

Subtraction of 50 Hz interference from the electrocardiogram

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1 Introduction

THE electrical activity of the heart, recorded by electrodes applied externally on the human body, is of low amplitude (approximately 1 mV) and often contains different artefacts and noise. One of the most common types of disturbance is the mains interference, due to strong electromagnetic fields of 50 or 60 Hz present in the modern hospital and home environment. The mains interference cannot be completely eliminated from the electrocardiogram (ECG), especially when the high-frequency components of the signal have to be adequately preserved. This can often be one of the major problems of different analysis and interpretation systems and even of standard ECG machines.

Many solutions to this problem are known, including thorough skin preparation and application of the electrodes, cable arrangement, careful earthing and shielding and use of high common-mode rejection amplifiers. Very good results have been obtained by the use of averaging and recursive digital filters (LYNN, 1977; TAYLOR and MACFARLANE, 1974). However, this type of digital filtering still affects the high-frequency signal components and/or introduces 'ringing' if the frequency characteristic cutoffs are very sharp (TAYLOR and MACFARLANE, 1974). Such filtering may suit most monitoring instrumentation very well, but may be unacceptable for diagnostic ECG and vector ECG recording, evaluation and interpretation systems.

2 Method and implementation

We developed, tested extensively and put into practice a method of digital 50 Hz interference elimination by computing the interference amplitudes and subtracting these data from the original signal (LEVKOV *et al.*, 1980). The method has been in use for four years and has been implemented in ECG screening/evaluation systems, an ECG/VCG analysis system and more recently in a family of microcomputer-based standard ECG machines. The latter convert the ECG into code form and perform lead selection and computation, filtering and printout of the fully synchronous standard 12 leads by a fast thermal dot printer. These microcomputer ECG instruments have been developed in the Institute of Medical Engineering, Medical Academy, Sofia, Bulgaria. The microcomputer-based ECG machines are manufactured by Maimex (Tx: 22712, maprez bg).

To present a brief description of the method its simplest practical implementation will be outlined. The ECG signal is digitised at a rate of 250 samples per second (4 ms sample spacing) and a resolution of 8 bits (256 levels), where one bit equals 20 μV referred to the input. The samples are stored into memory so that a desired signal epoch is obtained. We normally use 2·7–5 s epochs, depending on the type of ECG system, or up to 22 s for arrhythmia analysis. If the mains frequency is expected to vary more than the prescribed standard of $\pm$0·25 Hz the analogue-to-digital conversion (ADC) has to be mains synchronised by sample triggering, so that every fifth sample coincides with a given phase of the mains voltage.

We postulate that the interference can be measured in intervals of the ECG signal, where the latter is isoelectric or changes linearly with time. It can easily be shown that the sum of equally spaced sample amplitudes from one period of a periodic interference signal is zero. Thus, taking the average of an unfiltered signal in its isoelectric or linear intervals, the true signal amplitudes can be found. The criterion for the automatic selection of isoelectric and linear intervals is given below.

Let us consider several consecutive signal samples, shown in Fig. 1, where $X_0, X_1, \ldots, X_n$ are the sample moments, spaced at equal 4 ms intervals, and $Y_0, Y_1, \ldots, Y_n$ are the respective signal amplitudes. To find an isoelectric or linear

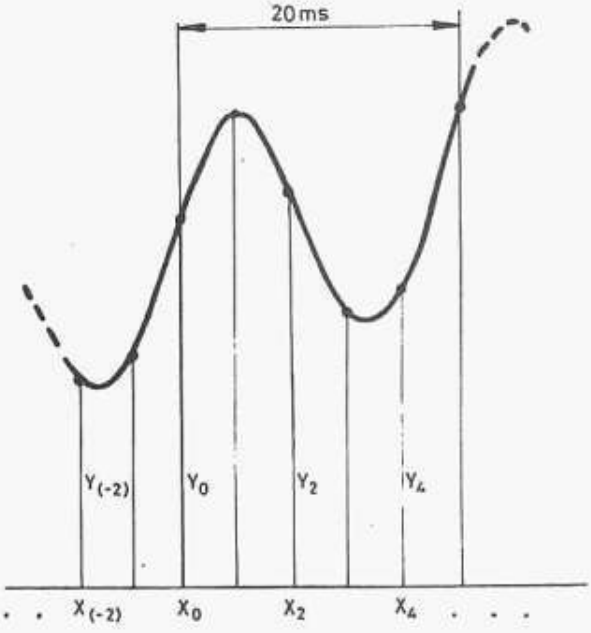

Fig. 1 *Samples of a portion of ECG with superimposed 50 Hz interference*

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segment of the signal regardless of the superimposed interference, the following differences D_i are taken:

$$D_0 = Y_{(-5)} - Y_0; D_1 = Y_{(-4)} - Y_1; \ldots; D_5 = Y_0 - Y_5$$

The maximum and minimum differences of these six are taken to form a new difference:

$$Cr = D_{max} - D_{min}$$

The value of Cr is a criterion for an isoelectric or linear interval of the signal. It can easily be seen that $Cr = 0$ means that the second derivative of the sample amplitudes is zero. For practical purposes it is impossible to use $Cr = 0$; therefore a low value should be selected. We normally use $Cr \leqslant 8$, which corresponds to $8 \times 20 = 160\,\mu V$ referred to the input. This value has been chosen as a result of empirical tests.

A simpler criterion has also been used:

$$Cr' = (Y_4 - Y_{(-1)}) - (Y_1 - Y_{(-4)})$$

The use of Cr' facilitates the use of a faster program, but small errors could be allowed in some particular cases. It is very difficult to assess the effect of threshold selection upon the accuracy of the procedure because the errors depend on the particular type of signal to be filtered. Our experience suggests that $Cr' \leqslant 8$ is a good choice, where the error does not exceed one discrete value ($\leqslant 20\,\mu V$) in more than 200 different signals tested by us, including the ones demonstrated in Figs. 2, 3 and 4.

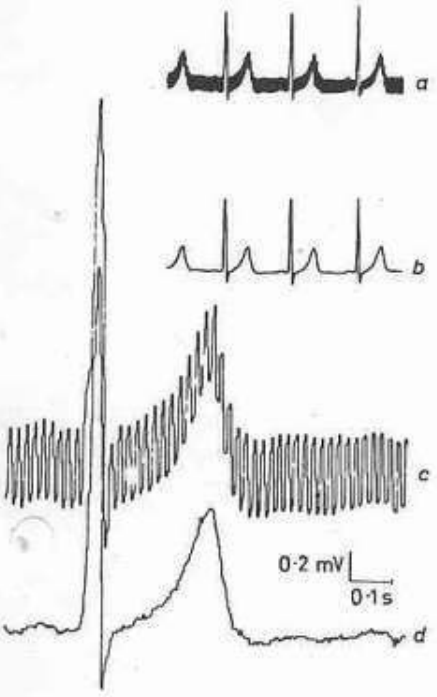

Fig. 2 *(a) unfiltered and (b) filtered V_5-lead ECG in normal scale (upper right) and (c), (d) in extended scale. Scale factors: 0·2 mV per division and 0·1 s per division*

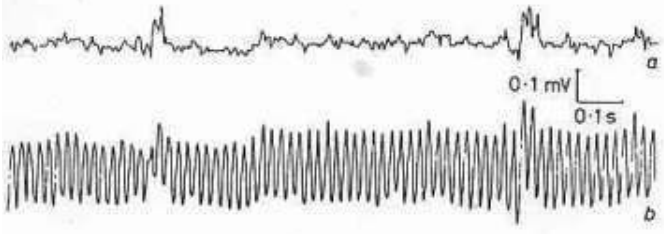

Fig. 3 *(a) filtered and (b) unfiltered III-lead ECG with muscle electrical activity. Scale factors: 0·1 mV per division and 0·1 s per division*

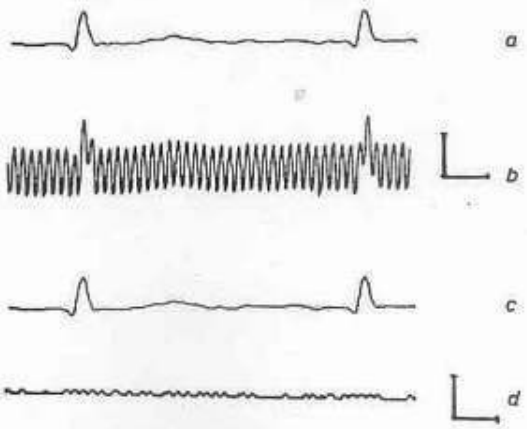

Fig. 4 *(a) original II-lead ECG signal (b) same signal with computer-added interference and (c) filtered signal, all with scale factors of 0·5 mV per division and 0·1 s per division. (d) amplified difference between original and filtered signals with scale factor 0·2 mV per division*

If $Cr \leqslant 8$, the interval of ± 5 samples around $X_0(Y_0)$ is considered to be acceptable and we proceed to find the filtered value of the signal Y_{0f} as

$$Y_{0f} = 1/5(Y_{(-2)} + Y_{(-1)} + Y_0 + Y_1 + Y_2)$$

The amplitude of the interference Y_{0i} in the sample Y_0 can be found as

$$Y_{0i} = Y_0 - Y_{0f}$$

Four more interference values are computed using the same procedure, each for its respective sample value around Y_0, namely for $Y_{(-2)}$, $Y_{(-1)}$, Y_1 and Y_2. Thus all five interference values are found and later subtracted from the original signal. The actual subtraction and replacement of the unprocessed samples with the processed ones in the storage takes place after a second interval has been found with $Cr \leqslant 8$.

The procedure of computing Cr and Y_{0i} is to be repeated taking the next sample to the right (Y_1) as a new 'centre' sample Y_0, etc., until all of the stored samples have been processed. If for a given 'centre' sample $Cr > 8$ occurs, the program moves sample-by-sample to the right until the condition $Cr \leqslant 8$ has been met. Then the five interference values are computed as usual and subtracted from the samples back around the 'centre' sample. In this procedure the phase positions should be carefully respected, i.e. each of the five interference values found is to be subtracted from each fifth original sample value back to the left.

It can be seen that the interference values are computed using the nearest possible samples to the ones where the subtraction takes place. This also provides for successful elimination of time-varying interference, except for the extremely rare case when an abrupt interference change would occur in a nonlinear signal interval, e.g. in some phase of the QRS complex.

The program implementing this method was written for the MC6802 microcomputer system in assembly language. The program runs for about 0·15 s for a 1 s signal epoch (250 samples). Of course, the running time depends on the type of signal, and this value is an average one. Much shorter running times can be obtained by a compromise with

accuracy, e.g. by taking $Cr \leqslant 16$ or replacing it with Cr'.

The program will not be executed and a flag will be set if $Cr \leqslant 8$ has not been found throughout the entire signal epoch, or when sample values of 00 or FF have been found, meaning that the ADC range has been exceeded.

3 Results and discussion

The efficiency of this method can be assessed by some selected examples. Fig. 2 shows a V_5-lead ECG with an R-S amplitude of approximately 2·8 mV, with 0·5 mV peak-to-peak 50 Hz interference. The unfiltered and the filtered signals are plotted one under the other in a normal scale (upper-right corner of the Figure) and in a vertically extended scale below. This example shows that the high-frequency components of the signal have been adequately preserved, which can be seen by noting the sharpness of the R and S peaks. The P-wave amplitude of the signal is approximately 50 μV, giving a signal-to-noise ratio of 1 : 10 with the interference, which has been successfully dealt with. Theoretically, an arbitrarily low ratio can be improved to an interference-free signal. The only practical limitation is the dynamic range of the ADC, which must not be exceeded by the original (unfiltered) signal.

Another example, shown in Fig. 3 is a low-amplitude ECG (III-lead) with muscle artefacts as well as with 0·2 mV 50 Hz interference, where the QRS complexes are approximately 1 mV. It can be seen that the 50 Hz signal changes with time from 0·2 mV to 0·25 mV. The interference has been completely eliminated and the fact that the muscle electrical activity remains proves again that the 50 Hz signal alone has been removed.

A more accurate assessment of the errors involved is demonstrated in Fig. 4. Here an interference-free signal (*a*) have been taken and a 50 Hz signal added by the computer, so that a noisy signal (*b*) has been obtained. The processed signal is shown (*c*) and the amplified difference (*d*) obtained does not exceed a single discrete value, equal in our case to 20 μV. Much lower error values (in our experience, to 1·5 μV) can be reached using a 12-bit analogue-to-digital convertor and double-byte word length in the microcomputer system.

The efficiency of this method for the subtraction of 50 Hz interference from the ECG allowed us to build an ECG system with greatly reduced requirements towards amplifiers, shielding, earthing, electrode quality and application procedure. Thus easier and faster patient processing has been reached in ECG screening evaluation, in ECG diagnostic units, in exercise tests, surface mapping, vector-ECG recording and evaluation.

References

LEVKOV, C., MICHOV, G., IVANOV, R. and DASKALOV, I. (1980). Method and device for mains interference elimination in bio-signal analysis. Bulgarian patent 30792.

LYNN, P. A. (1977) Online digital filters for biological signals: some fast designs for a small computer. *Med. & Biol. Eng. & Comput.*, **15**, 534–540.

TAYLOR, T. M. and MACFARLANE, P. W. (1974). Digital filtering of the e.c.g.—a comparison of low-pass digital filters on a small computer. *Med. & Biol. Eng.*, **12**, 493–502.