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ELECTRIC FIELD PLETHYSMOGRAPHY FOR MONITORING OF CARDIAC AND RESPIRATORY ACTIVITY

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Abstract: A project is reviewed which applies Electric Field Plethysmography to both respiratory and cardiac components in an equal way. Electrode positioning and signal processing are optimized in order to produce a sum-signal which finally is separated into a respiratory and a cardiac signal by means of adaptive filtering, Neural Networks, weighted subtraction or Fourier analysis, respectively. For the first time, the test system offers a simple tool for a precise determination of the exact synchronism between respiratory and cardiac activity.

Keywords: electric field plethysmography, respiration monitoring, cardiac output monitoring, neural Networks, physiological synchronism

1 INTRODUCTION

This paper gives a review about a project which has been aimed on a synchronous detection of respiration and cardiac activity applying the well known basic principle of Electric Field Plethysmography (EFPG). Initially [1], this term had been defined for a constant voltage technique in connection with a specifically designed electrode arrangement. However, we have adopted this term to refer in a general way to such four-electrode techniques which exhibit (widely) independent locations of current electrodes and voltage electrodes, respectively.

In a high amount of scientific studies (see, e.g. [2]), electrode configurations have been developed which proved effective for monitoring of human respiration, the high-frequency field (usually 20..200 kHz) mostly being impressed normal to the thorax axis. There result demodulated voltage signals which reflect ventilation in a rather undisturbed way, the cardiac activity usually arising as a weak artifact. As well, techniques have been designed for monitoring of the cardiac output, the field mostly being impressed roughly parallel to the axis. The respective respiration-caused artifact tends to be distinct, its suppression needing rather complicated techniques of hardware and/or software [2].

The basic idea of the present project was to replace the aim of specific signal detection by that of unspecific detection of "mixed" signals s which finally are separated into a respiratory portion s_R and a cardiac portion s_c, respectively, by means of advanced methods of signal processing. This strategy was based on the fact that medical practice mostly shows an interest in both the respiratory and the cardiac activity. In addition it seems advantageous to detect both activities by mere application of two pairs of electrodes, i.e. with very simple apparatus at the human thorax. The following brief review of the project discusses the developed methods of signal processing as well as some possibilities of practical application.

2 APPARATUS

Designs of electronic apparatus for the processing of EFPG signals usually are aiming for a selective enhancement of that physiological event which is of specific interest. I.e. for monitoring of the cardiac activity, the respiratory signal is suppressed by high-pass filter techniques, and vice versa. On the other hand, in the present case, an apparatus (block diagram in Fig. 1 [3]) was designed which is characterized by exactly constant gain for the relevant frequency range of both cardiac and respiratory

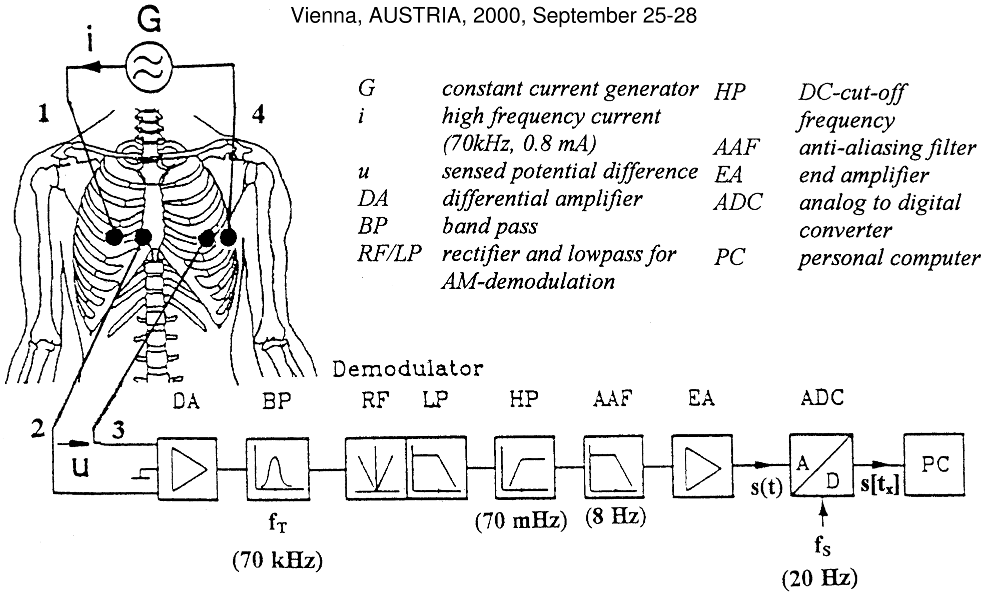

Figure 1. Principle of the applied EFPG system.

activity, i.e. down to the lower corner frequency of 0.07 Hz. With 8 Hz - defined by an anti-aliazing filter -, the upper corner frequency was chosen low aiming for a restriction of data, the sampling frequency f_S being 20 Hz. These corner frequencies were based on extensive evaluation of the physiological range of respiration frequency f_R and cardiac frequency f_c, respectively (details see in [3,4]).

3 ELECTRODE POSITIONING

Conventional positioning of electrodes usually is aimed on an enhanced detection either of respiration or of cardiac activity, respectively. In the present case, attempts were made to detect a *sum signal s* containing a portion s_R which is linearly proportional to the volume of inspired air, the degree of linearity being checked during a 1 min calibration phase by means of a conventional spirometer. As well, *s* should contain a portion s_c inversely proportional to the cardiac output. Here, noninvasive calibration is impossible.

Optimization was performed in an iterative way on the basis of 2D Finite Element modeling of the thorax [5]. A respective result is included in Fig. 2 showing respiration-caused shifts of equipotential surfaces as well as the resulting change of five portions of current. Modeling indicated that an electrode positioning N-D in the height of the 5th intercostal space yields an approximate inversial proportionality to the blood concentration of the hilum. This positioning was used in most experiments. Partly, an additional signal s* was detected between L and D, containing a weaker cardiac portion.

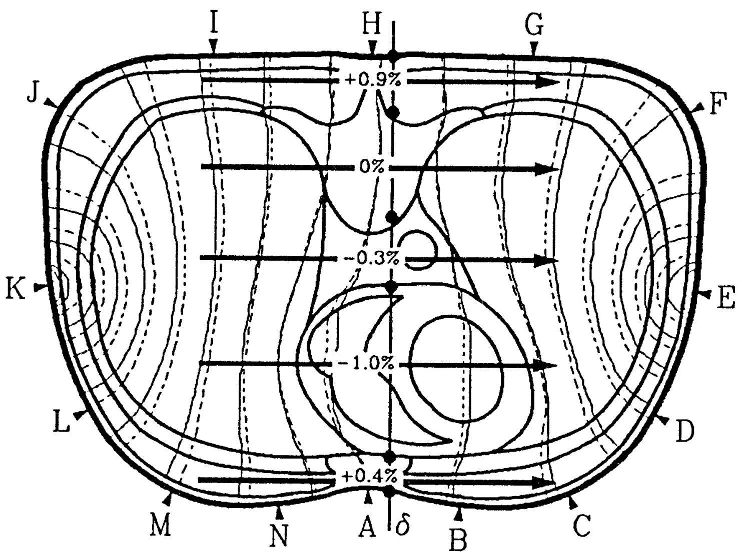

Figure 2. FE modeling of equipotential lines as to be expected in the thorax from current impression between the electrode positions K and E. The dashed lines indicate respiration-caused shifts as used for signal establishment.

4 METHODS FOR SIGNAL SEPARATION

Fig. 3 shows a technique which yields s_R and s_c from a weighted subtraction of s and s^* (details see in [6,7]). This yields s_R and s_c, provided that both s and s^* contain linearly correlating respiratory signals and linearly correlating cardiac signals. The weighting factors are determined during short calibration phases. The disadvantage of a second signal processing channel is compensated by the advantage of high stability. Insufficient separation results when linear correlations are not given. This is likely for cases of high body mass index which - however - tends to complicate EFPG techniques in a general way.

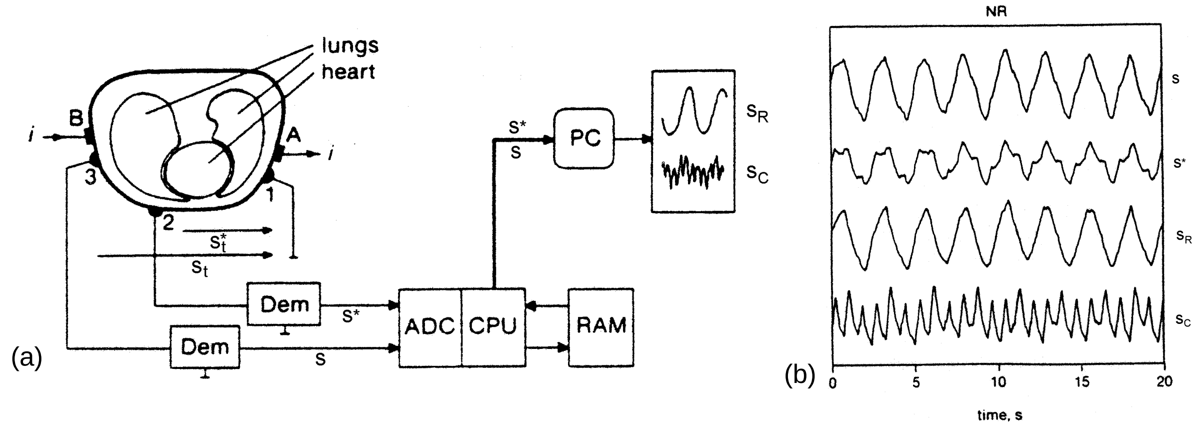

Figure 3. Five electrode technique. (a) Block diagram. (b) Typical result of signal separation.

Fig.4 shows results from a further development of this project [8]. Here s is passed through a digital low-pass filter (FIR-type of the order 130), the corner frequency of which is adapted by an ECG signal synchronously detected by the EFPG electrodes. The filter yields s_R; s_c results from $s_c = s - s_R$. Apart from restricted adaptation dynamics - e.g. in connection with movement artifacts (MAs) - the method shows very good performance. Alternatively, s_c is attained by means of a Neural Network with 64 input neurons corresponding to a moving signal window of 3.2 s. The hidden layer of 32 neurons works on a single output neuron which yields the first s_c value of the window. On the condition of sufficient supervised training, the method shows almost as good effectiveness as the filter technique (compare Fig. 4b with Fig.4c).

The above-described techniques allow for the monitoring of long-term time changes of respiration and cardiac activity, e.g. during anesthesia. For studies of short term synchronism, we developed a soft ware system [4] which analyses successive 1.6 second long samples of s. These samples are subject to short-time Fourier transformation applying a Hamming window on the signal sample. The technique yields short-time frequencies f_R and f_c including up to about four harmonics presented in the time-frequency domain. Fig.5 indicates the high effectivity of this technique for studies of short-term interdependencies of respiratory and cardiac activities. For example, in a clear way the sub-spectra of f_c-harmonics visualize side bands of width $k \cdot f_{R,1}$ reflecting cardio-respiratory intermodulations.

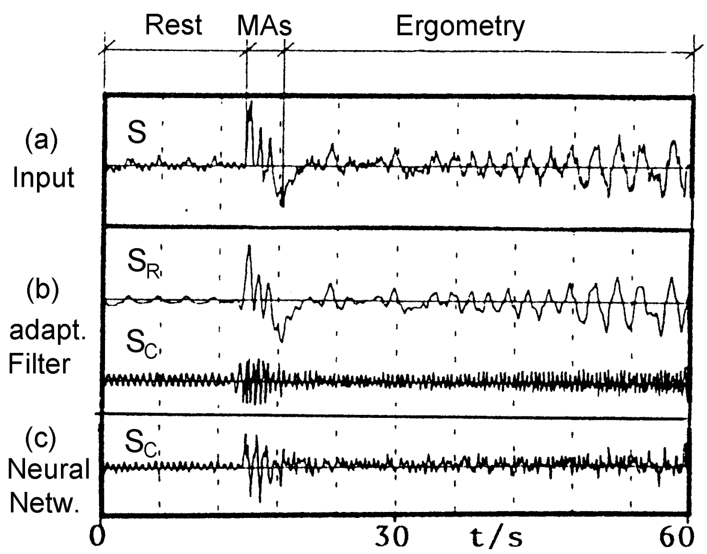

Figure 4.
Software separation techniques.
(a) Input signal including a strong movement artifact (MA).
(b) Respiratory signal and cardiac signal as established by adaptive filtering.
(c) Cardiac signal as established by a "Neural Network".

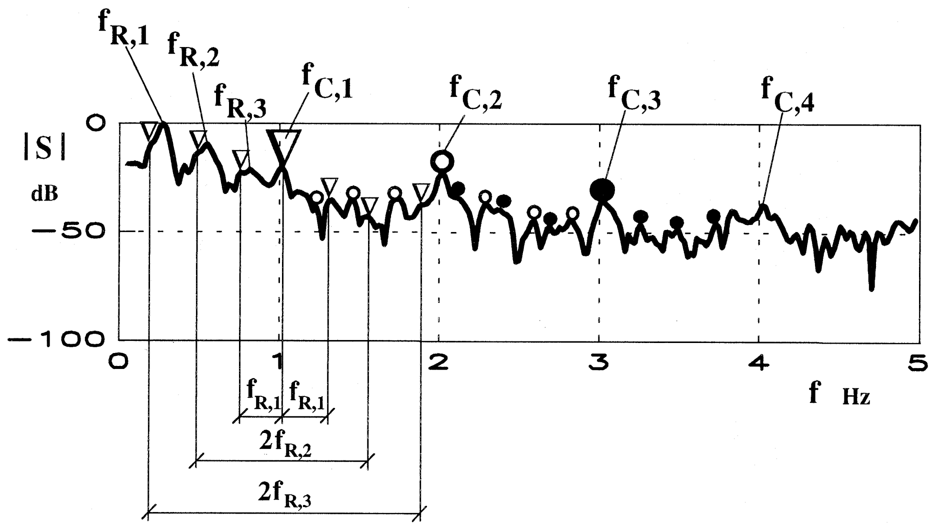

Figure 5. Typical result of short time studies applying FFT on 1.6 s long signal samples (see text).

5 CONCLUSIONS

Detection and processing of "mixed" EFPG-signals provide a simple tool for the determination of both respiratory and cardiac activity in a synchronous way - including short-time synchronism within a period of respiration. The results tend to be affected by movement artifacts which restricts applications for ergometry to monitoring during brakes. On the other hand, high effectiveness is given for long term monitoring during rest, anesthesia or sleep (apnea detection for infants - SIDS - or adults).

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