BEAMING SIGNAL SOURCES IN MEASUREMENT OF FOCAL VISUAL EVOKED CORTICAL POTENTIALS

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Abstract - **VECPs (Visual Evoked Cortical Potential) after focal stimulation used in perimetry have weak amplitudes in comparison to the spontaneous EEG, thus the SNR (Signal-to-Noise Ratio) falls off down to -20dB and less. The shape of the VECP waves depends on several parameters and is unknown in general. Then for SNR enhancement and signal detection shape-independent methods can be used only. The most common of them is the stimulus synchronized averaging, which causes cumulative prolongation of the measurement time corresponding to the averaging order. For online measurements of VECP other ways in signal improvement are needed. In this paper a new method for SNR enhancement based on beam forming is introduced. While the anatomical structures of sources generating the focal VECP are known roughly and the electrode positions have sufficient density over the visual cortex, signal sources can be focused by controlling the channel delay.**

Keywords - **VECP, beam forming, space filtering**

I. INTRODUCTION

In functional diagnostics of the visual field known as perimetry, focal stimuli coming from different directions scan the visual field. The task is to detect a visual field loss and to find its extension. Each focal flash excites different retinal area producing its individual projection in the visual cortex. Thus the shape of the VECP depends significantly on the stimulated area, a general waveform cannot be given [1], [2].

In the focal stimulation the VECP amplitudes are very small; they amount to levels in order of few microvolts embedded in the spontaneous EEG of up to one hundred microvolts, thus the Signal-to-Noise Ratio (SNR) falls off down to –20dB or less. The most simple but effective method for SNR enhancement is the stimulus related averaging. To obtain a sufficient VECP 10 to 1000 averaging steps are needed [3], [4].

In perimetric examinations of the visual field about 100 locations of the retina are to be checked. A complete objective VECP based test takes in the region of a few hours. This amount of time is necessary to obtain reliable strength of the focal VECP, but physicians do not undertake it because of lack of time due to an overload of patients. . It is therefore too time intensive. Consequently, other procedures for SNR enhancement are needed to shorten the time.

To obtain maximum EEG signal power in focal stimulation, a matrix of closely placed electrodes over the visual cortex can be used. After a sufficient amplification and ADC (Analog-to-Digital Conversion) the channel signals can be computed by DSP (Digital Signal Processing) methods to optimize the signal properties, especially the SNR. In this new method the channel delay is controlled to create electronically a beam focusing a signal source in the visual cortex.

II. METHODOLOGY

A. Theory

Assuming a spatial configuration of noise and signal sources, a spherical array of sensors as shown in Fig.1, and it is also supposed that the medium in the sphere is homogenous. Each sensor receives the SOI (Signal Of Interest) coming from the source. This is superimposed by gaussian white spatial uncorrelated noise. The SOI is a synthetical transient visual evoked response cognizable as a short wave train as shown in Fig.2. The SNR (Signal-to-Noise Ratio) is defined according to (1) as the quotient of the signal energy e_s and the noise power p_n, where $s(t)$ is the transient SOI and $n(t)$ gaussian white noise.

$$snr = \frac{e_s}{p_n} = \frac{\int_T s^2(t)dt}{\frac{1}{T}\int_{T\to\infty} n^2(t)dt} \qquad (1)$$

Assume that the channel signals are ensemble averaged as usual according to (2),

$$ave(t) = \frac{1}{N}\sum_i^N x_i(t) \qquad (2),$$

where $x_i(t)=s_i(t)+n_i(t)$ are the channel signals and i the channel index. The signal at the most significantly average output is shown in Fig.3. If the transients in the channels don't overlap they are suppressed in the resulting trace. By the same way the noise is reduced.
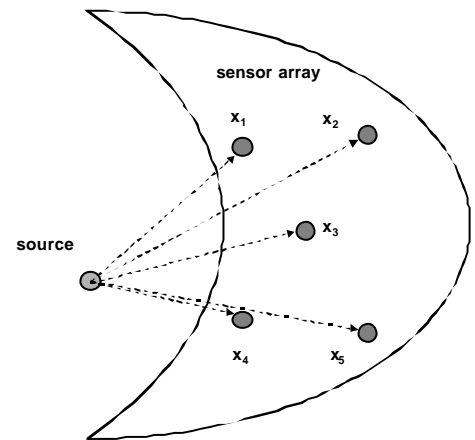

Fig.1. Spatial model of signal pathways and sensor array. Sensors are placed on the surface of a sphere; the source is inside of the sphere.

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Abstract

Subject Terms

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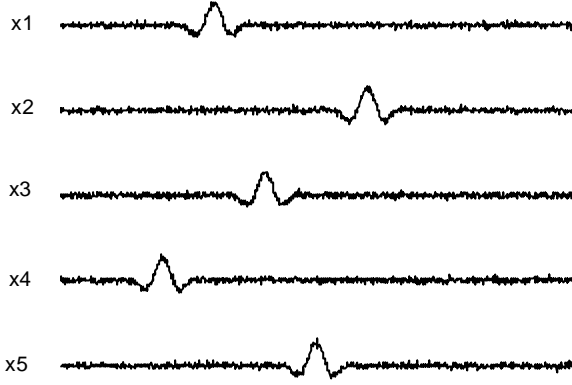Fig.4. Additional delay in channels before ensemble averaging. The control algorithm is application specific.

Fig.2: Channel signals coming from a signal source received by sensors placed on a sphere surface. The pathways between the source and the sensors are different in general for arbitrary placements, thus the appearing times are not simultaneous.

After the controlled synchronization the transient SOI remains unchanged. The noise is reduced and the SNR is enhanced as expected in ensemble averaging according to (5), where are snr_{orig} the original single channel SNR, snr_{syn} the SNR after synchronized ensemble averaging and N number of channels.

Hence, the SNR remains unchanged according to (3), where are snr_{orig} the original SNR in one channel and snr_{ave} the SNR after ensemble averaging.

$$snr_{ave} = snr_{orig} \qquad (3)$$

$$snr_{syn} = N \cdot snr_{orig} \qquad (5)$$

The resulting signal after perfect synchronization and ensemble averaging is shown in Fig.5.

To obtain an enhancement in the SNR by averaging it is necessary to fulfill the condition of concurrency regarding the appearance of the transient signals. Thus an additional delay has to be inserted into the channels as shown in Fig. 4. In this example the latest appearance shows the channel number two, all other channels will be delayed to obtain a perfect concurrency. The resulting signal $z(t)$ according to (4) is the ensemble average of the delayed channel signals.

B. Real data

a. Stimulation

For visual stimulation bright yellow-green LEDs (light emitting diodes) placed in a conventional perimeter bowl building the G1 visual test field were used. The flash pulse width was 20 milliseconds, the pulse period 1.6 seconds. Sixty four repetitive flashes were used per stimulus position.

$$z(t) = \frac{1}{N}\sum_i y_i(t) = \frac{1}{N}\sum_i x(t - \mathbf{t}_i) \qquad (4)$$

b. Recording

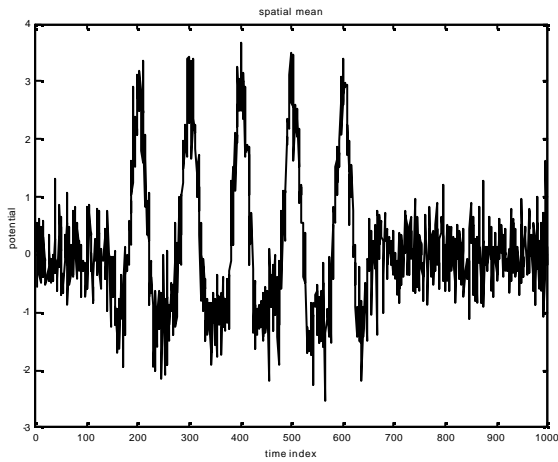The EEG (electro-encephalogram) was amplified by a conventional amplifier with an analogue lowpass at the edge

Fig.3. Ensemble average of channels. Transients appear at different times, thus are suppressed after averaging. The noise is reduced, too, the SNR remains.
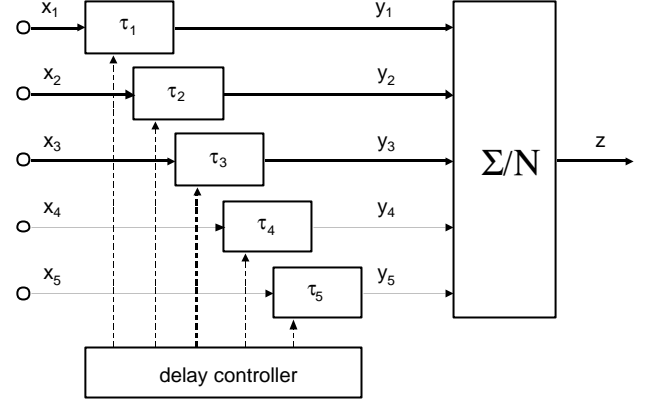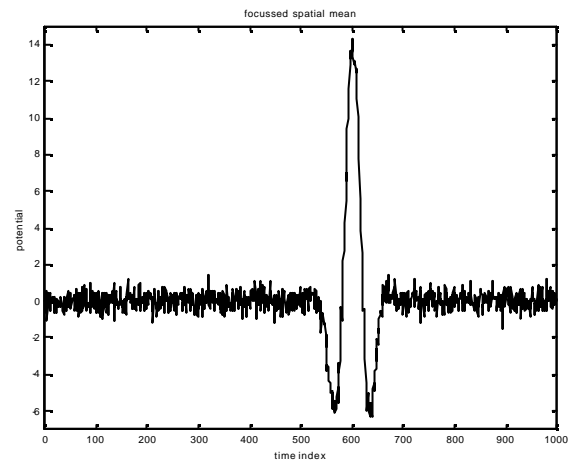

Fig.5. Output signal of a system containing several sensors, controlled channel delay and ensemble averager.
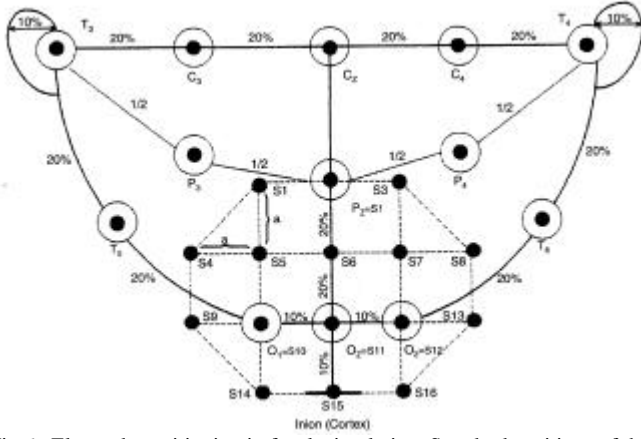
Fig.6. Electrode positioning in focal stimulation. Standard positions of the 10-20 system are denoted by rings. S1…S16 are electrodes used in this investigation.

frequency of 40 Hz and an analogue highpass at the edge frequency of 0.3 Hz. An amplification factor of 200.000 is applied. The sampling rate was 250 sps (samples per second), while 128 prestimulus and 128 poststimulus samples, i.e. 512ms before and 512ms after a flash were recorded.

c. Electrode positioning

For measurement of the EEG a special configuration of electrodes shown in Fig.6 was used. Since conventional 10-20 system is not suitable for investigations of focal sources, other ways in electrode configurations are needed in special problems. By the configuration shown in Fig.6 we tried to obtain vertical and horizontal projections of stimulus responses in sufficient placement density.

d. Analysis of data

In general, it is understood that real data have worse properties as simplified models. We have to consider that the noise sources are present in the whole investigated volume. Hence, at first by (6) we computed the common average $ca(k)$ and then subtract them from the sensor signals according to (7).

$$ca(k) = \frac{1}{N}\sum_{i=1}^{N} x_i(k) \qquad (6)$$
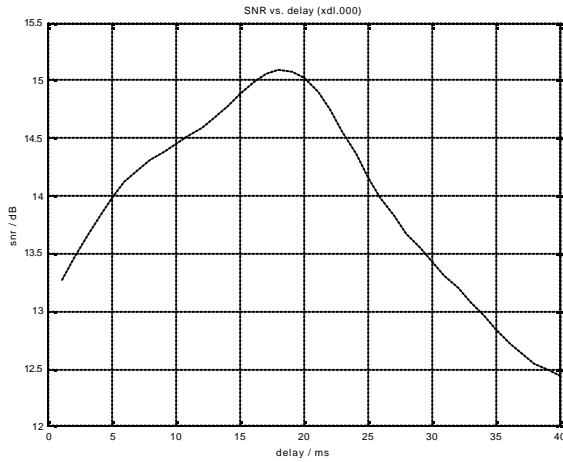
$$x_i^{ca}(k) = x_i(k) - ca(k) \qquad (7)$$

Fig. 7. SNR vs. delay for circular symmetric beam, axis at channel 6.
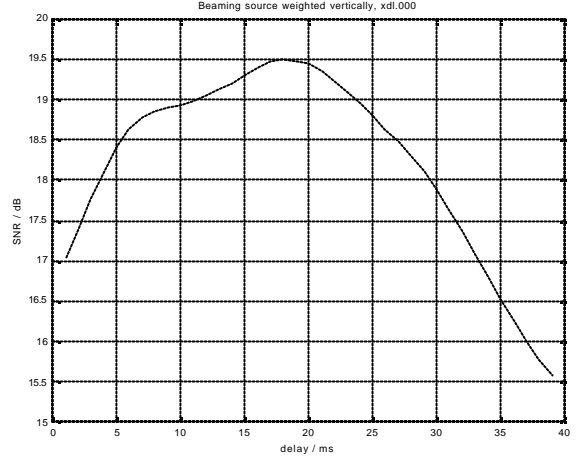

Fig. 8. SNR vs. delay for vertically oriented beam, axis at channels 6 and 11.

The SNR of real signals was computed by (8), where negative k stands for prestimulus part of the EEG and positive k for poststimulus part of the EEG possibly containing a stimulus response.

$$snr = \sum_{k=1}^{128} z^2(k) \Big/ \sum_{k=-127}^{0} z^2(k) - 1 \qquad (8)$$

III. RESULTS

First we investigated if there is a significant maximum in the dependence of the SNR on the delay. The exact positions of signal sources in the visual cortex are not known in general. To assure that a known structure will be excited we stimulated the central visual field, thus it should be sure that the centrum of the visual cortex was activated.

The dependence of the SNR on the delay was investigated in the following way: the delay was changed in basic steps of one millisecond, while the channel specific delay was multiplied by its distance from the channels defining the axis of symmetry.

Theoretically the SNR enhancement in 16 channels could be up to 12dB. This value will be not reached in real signals.
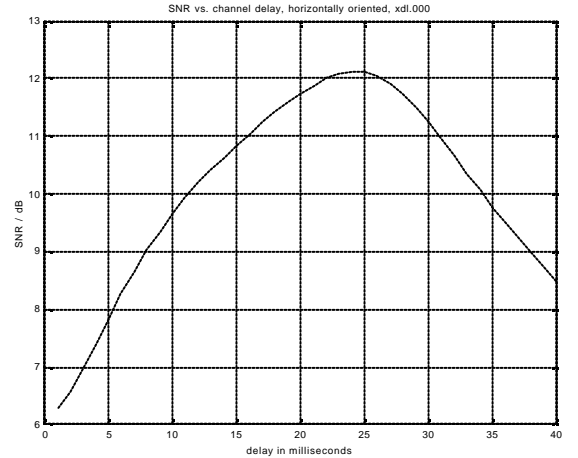

Fig.9. SNR vs. delay for horizontally oriented beam, axis at channels 5, 6, 7.
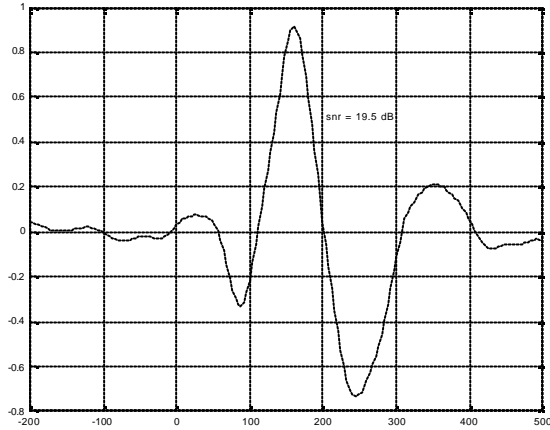
Fig. 10. Resulting VECP by vertically oriented beam at a basic delay of 18 milliseconds according to the absolute maximum SNR of 19.5 dB. Averaged over 64 single trials.

The beaming based SNR enhancement in real data is 2…6 dB. The maximal enhancement is the quotient of the maximal SNR be reached and the beginning SNR at starting delay according to (9).

$$\Delta snr_{max} = snr_{max} / snr_{start} \qquad (9)$$

IV. DISCUSSION

As could be expected, the real data do not hold the wide simplifying assumptions made in the space model shown in Fig.1. According to the properties of real data a significant increase of the SNR will be reached by subtracting the common average.

Data of volunteers were analyzed and compared. From these results certain qualitative behavior can be generalized: The analysis results show a clear dependence of the SNR on the delay in EEG channels, i.e. a dependence on the distance of the computationally controlled focus of the electrode beam.

From other investigations it is known that the signal sources change their direction of projection on the visual cortex. Our results have shown that in transient VECP the most signal power is oriented vertically, i.e. along the axis built by the channels 6 and 11 according to Fig.6. Thus the result shown in Fig.9 is surprising: although the maximum of 12 dB is less than in vertical or circular orientation, the horizontal beam orientation shows the maximal enhancement of 6 dB. A possible explanation could be that the horizontal orientation of the beam causes a better vertical beaming sharpness.

Because of multiple waves in the VECP the slowness aliasing [5] cannot be excluded in general, but in this transient responses it should be improbable. However, further investigations will clear this problem.

V. CONCLUSION

An electrode matrix placed over the visual cortex form a hypothetical reflector, which can focus signal sources. The simplest way to form a circular formed beam is to choose a sensor to be the point of origin and to delay the channels in the neighborhood by identical amount of time. If other anatomical structures are of interest, it is necessary to move that focus from the physically defined origin to a desired spatial point. Because of the configuration of electrode positions in space, the focus has to be moved electronically. Inserting additional delay into the EEG channels, which is controlled by any beaming algorithm, can do this.

In this contribution we have shown that it is possible to look for visual excited signal sources in the cortex. If some basic informations, such as the general direction, are known, the beam can be controlled.

The first results show that we have to consider multiple signal sources with strong changes in space and intensity. Taking into account that the qualitative behavior seems to be stable, new methods looking for the moving source in real time are to be developed.

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