TDAT—Time Domain Analysis Tool for EEG Analysis

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Abstract—An interactive design and analysis tool for displaying and quantifying multiple channels of data is presented. The system allows one to easily visualize multiple data channels and simultaneously observe the effects of filters on the data and to evaluate signal detection algorithms. The software is designed for a workstation environment; it will find application in a variety of applications where one needs to simultaneously visualize multiple data channels. TDAT is being used for the design and evaluation of filters and detection algorithms for electroencephalogram (EEG) waveforms, and it is serving as a prototype of a paperless system to be used by electroencephalographers.

This paper describes the general software structure of the system and illustrates many of the system features with examples.

INTRODUCTION

THE HUMAN electroencephalogram (EEG) is usually recorded from electrodes attached to the scalp using high-gain amplifiers which are usually ac coupled to the scalp electrodes. The amplified signals are written out on paper via a polygraph, which contains typically 8 to 16 channels. Normal subjects usually exhibit alpha, beta, theta, and delta activities, while abnormal brain activity may be manifested by a slowing and decrease in amplitude of the EEG, increase in the EEG frequency, and presence of sudden EEG discharges (paroxysmal activity) different from the background either in frequency content or amplitude or pattern. [3]

The electroencephalogram (EEG) is a powerful tool for the diagnosis of neurological disorders. Since its discovery, the EEG has been used for the diagnosis of epilepsy, for trauma assessment, for sleep research, and for the analysis of higher brain function. The EEG is highly dependent upon the availability of high quality instrumentation, and almost from the beginning, automated methods of signal quantification have been applied. One of the primary goals is to help the electroencephalographer (EEGer) in the time consuming task of quantifying a signal that appears to the eye as a low information content background intermixed with either bursts of rhythmic activity with different frequencies (the EEG rhythms) or short transients of clinical significance (such as spikes). In spite of years of research to produce universal automated detection methods, success has been achieved only in specific areas. Accomplishments include automatically sleep staging with a high degree of accuracy [1]; counting spikes and wave complexes [2]–[4], and monitoring in intensive care units [5]. However, clinicians still rely on visual analysis for clinical applications.

The human eye–brain can be trained to recognize extensively defined patterns in multichannel EEG recordings. However, ostensive definitions are not readily disseminated. A description of a mental image by words is normally poor and lengthy. What is needed in clinical practice is a way of exploring the great pattern recognition capabilities of the human visual system and enhancing the efficiency of the visual data communication.

Computers can bring quantification to EEG analysis in the form of precise measurements (microvolt and millisecond precision), but at this time, they cannot always use the measured data to identify clinically significant features.

All these aspects lead us to approach the use of computers in EEG research from a slightly different angle. We are also researching the design of computer-based environments that will help the doctor in the visual clinical assessment of multichannel EEG recordings, and the engineer in the design of better detectors.

An obvious role of the computer is the creation of environments where the EEGer can visualize the data (mimicking the paper output of the EEG polygraph) and which are enhanced with the power of computer-based measurements and manipulation (i.e., storage and retrieval of very large data bases), good report generation, automated detection methods that can direct the EEGer attention to suspicious events. The environment described in this paper called TDAT (time domain analysis tool) is a preliminary step towards this goal.

Many engineering problems require the detection of relatively brief phasic events which are visualized or defined in the time domain. Any filtering done on the data to enhance the detection may distort the temporal characteristics of the signal of interest. These effects are often best described by visually observing the data before and after filtering. We are faced with this particular need in the design of algorithms for the detection of phasic events.
in the electroencephalogram (EEG). The time domain analysis tool (TDAT) was developed to provide an interactive means for visualizing data in the time domain, accurately measuring temporal features, and to provide a means of visualizing the effects of various types of filters. This tool can find wide application in data analysis, particularly biomedical signal processing. This paper describes the nature of the problem for which the system was designed and provides examples of its use.

**Computer-Based Environments for EEG Visualization**

A goal of our research is to design a paperless workstation environment which replaces the multichannel polygraph now used for EEG monitoring. TDAT is serving as a prototype for this design. It is also serving as a workstation environment for implementing new filtering and detection algorithms, and for visualizing the results.

Most of the visual information extracted from the EEG is related to recurring short-term spatio-temporal characteristics of the signal. A computer environment for monitoring EEG recordings should display high quality multichannel EEG signals, enabling the user to change the amplitude scale (gain), horizontally scroll the data at selectable speeds, zoom in on a particular segment of the record to perform amplitude and period measurements, navigate at will in the EEG record, extract and compare segments, and apply digital signal processing algorithms to separate a signal from artifacts or background activity.

In order to be useful to the clinician, such a tool must also be made user-friendly. The concept of user-friendliness is vague, but it is not limited to being able to physically interact with the computer (mouse, windows, etc). Most importantly, the software should raise the level of human–machine interaction to the level of the human decision making. With conventional programming, the user must control the machine at a very low level (the level of the program commands). Clinical communication involves specific questions which are directly related to the patient and the clinical environment. One natural way to harmonize the user goals with the computer specifics is to create an object-oriented environment centered around the clinical issues. TDAT already incorporates some features of an object-oriented environment such as its structure, the translation of clinical functions into software processes (such as the display, the measurements, the analysis), and the communication between processes.

The EEGer interacts with TDAT by using almost exclusively the mouse. All the information is presented to the user in the form of environments (implemented as windows) with mouse sensitive areas (commands). Other aspects taken into consideration during software development are expandibility and versatility. The computer is simultaneously used as a powerful number crunching device for digital signal processing algorithms and a high quality data storage/display system.

TDAT is not only useful to EEGer’s, but it is also used in our laboratory as a key tool to design and validate automated EEG waveform detectors. The computer simultaneously serves as the simulation environment for implementing digital signal processing algorithms and for visualizing the application of such algorithms. The visual feedback considerably decreases the algorithm development time; TDAT also serves as a rapid prototyping medium for new ideas.

**Human Assessment of EEG Data**

TDAT was designed with the visualization and analysis of the EEG in mind. Key points were identified as follows:

- EEG interpretation involves scanning large amounts of data. This requires a large data storage medium in the computer. The user must be able to navigate through data at will, i.e., go forward and backward through the record. An epoch should be displayed with multiple time and amplitude scales. The system must provide an epoch finder, i.e., a visual cue indicating the current position in the record. Searches should be fast (less than one second).

- In EEG interpretation, the EEGer visually analyzes the record (typically 4, 8, or 16 channels). The computer display must closely mimic the EEG tracings obtained with a polygraph. Sometimes there is a need to zoom-in on a particular data segment and measure the amplitude and period of particular waveforms. Moreover, the EEGer may want to select particular portions of the record for further analysis and comparison. The signal analysis can benefit from filtering to attenuate unwanted activity (e.g., base line drifts and high-frequency artifacts). Also, from the engineer’s point of view, accurate measurements are important for quantifying the effects of filtering, or establishing thresholds for automated detection algorithms. The capability to compare different filters, or detection algorithms (like peak detection) is also very convenient.

- Finally, the EEGer needs to collect clinically relevant portions of the data and put them in the patient record for future use. The printouts should describe what the clinician sees of clinical relevance. The engineer also needs paper records for illustration and documentation purposes.

**Overall System Architecture**

The software is written so that the user can access and control, from the console, the different aspects of the data visualization/analysis. The main software modules are associated with the data search and display, and with data processing. Central to the functionality of TDAT is the control structure that is called the system kernel. The kernel’s overall functional block diagram is shown in Fig. 1. Versatility in data analysis/visualization is achieved with software modularization (influenced by the application), with the following data structure: the EEG data are digitized at a sampling rate of 250 Hz by 10 bit A/D converter and placed in mass storage. Data existing in mass storage are not directly displayed on the console. The stored EEG data are mapped into a global data buffer.
(GDB), and the screen is mapped into a global screen buffer (GSB). While the GSB can be a copy of the GDB (direct display of EEG data), the function executor can, at the user command, modify the data stored in the GDB before it is sent to the GSB for display. These modifications are associated with the requirements mentioned above for EEG analysis/visualization (scale change, zoom, the application of signal processing algorithms, etc.). The repertoire of available fundamental signal processing routines is kept in the function library, and can be expanded at will by the user, provided the set of standard procedures discussed below are followed. The fundamental function routines, which implement template signal processing algorithms (such as FIR, IIR filters, waveform detectors, etc.), can have up to 20 function units. The user specifies the algorithm parameters in the function units (e.g., a bandpass FIR filter with a 10 Hz center frequency and 5 Hz bandwidth to analyze alpha activity). The block receives data from the GDB and puts it in intermediate buffers that can be mapped to the GSB and which can serve as the input to other signal processing modules. Several signal processing units are often applied in cascade to implement sophisticated signal processing algorithms. With this flexible arrangement, the user can test and visually evaluate single or combinations of signal processing units.

The currently active subject in EEG database together with time and amplitude scale information, the description of combinations of the fundamental function units, the configuration of TDAT are kept in the system database. The user interacts with the system database through the main menu of TDAT setup window (shown in Fig. 2). The user can access this menu at any point in the program session modifying any parameter of the visualization/signal processing algorithms. Fig. 2 exemplifies a session to set up the system database, in which the user selected the data file ‘va0719.dat’ and the 30 s epoch by which the user can navigate the data file and eight display channels. The original data are to be low-pass filtered, peak detected, screened for spikes (with the parameters shown in spike 1), the output data are displayed in the first display channel (screen buffer 1). The user can choose other built-in functions by clicking the arrow in function set (a pop-up menu appears). The user can also register new function classes in this menu, or execute Unix commands in the window with the shell prompt.

The function library is expanded by writing code which conforms to its input/output format and by executing the automatic function expansion system (AFES). The AFES checks the code syntax and its compatibility with TDAT, compiles the code, and adds it to the function library. In addition, the AFES provides the capability to debug the logical validity of the code separately from the main TDAT software. TDAT runs under Unix on Sun workstations, and most of the software is written in C. The implementation of the TDAT user interface is based on the Sun view system (Sun visual/integrated environment for workstations). Various items and subwindows provided by the Sun view system simplify building user-friendly, interactive, graphic, menu-driven interface. The full resolution (1152 × 900) of the Sun bit-mapped screen is used for waveform display.

The EEG data are presently being collected in an IBM PC compatible computer (10 b, 250 Hz) and sent to the SUN 3 through an ethernet link (offline). Table I presents the functions currently implemented in TDAT.

**Visualization**

The identified tasks for EEG visualization are mapped into program environments. For easy interfacing, each environment corresponds to a window where the user selects, in command sensitive areas, the available commands.

Data browsing is accomplished in the main display window (shown in Fig. 3). Depending on the sampling rate, the window can display up to 30 s of eight data channels. The available commands are displayed in the screen's top row. The user simply selects the required function, and the program guides him/her through the steps by creating appropriate graphic menus. In the display window, the user can change the amplitude level and the time scale, move forward and backward in the data, or jump to a selected epoch by using the epoch finder.

The most frequently issued subwindow is the zoom window (shown in Fig. 4), in which the user can closely scrutinize the data. The zoom window works as a soft-
TABLE I

THE CURRENTLY AVAILABLE FUNCTIONS IN TDAT

<table>
<thead>
<tr>
<th>Function Class Name</th>
<th>Function Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>fir</td>
<td>Fir filter</td>
</tr>
<tr>
<td>iir</td>
<td>IIR filter</td>
</tr>
<tr>
<td>scalespace</td>
<td>Scale space filter</td>
</tr>
<tr>
<td>median</td>
<td>Median filter</td>
</tr>
<tr>
<td>diff</td>
<td>Discrete differentiation</td>
</tr>
<tr>
<td>peakdetect</td>
<td>Detect global peak points</td>
</tr>
<tr>
<td>spike-detect</td>
<td>Detect zero-crossing points</td>
</tr>
<tr>
<td>alpha-detect</td>
<td>Detect alpha activity</td>
</tr>
<tr>
<td>sigma-detect</td>
<td>Detect sigma spindles</td>
</tr>
<tr>
<td>eye-detect</td>
<td>Detect eye-movements</td>
</tr>
<tr>
<td>muscle-detect</td>
<td>Detect high-amplitude muscle activity</td>
</tr>
<tr>
<td>eegdim</td>
<td>Calculate correlation dimension</td>
</tr>
<tr>
<td>sinusoid</td>
<td>Generate sinusoidal waveform</td>
</tr>
<tr>
<td>whitenoise</td>
<td>Generate pseudo-white noise</td>
</tr>
</tbody>
</table>

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Fig. 3. Main display window.

Fig. 4. Zoom window.
comparison window (shown in Fig. 7) presents the differences between two display channels of the main display window. This is especially useful for evaluating a noise reduction algorithm, or for determining how much a filter routine suppresses unwanted detail. In this example, the differences between low-pass filtering and a linear interpolation between valid peaks algorithm are shown. The comparison window can also accentuate asymmetries between EEG channels.

Another important visualization facility is a laser printer driver, which produces permanent archives of the computer screen. TDAT provides two kinds of hardcopy: screen-dump and laser-plot. Screen-dump creates a hard copy of the computer screen with a resolution of 100 dots per inch, while laser-plot produces a high resolution plot (300 dots per inch in most laser printers) of the EEG data. This is equivalent to the conventional polygraph paper tracing at a speed of 20 mm/s. In spite of the existence of high resolution monitors, it is still difficult to achieve a computer display with the quality of a conventional polygraph paper tracing. The laser printer driver provides a quality that rivals ink jet EEG polygraph output.

**The Application of TDAT for Epileptogenic Spike Detection**

The automatic detection of epileptogenic spikes is one of the problems to which TDAT can be applied. The problem illustrates well the need for a computer environment that integrates data visualization/storage with signal processing. There is no precise definition of a "characteristic" epileptogenic spike. Spikes are not objectively defined, they are identified by human visual inspection,
but the task is very time-consuming in long-term monitoring of patients with epileptic seizures (from 8 h to a week). We are developing a computer-based detection system that automatically screens long-term EEG recordings and displays the EEG segments that have epileptogenic activity. The clinician then analyzes chosen segments (normally from 1/2 h EEG recordings). In order to distinguish epileptogenic spikes from background EEG activity, the EEG data are passed through a preconditioning algorithm. The algorithm minimizes the distortion of
the spike morphology while maximizing the suppression of unwanted detail and fast artifactual activity. Fig. 8 shows a sample session of the main display window in which two proposed preconditioning algorithms are being compared. The first channel displays the original data; the second and third channels show the outputs from a FIR low-pass filter and a peak detection filter, respectively. From the analysis of Fig. 8, the signal processing parameters can be set by the user to avoid gross distortions. The user can also choose the preconditioning method that best suits the patient's EEG characteristics. The computer records the parameters, establishing quantitative definitions. Once the preconditioning algorithm is chosen, a spike descriptor set can then be determined. This is achieved by scrutinizing the spikes collected from the patient EEG and extracting their prominent morphological features. This procedure is accomplished in the zoom window. The clinician can perform these measurements at the console by selecting the events.

The detection algorithm is constructed by combining modules, each dealing with a corresponding morphological feature. The algorithm can then be refined by visually analyzing results produced by a specific parameter set. The parameter set is modified interactively within the setup window. The performance of the algorithm is evaluated in the main display window by comparing its results with the original data. Fig. 9 contains both the original data and the resultant output obtained from one of the spike detection algorithms developed with the TDAT [6]. When the operator is satisfied with the performance of an algorithm, the automated detection application can be launched, and the system will select from the whole data set the events that meet the definition.

**CONCLUSION**

Present day computer systems can be used for the time domain visualization of multichannel EEG data. In this sense, they can replace the currently used (paper) polygraph systems. However, computer-based systems are much more flexible. The operator can modify the data, quantify it, and enhance some of its features through digital signal processing. These characteristics are the basis for a much more productive interaction with the data. In computer-based systems the operator can examine and quantify in detail the waveform features. The computer provides a ready means for adding a broad class of signal processing algorithms (including linear phase filters), and for visualizing the effects of the filtering on the data. The computer provides a means of quantifying ostensibly defined waveforms, random access to any segment, data archives and high-quality printouts.

Functionality in computer-based systems is achieved through programming. In this paper we described a soft-
ware architecture that was derived from the peculiarities of the clinical assessment of EEG data and from the need to develop automated EEG waveform detectors. As the end result the EEGcr has at his finger tips the added power of computer quantification, but his formal training can still be fully exploited because TDAT creates an environment centered around the signal and the operations to be performed on it. For the engineer interested in the design of waveform detectors, TDAT is also very helpful since it provides a ready means of prototyping and validating new detectors.

In engineering terms we would like to stress the open nature of the package and the graphic interface (both for menu selection and for building the signal processing algorithms). A current limitation compared to polygraphs is the screen resolution. A computer screen with 1200 horizontal pixels can only provide an equivalent sampling rate of 40 samples/s if 30 s of data are to be displayed. The user's manual of TDAT was recently completed [7].

REFERENCES


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