TOPOGRAPHIC MAPPING OF THE BRAIN ELECTRICAL ACTIVITY

R. Murali Shankar and #A. G. Ramakrishnan

Department of Instrumentation Technology, S. J. C. E., Mysore 570 006.
#Department of Electrical Engineering, Indian Institute of Science, Bangalore 560 012.

ABSTRACT

Topographic mapping is a widely used tool in clinical neurophysiology in order to have a pictorial representation of the measured electromagnetic field on the surface of the skull. This paper presents pseudocolour mapping of electroencephalogram (EEG) in both the time and the frequency domains. A 19-channel EEG signal is analysed. FFT is used to convert the time-domain signal to the frequency domain to obtain power in the delta, theta, alpha and beta frequency bands, respectively, for consecutive epochs. For each band, interpolation is carried out to obtain power at discrete points between the electrodes. Colour map is displayed for individual frequency bands to represent spatial distribution of the power. Here, bilinear interpolation is used because it is computationally simpler and also entails smooth variations in the spatial values. Different colours are used to represent specific ranges of values of power levels. By a similar approach, the amplitude distribution of the EEG on the scalp, at any specific instant of time, is also displayed as a map. Amplitude mapping is used to find the distributions of epileptic seizures. The resolution of the colour map is 80x80 pixels. The system can also display power spectrum of individual channels at regular time intervals. Coherence spectrum, that indicates the correlation in the frequency domain between the EEG activity recorded at different locations on the scalp, is also displayed.

Introduction

Advances in computer technology and software have made it possible for sophisticated techniques to be developed in the past 10 years that permit the visualization of the structures and functional processes of the human brain. Unlike the imaging techniques such as X-ray or CT, the Electroencephalographic (EEG) mappings do not portray anatomic structures but the constantly varying spatial distribution of the electrical field generated by the brain. Brain mapping is non-invasive, permitting follow-up examinations to be performed as often as needed, and has extremely short analysis times (in the range of milliseconds). This type of representation is affected by the fact that the sampling in space (via the standard 10-20 electrodes) may be insufficient. To this end, more number of electrodes could be used, equally spaced over the cortical region of interest, that could be the whole scalp. Usually 32, 64, or even 128 electrodes are used, aiming to reduce the interelectrode distance down to a few centimeters, for recording the electric field. While considering the electrical properties of the biological media from the cortex to the skull, a resolution of 2 cm has been shown to be a good compromise between ignoring the contribution of some portion of the cortex, and receiving the same cortical field contribution at contiguous electrodes. Secondly, interpolation procedures are affected by approximations in the geometrical description of the head (usually modeled as a sphere) and cartographic approximations in projecting a 3-D surface (skull) onto a 2-D space and also assumptions in the interpolation algorithms to compute the field values for the points that lie in between. Nevertheless, such a lack of local precision in the computed map does not affect the power of the representation in giving an approximate pictorial description of the brain activity in different regions. The need for better precision arises when the aim is to map the anatomical sources of the detected potential, which is not the focus of the present paper.

We discuss the development a of package for the colour display of EEG data in time, frequency and spatial domains. Apart from mapping of the EEG data, additional tools like Power-spectral array and Coherence spectral array (COSPAR) are provided for quantitative EEG analysis. This type of EEG analysis is highly sensitive to qualitative transitions in mental state. Some of the subjective transitions are accompanied by observable changes in an appropriate mathematical measure of the correlation between the EEG activity recorded at different locations on the scalp. For quantifying correlations, we have chosen the coherence spectrum, primarily because of its prior use in EEG analysis and its availability as a by product of the Fast Fourier transform (which is used for

frequency-domain mapping). The coherence spectrum may be interpreted as a measure of the consistency of relationship between matching frequency components of two signals over a length of time determined by the analysis epochs employed. Generally, a high coherence (near unity) at a given frequency implies both phase locking and near stationarity of the individual signals at that frequency for the epoch length in question. Hence, coherence relates to order in the time domain as well. To provide a synoptic display of coherence spectra, we have employed the well-known compressed spectral array technique. First, we average the power-spectra and cross power-spectra (between channels considered for coherence analysis) of overlapping segments of data, a procedure first discussed by Welch. Second, we threshold the coherence spectra at a fixed coherence level. Third, we include in the display an epoch by epoch record of a measure of coherence averaged over a broad band of EEG frequencies. Finally, we introduce a non-linear filtering technique, whereby, (above threshold) coherence at a given frequency must appear in at least two successive epochs in order to be displayed by the compressed array - a procedure that eliminates sporadic events (including most forms of artifact) in order to emphasize consistent ongoing processes.

Amplitude Mapping

Here, the amplitude values of the EEG at a certain point in time are mapped. The principal use of amplitude values is in the cartography of epileptic features, focal disturbances and display of spatial EEG patterns such as k-complexes, spindles, activity, and similar phenomena. Fig. 1 shows an amplitude map of the EEG data.

Frequency Mapping

EEG is often dominated by one or the other frequency band. In order to transform EEG data from the time-domain to the frequency-domain, we used Cooley and Tukey FFT algorithm. Data in the power-spectral domain are expressed in terms of square microvolts / Hertz (μV^2 / Hz) or square microvolts (μV^2) within a frequency band such as alpha. The disadvantages of this representation is related to the fact that dominant frequencies are overemphasized due to the mathematical squaring of these values. Here, the maps shown in Fig. 2 are based on the square root of power and hence expressed in μV. The power-spectral array for an individual channel is shown in Fig. 3.

Map Construction

Starting with a limited number of actual, measured data points, an image consisting of thousands of data points (pixels) needs to be generated. Bilinear interpolation is used to fill in the gaps between the 25 values. This uses four nearest electrodes, i.e. a pixel value is obtained as the weighted average of the four nearest electrodes, the weight being inversely proportional to distance from each. Bilinear interpolation has the advantage of rapid calculation by the computer. A disadvantage is that maxima and minima of activity are always located at electrode sites. Other interpolation methods, such as surface spline interpolation exhibit maxima or minima between electrodes and produce smoother maps; however, the computing time required is considerably longer.

Each map is generally accompanied by a calibration bar indicating amplitude ranges (μV) in the case of EEG events in the time-domain and activity ranges (μV) in the case of the frequency-domain.
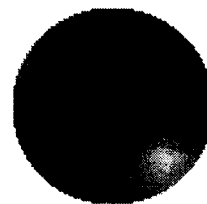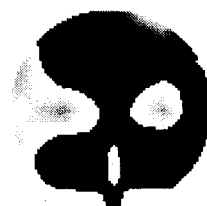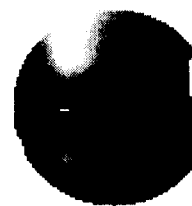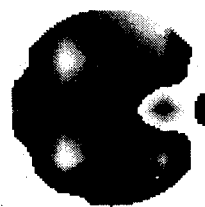

FIG. 1 Amplitude Mapping

Delta: 1Hz-4Hz   Theta: 4Hz-7.5Hz

Alpha: 8Hz-12Hz   Beta: 12Hz-25Hz

Fig. 2. Frequency Map

POWER-SPECTRAL ARRAY

Time in sec ---> 76.8

Frequency in Hz ----->

Fig. 3. Power-spectral array.

TEMPORAL FILTERED COHERENCE SPECTRA
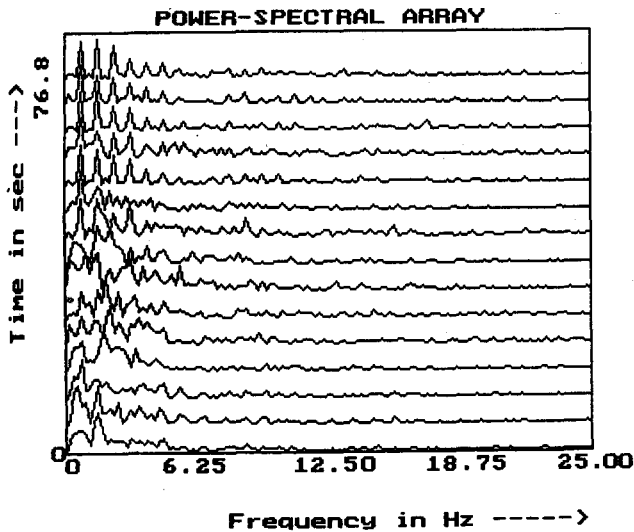
Time in sec ---> 51.2

Frequency in Hz ----->

Fig. 4. Coherence spectral array.

Computation of the COSPAR

The coherence-spectrum is computed for each epoch from the normalized amplitude of the averaged cross-power spectrum formed from two channels of data using the FFT algorithm. Here, we averaged over 19 overlapping, 2.56 second, sub-intervals for COSPAR generation, because it appears to be better suited to the detection of phase-locked signals where the phase difference switches rapidly amongst a discrete set of alternatives and where the occurrence of such activity is sporadic. The choice of 19 as the number of sub-intervals was made on the basis of computation time considerations rather than from an optimization standpoint. Data windowing to reduce spectral sidelobes and elimination of non-zero mean and trend prior to spectral analysis could be added to improve the statistical properties of the spectral estimates. Such techniques have not been employed in the COSPARs presented here, primarily for expediency and the limited objectives of the study. The raw coherence-spectra are then thresholded so that only coherence in excess of a fixed level is passed on to the next processing step. The threshold is intentionally set at a rather high level of 0.95 in order to reduce the likelihood of "accidental coherence" (i.e., coherence not indicative of true long-range order) between independent generators of EEG activity. Finally, a coherence peak is passed on to the compressed array, only if coherence above threshold is observed in at least two successive epochs at the same frequency.
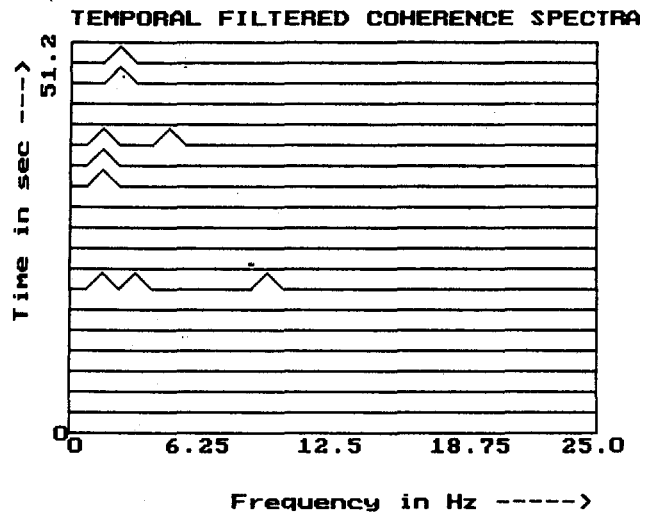
Conclusions

Brain maps may be constructed simply to be used as illustrations of the EEG state of a given subject. In these cases, the map becomes by itself the phenomenon that characterizes the EEG of a subject in a given state. Following this approach, a phenomenology of brain mapping can be developed, by means of which different patterns are considered to be characteristic of certain EEG states of a given category of patients. This approach is free from any model-based assumptions. However, one can go beyond brain mapping, if it is possible to assume that a given EEG spatial distribution corresponds to a definable electric source within the brain. This may be the case when sensory evoked potentials or epileptiform spike-and-wave complexes are analyzed.

The COSPAR appears to be a promising addition to the armamentarium of quantitative EEG analysis, particularly for researchers interested in the characterization of states of conscious experience that do not fit well into the binary classification of wakefulness vis a vis sleep.

References

1. Atlas of Brain Mapping by Konard Maurer and Thomas Dierks, Springer-Verlag, Berlin, 1991.
2. Diego Liberati, Stefano DiCorrado, and Stefano Mandelli, "Topographic mapping of Single Sweep Evoked Potentials in the Brain," IEEE Trans. Biomed. Eng., Vol. 39, No. 9, pp. 943-952, 1992.