A software for recording and analysis of human tremor

M. Lauk[1,4]
J. Timmer[1]
C.H. Lücking[2]
J. Honerkamp[1]
G. Deuschl[3]

[1]Zentrum für Datenanalyse und Modellbildung
and Department of Physics, University of Freiburg
Eckerstr. 1, 79104 Freiburg, Germany
[2]Department of Neurology and Clinical Neurophysiology,
University of Freiburg, Breisacher Str. 64, 79110 Freiburg, Germany
[3]Department of Neurology, University of Kiel,
Niemannsweg 147, Kiel, Germany
[4]Center for BioDynamics, Boston University
44 Cummington St, Boston MA 02215

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Address:
M. Lauk, Freiburger Zentrum für Datenanalyse und Modellbildung
Eckerstr. 1, 79104 Freiburg, Germany
Phone: +49 761 203-7710, Fax: -7700, email: lauk@fdm.uni-freiburg.de

Abstract

For many diseases various methods for the diagnosis and treatment monitoring are available. Presently, such methods are not established for an investigation of tremor diseases, although the different forms of tremor are common neurological symptoms and occur frequently in various neurological diseases and also other conditions. We developed an easy-to-use application for tremor-analysis and recording, running under MS-Windows, which allows to investigate different forms of tremor by advanced mathematical methods of time series analysis. The application is also useful for users who are not familiar with these kinds of data analysis. It provides tools for the diagnosis and treatment monitoring under laboratory conditions, based on previously developed and established methods of spectral and cross spectral analysis of tremor and electromyographic time series.

1 Introduction

The electrophysiological analysis of human tremor has a long tradition. The earliest works on this field usually investigated electromyographies (EMG), recorded from different muscles and plotted with analog devices ([1, 2, 3]). In the sixties, different techniques were used to measure the amplitude and frequency of tremor ([4, 5]). Spectral analysis was performed with analog computer devices. Later, with the fast development of digital computers, one began to sample the tremor records to analyze the data off-line mainly by the new developed methods of spectral and cross-spectral analysis of stochastic processes ([6, 7, 8, 9, 10, 11, 12]). From this time, the tremor has been usually measured with piezoresistive accelerometers (ACC). In the following years researchers presented a lot of different approaches to measure and modeling tremor ([13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23]).

Despite these intensive works, until today, the electro-physiological analysis of tremor using advanced mathematical methods is reserved to specialized laboratories. Each group working in tremor research uses its own developed soft- and hardware. A software or tools for tremor analysis, also available for people who are not specialized on this field could help to improve diagnosis and treatment monitoring of tremor diseases in widespread areas of neurology, rehabilitation and pharmacology.

In the meantime, the needed mathematical methods, e.g. the theory of linear stochastic processes or linear time series analysis, have been well investigated ([24, 25, 26, 27, 28, 29, 30]). Also the different proposed recording techniques, e.g. systems based on ACCs or lasers, have been well established and used in widespread areas of other sciences and in industry. The difficults are rather the proper interpretations of results in terms of physiology and physics and the development of so-called "data-driven" algorithms for special tasks like tremor analysis.

We developed a software for tremor recording and analysis (TRAS) which is useful for at least two different user groups. Firstly, people who want to analyze tremor records in a standardized daily clinical procedure, and secondly, users who work in the different fields of tremor research. The difference between the requirements of these two groups is the way they are working with an application: For the first group the software should provide the possibility to get the results of a tremor analysis by just "pushing two or three buttons" on the desktop, whereas researchers usually need the possibility to modify configurations and parameters. We here describe how this two different concepts were realized in TRAS.

TRAS was planned, written and tested together with clinical laboratories during the different stages of the development. Therefore, we could secure that our application is able to fulfill different criteria that would be necessary to build a software which will be accepted by clinical and laboratory staff.

This paper does not describe in detail any research work on both mathematical or clinical aspects of tremors. It was rather written to describe the implementation of new analysis methods, investigated and established in earlier clinical and methodological studies, in a highly integrated, actual software system.

The paper is organized as follows: The second section describes the basic concepts and the programming methods used. The third section describes the recording procedures, storage and pre-processing of data. Spectral-analysis methods are described in the fourth section. The fifth section gives an outline of the possibilities of cross spectral methods. Finally, we discuss prospects to future implementations and the use of our software in other applications.

2 Basic concepts

2.1 Outline of problems and tasks

As mentioned in the introduction, the electrophysiological analysis of the different tremor-related disorders and diseases has up to now only been done by a few specialized laboratories. TRAS is designed to provide solutions for the following tasks:

- Data recording: What technique should be used, how long should the data-record be and how many different channels are useful? Although these questions are not explicitly subject to the software development, it is important to discuss them here because the basis of each analysis method is the availability of proper recording methods and concepts.

- Quality of recorded data: In some cases the data consists of different recording failures and artifacts which could lead to serious misinterpretations. Examples of such failures are trends or drifts reflecting voluntary movements or crossing of the maximum A/D range.

- Data analysis: Advanced mathematical methods in data analysis often need to chose some initial parameter settings which require sometimes preliminary knowledge of the dynamics or assumptions on the underlying process for the data under investigation.

- Quantitative results should be given with confidence regions for a particular value to allow a comparison to well investigated populations of different groups. (i.e. controls and patients with different tremor diseases).

- Interpreting qualitative results of spectral and cross spectral methods in terms of physics and physiology is a difficult task and must be assisted by the application.

The bigger part of the above issues are caused by the fact that the various forms cover a wide range of different possible dynamics, though. They range from linear stochastic processes for the physiological tremor (PT) to non-linear, almost deterministic processes for some pathological forms of tremor ([31, 32, 33, 34]). The amplitude often differs more than three magnitudes between a weak PT and some pathological tremors ([23]).

Finally, a comfortable graphical and interactive user-interface with support for mouse, menus, icons and buttons provides an user-friendly, common interface which gives potentially any person the possibility to work with it.

2.2 Programming concepts and language

The application uses a multi-document-interface (MDI). Thus, the user can work with it in the same way he is used to work with common applications, e.g. word processing programs. An even bigger advantage of this strategy is the possibility to compare different records and results directly on the screen. The only restriction is the amount of available system resources.

TRAS was developed in C and C++. We separated strictly numerical parts and parts containing the interface sources and I/O routines. All numerical parts were developed in standard C without using any object-orientated programming feature. The other parts of the software which provide the user interface and different kinds of I/O, e.g. menus, dialog-boxes, graphics display and print-outs, were realized in a few C++ classes, based on Borland's Object-Windows, which is a C++ class library for the development of Windows applications ([35]). This strict separation between numerical and system dependent elements provides an easy portability of the software to other platforms and also other programming languages. Furthermore, all strings like menus, titles, error messages and letterings reside in seperate resource files, which allows it to easyly create versions for other countries. Presently, English and German versions are available, running under Microsoft's Windows 3.1(1), Windows 95, Windows NT 3.51 and NT 4.0.

Each data record, i.e. each stored data file, is coupled with a MDI-child window, in the following referred as the main window (MW). This window is based on a class which is responsible for the parameter settings, all analytic operations and storage and export of data. In the first instance, this main class represents an abstract, virtual class which can perform all operations on a single data-channel. Further instances of the main class, derived from the first instance, realize multi channel classes, i.e. classes which inherit all functionality of the main class but handle in addition multiple, simultaneously recorded channels. All graphs of the different analysis results reside in their own MDI-child classes and are independent of the main class. If the user requests the graph, the main class transfers the corresponding data to the graphics class, i.e. the graphics window. Fig. 1 displays schematically the basic structures of TRAS.

The main advantages of this concept are: (1) It allows easily to modify existing and to create new instances of multi channel classes due to its modular structure. (2) Further data analysis methods and graphics classes can be added in the future without any modification of the existing classes. (3) Since each graphically displayed result is independent from other windows, one can compare results originating from calculations with different parameter settings simultaneously on the screen. This is often needed in research applications.

2.3 General I/O concepts

All diagrams and graphics are implemented as objects which receive the corresponding data from only one channel to plot them automatically in a defined rectangular region on an arbitrary device context. Therefore, all graphics displaying results of multiple channels in one plot are highly modular and can also be easily extended to plot them on other devices as the so far implemented screen- and printer-outputs.

Furthermore, TRAS provides the possibility to export all kinds of analysis results in an ASCII format which can be read by other programs. To our experience this is helpful or even needed, especially for research applications. Beside the graphs offered by TRAS itself, users can create arbitrarily styled presentation graphics using results calculated by TRAS.

Note that TRAS does not store any result in own data formats and does not read any files containing results. Since the calculation of the results from raw-data, even for the most time-consuming analysis methods of TRAS, takes a maximum of only about 0.5 s for each channel on a standard Pentium 133 MHz PC (see also Tab. 1). Therefore, a storage and re-read of analysis results beside the provided ASCII export is not necessary. In addition, an advantage of this strategy is that changes in future releases will only affect the raw data files.

3 Recording procedures and pre-processing of data

3.1 Recording technique

Different approaches for tremor measurement have been proposed ([5, 19, 22, 23, 36, 37]). We recommend to measure tremor with ACCs since: (1) The "natural" high-pass filter effect of the ACCs reduce significantly the slow drifts which are often present due to voluntary movements ([19]). (2) ACCs are able to measure accurately over a wide range of amplitudes from less than 1 mm/s^2 to a few m/s^2. This is important to cover all types of tremor with the same measurement system.

Channel configuration 6 channels are measured for a standard tremor analysis, 3 per side of the body. In this standard measurements two ACCs, attached to the left and right belly of the hand, and four EMG, measured from the Flexor and Extensor carpi ulnaris of each body side, are recorded simultaneously.

Beside this suggested standard configuration, an arbitrary channel configuration can be chosen by the user. This is done with an interactive dialog-box displayed in Fig. 2. Along with a description and a short abbreviation which is displayed for each channel in graphs and print-outs, there are check-boxes to indicate whether the channel will be digitally rectified and filtered or not. Furthermore, one can choose if the channels 1 and 4 are ACCs or EMGs. TRAS excludes senseless configurations, e.g. a rectified ACC channel. The digital EMG-filters are non-causal high-pass filters which act in the Fourier space ([38]). They could be used to cut off signals lower than 60 Hz in unrectified EMGs to eliminate slow movement-artifacts. General aspects concerning EMG recordings can be found in ([19, 39]).

The use of digital filters and digitally rectified EMGs depends on the hardware and can not be dictated by the software. Nevertheless, the complete channel configuration can be saved interactively in configuration files together with later discussed parameters to prevent inexperienced users from erroneous decisions.

3.2 Recording procedure

TRAS uses a Keithley DAS 1602 A/D converter. This relatively cheap 12 bit A/D converter covers all needed features. Since Windows is far away from being a system which can be used for real-time routines, we realized the real time A/D sampling with direct memory access (DMA) by a cycling DMA buffer which is accessible under Windows. The timing during the sampling process is done by the A/D hardware.

The success of such a routine depends on the system's and the graphic's speed. With a standard Pentium 133 MHz PC sampling frequencies over 15 kHz per channel are reached; this is far away from the sampling intervals needed to record ACC- and EMG data. Tremor records are usually done with 1 kHz or even below 300 Hz if the EMGs are rectified by analog devices. Nevertheless, TRAS also checks during the recording procedure if an overrun of the cycling DMA buffer occurred.

During the records, the six channels are displayed in real-time consecutively with different colors from the upper to lower borders of a modal child window. A black, vertical line is running over the screen to indicate the actual position. On the top of the record window are buttons to control the recording. One of them starts the recording procedure without saving the sampled values as long as the user does not press a stop button. This is used as a preview of measured data, e.g. for setting up the different amplifiers and analog hardware before starting a tremor record. Another button starts a tremor record and is running as long as the user does not push the stop button or the previously chosen record length is reached.

We included the possibility to call an arbitrary external recording software by indicating the name and parameters of the external recording program in the initialization file of TRAS. In this case the external software is responsible to store the data in a format which can be read by TRAS. Since TRAS is a single-instance application, the external recording program just has to call the program again after it stopped its recording procedure. Further calls of our software with a filename as command-line parameter open the file but not further instances.

3.3 Testing the quality of data

For all further steps and analyses, the mean is subtracted from each record.

TRAS provides a heuristic test to check tremor time series for different recording failures and artifacts. Some kinds of tremor differ up to 4 magnitudes in amplitude which renders it sometimes difficult to chose the correct amplification for EMGs and ACCs. The first test shows an error if either the total variance is too small, i.e. the digitized series covers only $\frac{1}{100}$ or less of the maximum A/D range, or the variance is too high, i.e. the series reaches at least once the maximum A/D range of 0 resp. 4096 (12 Bit).

The second test is a heuristic test for stationarity of the mean. Due to voluntary movements during a trial it sometimes occurs that the mean of a series shows slowly varying trends over more than 20 tremor periods (partially caused by the bridge amplifiers used for the ACCs). An error is signaled whenever the mean of the series fluctuates between two or more of 20 period pieces more than the standard deviation of the whole data set.

The test is performed by pushing a button on the desktop. If the algorithm detects one or more of the described errors, a warning message with detailed informations on the error is displayed and the investigator is asked to repeat the measurement.

3.4 Storage and display of data

During a tremor recording the series are temporarily stored on the disk. By the menu-item "Save As" or the corresponding button the program displays a standard Windows File dialog box, where one can chose the location and name of the file. The data are stored as 2 Byte binary integer values, each channel in one block of size $2\,N$, where N denotes the number of data-points. Stored raw-data can be exported in an ordinary ASCII format.

All further informations like the channel configuration, amplification factors and the subject's personal data are stored in a file header of size 4 kByte. Fig. 3 displays the dialog box to enter the informations on the investigated person, amplification factors and individual measurement specifications which are stored in the file header along with the channel configuration.

TRAS provides a multi-channel data scroller which displays multiple channels of recorded raw data in one horizontally scrollable window. The scroller provides different zoom factors and the possibility to print a previously chosen part of the data as a polygraphy. The chosen region can also be exported in ASCII. The scroller is important to visually inspect recorded data. It is realized with an object which reads raw data and displays them automatically in a defined rectangular region on an arbitrary given device context. The scroller is therefore highly modular and just consist of i times the raw-data graphics object whereas i is the number of channels displayed.

4 Spectral methods

In this section we discuss univariate spectral analysis methods. Since all multiple channel calculations and plots are based on one-channel classes and then expanded to multiple-channel objects as explained in Section 2.3, all further described concepts and results are only explained for one single channels. To overcome leakage ([26]), the data can be tapered (optional) before performing spectral and cross-spectral analyses.

4.1 Spectral estimation procedures

Although discrete Fourier transformations (FT) are defined on any number of data points, conventional Fast Fourier transformations (FFT) are restricted to numbers $N = 2^j$ where j is an integer ([38]). Often the data series is filled up with zeros to reach the next number that can be written as $N = 2^j$. Unfortunately, this operation seriously modifies the statistics of the periodogram and the estimated spectrum ([26]). Therefore, we use an algorithm which handles all numbers N and is as fast as the FFT for numbers which can be written as $N = 2^{j_1}\,3^{j_2}\,5^{j_3}$, where the j_k are integers [40, 38]. Especially for the estimation of auto- and cross-correlation functions by FFTs this is needed. For these calculations one can not fill a series with zeros up to the next possible number $N = 2^j$ and therefore would have to cut the series to reach the next possible lower $N = 2^{j-1}$.

After calculating the FT of a series, the spectra are estimated by a direct spectral estimation procedure([25, 26, 27, 28]) which was designed especially for this purpose. A detailed description of the estimation procedure is given in ([41]). Briefly, the periodogram is convolved with a triangular window of a variable width. The window width is determined automatically based on the broadness of the highest peak found in a preliminary estimation. This routine leads to good results for very low amplitude physiological tremors as well as for high amplitude, almost deterministic spectra of data recorded from severe pathological forms of tremor ([41]) without asking the user for special parameter settings or a kind of "a priori" knowledge of the underlying dynamics. Based on the confidence levels of the spectral estimate ([26]), TRAS searches for significant peaks in each spectrum. In addition, as described in detail elsewhere ([42]), confidence intervals for peak frequencies can be calculated by a bootstrap method. For each series a Kolmogorov-Smirnov-Test ([29, 38, 41]) is automatically performed to test the hypothesis that the series is consistent with white noise.

By pushing a button on the desktop, TRAS calculates all spectra of a record and displays them in a window which can be printed along with the patient's data and a table with all quantitative results including confidence regions. Significant peaks are indicated by vertical lines. The calculation time for a standard 6-channel record, consisting of 6 series with 30000 points each, is about 3 s on a standard Pentium 133 MHz system. Fig. 4 displays an example for the estimated spectra of a standard 6-channel hand tremor recording of a patient suffering from an unilateral Parkinsonian tremor. On the unaffected left side, the tremor shows the typical characteristic of a physiological tremor. A single broad peak in the ACC spectrum and weak synchronizations in the EMG spectra appearing at higher frequencies as the ACC peak. On the affected right side, one can see a sharp peak with its higher harmonics in the ACC and EMG spectra at the same frequency, which is the typical picture for a Parkinsonian tremor.

Beside this standard estimation procedure there exists the option to choose different spectral estimators. Furthermore, users can modify all necessary parameters as the displayed frequency range, confidence levels, width of the spectral estimator and the tapering. This can be done conveniently by interactive dialog boxes and can also be stored in the above mentioned configuration files for later use.

Quantitative and qualitative values obtained with the spectral estimation methods can be compared to the results from a control population (approximately 240 subjects) and patients with different common and also uncommon tremor diseases (over 1000 subjects). These records have been done by the Departments of Neurology at the Universities in Freiburg and Kiel, Germany, during the last 5 years.

4.2 Autocorrelation function

Autocorrelation functions (ACF) are estimated using the FT. We use the "biased" estimator, since the ACF of tremor time series decay fast enough with increasing time lags ([28]). This is only available for one channel at a time because it is not a part of the suggested standard tremor analysis. Nevertheless, the result is also displayed in a independent MDI child window and can, therefore, be compared with other channels and/or trials. By default, the maximum time-lag displayed is 2 s. It can be modified using an interactive dialog box. The parameters are also stored in the configuration file.

Especially for tremor records the sometimes present asymmetric decay of the ACF is of interest ([32, 43]). A value representing the difference between the first two local maxima of the magnitude of the ACF is also calculated as described in ([32, 43]). The ACF is displayed together with the confidence intervals for a test against the hypothesis of linear independence ([25]). A plot of the ACF can also be printed and exported in an ASCII–file.

5 Cross spectral methods

In this section we give a brief overview on multivariate methods provided by TRAS. The spectral estimation procedures are the same as described for the univariate case without the variable window width in the direct estimation procedure. Confidence intervals and general aspects of the used estimators are discussed in ([25, 26, 27, 28]). Special aspects of the multivariate methods with respect to tremor time series are given in ([33]).

All multivariate methods are applicable to pairs of channels. The user chooses the first channel to be analyzed in the main window. After selecting a cross spectral method from the menu or by pushing the corresponding button, a dialog box for choosing the second channel to be analyzed from the list of the other available channels is coming up. Again, all results are displayed in separate, independent MDI child windows and, therefore, easily comparable with respect to different parameter settings and/or different trials. All results discussed in this section can be printed out and exported in ASCII-files.

5.1 Cross-correlation

The cross-correlation functions (CCF) are estimated using the FT. Similar to the ACF, the CCF is displayed with the confidence interval for the test against the hypothesis of zero correlation ([26, 33]). Note, that these confidence levels are only valid if at least one of the two series under investigation has a flat spectrum, i.e. is consistent with white noise ([25, 33]). Although there exists a filter method to obtain series with a flat spectrum, the so called "Prewhitening" ([25]), we recommend to do the test on significant correlations in the frequency domain using the coherency spectrum.

In general, CCF's are difficult to interpret ([33]). Their use to investigate tremor records in a standardized manner is limited. One example for the use of CCFs in tremor analysis is the detection of EMG crosstalk ([44]). Since crosstalk is an instantaneous effect, the CCF between two EMGs affected by crosstalk shows a sharp, non-continuous "peak" at the time lag zero, which allows to detect and quantify crosstalk ([33]).

5.2 Coherence and Phase spectra

The normalized magnitude resp. the phase of the cross-spectrum are defined as the coherency resp. the phase spectrum ([25]). The coherency can be interpreted as measure of linear predictability ([33]). Phase and coherency spectra are useful to investigate tremor origins as well as their mechanisms ([34, 45]).

TRAS estimates the cross-spectrum and the coherency and phase spectra. The coherency and the phase are displayed in a new MDI-child window together with confidence regions and error bars (see Fig. 5 for an example). Phase spectra are drawn 2π periodically to simplify the by-eye detection of particular functional dependencies over a certain frequency range, e.g. a straight line in case of a time delay between the two series under investigation ([28]). Furthermore, TRAS provides a test against the hypothesis of zero coherency ([26, 33]).

The particular interpretation of phase spectra requires strong assumptions on the underlying dynamics of the analyzed series. An automated procedure for the interpretation of phase spectra is not available so far, but is planned to be realized in future releases. One simple example is the above mentioned time delay. If one series lags or leads the other one the phase spectrum is just a straight line whose gradient is proportional to the time delay.

Again, all parameters needed for this kind of analysis can be modified in interactive dialog-boxes.

Finally, TRAS provides an "overview" plot of two channels containing the ACFs, CCF, auto-spectra and cross-spectra, the coherency and the phase-spectrum to give an overview of the dynamics of the series at a glance.

6 Conclusion and Discussion

6.1 Conclusion

Our software shows that it is possible to integrate advanced mathematical methods in an easy-to-use application which is not designed for specialists in methodological and technical fields. In the meantime, our application is accepted as a convenient, powerful and fast but also secure tool in different hospitals. It is used for daily clinical routine as well as research purposes.

Figure 6 displays a screen-shot over the whole application frame window to give an impression of the design of our software.

6.2 Summary of features and performance

Table 1 summarizes the analysis methods provided by TRAS and the time they consume on a standard Pentium 133 MHz personal computer running under Microsoft's Windows NT 4.0 (32 MB of RAM). The test data-set consists of 30000 point each channel, sampled at 1000 Hz.

6.3 Discussion

The concept to develop specialized software for particular tasks might seem to be expensive and time consumable. On the other hand, it is the only way to provide applications which are accepted by those who are not familiar with the used mathematical methods and/or algorithms. Other software packages which basically provide tools for time series analysis are available. But usually they require fully-fledged staff, which is too expensive for a daily clinical routine. Secondly, numerous mathematical methods can not be applied "naively" to arbitrary data. It is often essential to modify existing concepts to thread a special problem, which could not be provided by an analysis package like MatLab.

Besides its application in tremor research and clinical routine, TRAS has been recently used successfully to study Doppler signals and other cardio-vascular time series, motion analysis time series, arbitrary EMG and EEG data and the postural control system. It was obvious that there is a lack of easy-to-use software for analyzing electrophysiological time series in the framework of linear stochastic processes.

We always tried to work as close as possible with the future users, i.e. medical doctors and their laboratory assistants. This was one of the most important issues in developing such an application. Clinical tests have been done since three years in different European hospitals. Based on the results of these tests and suggestions or complaints of the users, we are permanently modifying the application to improve its performance and user acceptance. Furthermore, we implement newly established analysis methods as fast as possible and adopt new results from different fields of tremor research. Due to the modular structure of our application this could be done without modifying source codes of the existing application.

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Address for correspondence
M. Lauk
Freiburger Zentrum für Datenanalyse und Modellbildung
Universität Freiburg
Eckerstr. 1
79104 Freiburg, Germany
Phone: +49 761 203-7710
Fax: +49 761 203-7700
email: lauk@fdm.uni-freiburg.de
URL: `http://www.fdm.uni-freiburg.de/~lauk`

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Tables

Method	Analyzed series	Time in s
Heuristic data test	All 6 channels	0.4
Spectral estimation	6 channels, constant estimator	2.0
(including statistics)	6 channels, variable estimator	3.0
Autocorrelation	1 channel	0.6
Cross-correlation	2 channels	0.7
Cross-spectrum, coherency and phase	2 channels	0.4
Overview-plot (see text)	2 channels	0.9

Table 1: Available analysis methods and performance of the calculations (including the respective statistics as descibed in the text) on a standard Pentium 133 MHz personal computer. The operating system is Microsoft's Windows NT 4.0, the computer has 32 MB of RAM.

Figure and Table captions

Fig. 1 Schematic display of the basic structure of the application. Dashed lines symbolize inheritance, solid lines simple I/O in the sense of function calls and the "use" of other classes. For sake of clarity the recording MDI child which interacts with the multi channel MDI window is not shown. All numerical parts are realized in standard C and do not use OOP-features.

Fig. 2 Screen shot of the channel configuration dialog-box. Channels 1 and 4 can be used as ACC or EMG channels, the other 4 channels for EMGs only. If the field "filter" is checked, the corresponding channel is digitally high-pass filtered to avoid movement artifacts in the EMG. If the button "Rect." is checked, the corresponding channel is digitally rectified. The program avoids impossible combinations like, e.g., rectifying an ACC signal.

Fig. 3 Screen shot of the dialog box to enter recording informations and personal data for the recorded person. With the use of newer hardware, the explicit input of the amplification factors is obsolete, since they are transferred automatically to the program via the A/D converter or the parallel port (depending on the used amplification system).

Fig. 4 The MDI child window containing the estimated spectra of all 6 channels. The displayed example is a hand tremor of a patient with Parkinson's disease (from the upper right edge to the lower left: ACC-spectrum right side, ACC left side, EMG-spectrum of the Flexor carpi ulnaris (Flex) right side, Flex left side, EMG-spectrum of the Extensor carpi ulnaris (Ext) right side, Ext left side). Each plot contains the estimated spectrum (thick solid line) and the upper and lower confidence intervals (dashed lines). The vertical straight solid lines mark the significant peaks detected by the algorithm and the vertical dashed lines represent the peak width, which is determined by the frequencies where the power is half the maximum value at the peak. The sum over the power of this "half value with" is a good and also robust measure for the tremor power. This display can be printed out. The print-out also contains the numerical values. In the program, numerical values appear in the main-window (see Fig. 6).

Fig. 5 Coherency and phase between two EMGs of an orthostatic tremor (OT) in the corresponding MDI child window. The upper plot shows the coherency which is very high in a range around 15 Hz. This is a typical scenario for an OT, indicating that the two EMGs measured are driven by the same sources and/or mechanisms. The horizontal straight line corresponds to the level of significance (95%) for a test against the hypothesis of zero coherency. The lower plot shows the phase spectrum, plotted 2π periodically. The error bars are plotted on each fifth point. The error in the phase spectrum depends on the coherency, i.e. large errors in regions where the coherency is high and vice versa. Again, corresponding numerical values are displayed only in the main window and on the print-out.

Fig. 6 Screen-shot of the application. On top is the main window which is linked to the data file. Also displayed is the 6-channel-scroller (lower left window) and a part of the "overview-window", containing the ACFs, CCF, Coherency, Phase, auto-spectra and the cross-spectrum of two series.

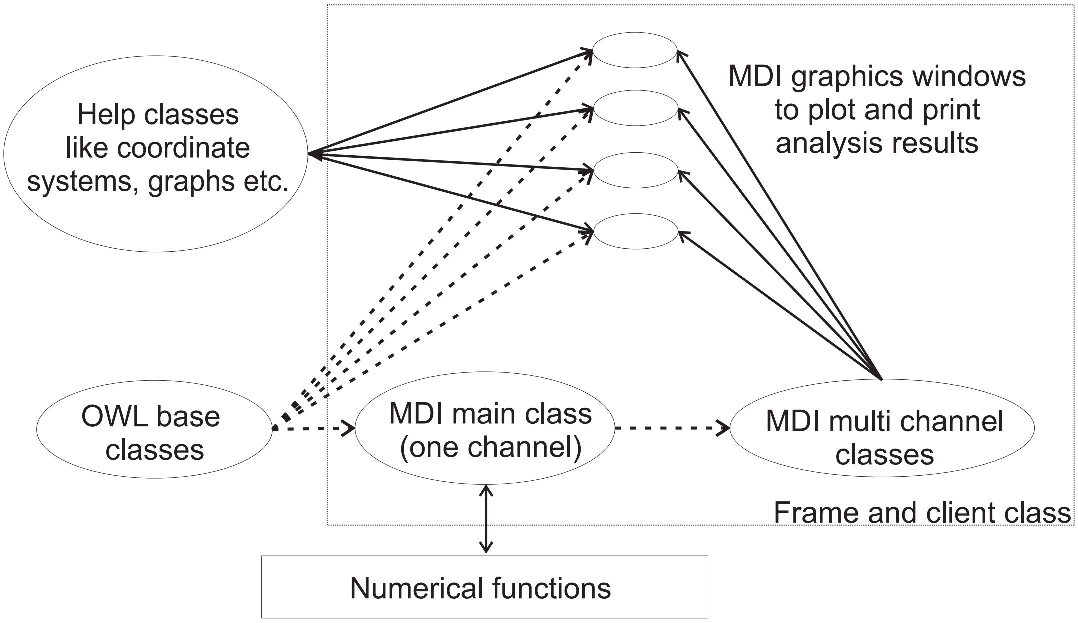
MDI graphics windows
to plot and print
analysis results
Help classes
like coordinate
systems, graphs etc.
OWL base
classes
MDI main class
(one channel)
MDI multi channel
classes
Frame and client class
Numerical functions

Figure 1

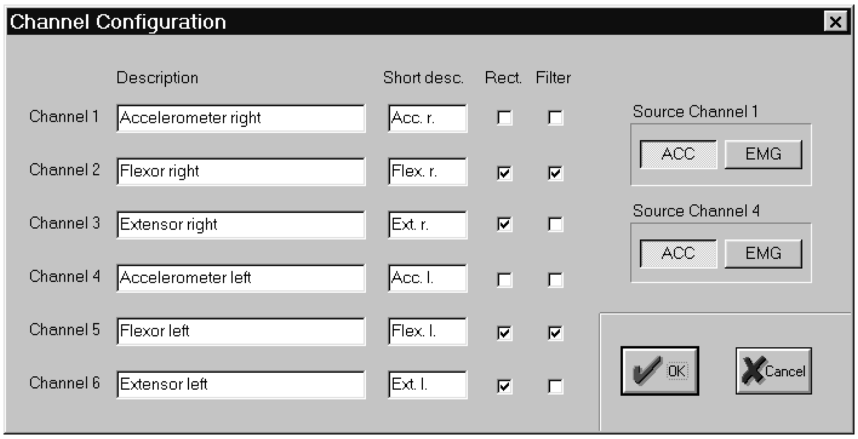
Channel Configuration
Description
Short desc.
Rect.
Filter
Channel 1
Accelerometer right
Acc. r.
Channel 2
Flexor right
Flex. r.
Channel 3
Extensor right
Ext. r.
Channel 4
Accelerometer left
Acc. l.
Channel 5
Flexor left
Flex. l.
Channel 6
Extensor left
Ext. l.
Source Channel 1
ACC
EMG
Source Channel 4
ACC
EMG
OK
Cancel

Figure 2

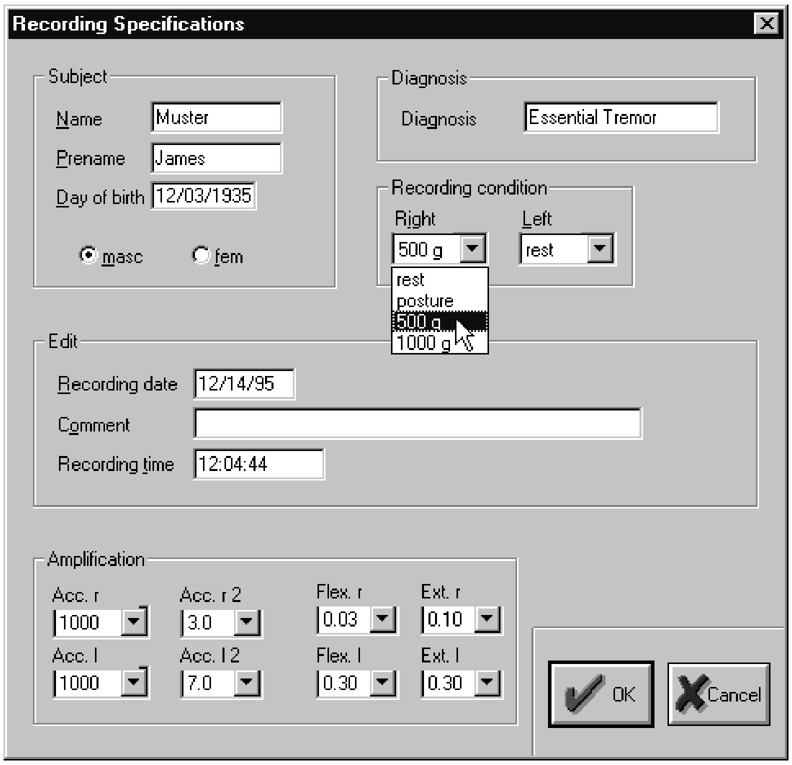
Recording Specifications
Subject
Name
Muster
Prename
James
Day of birth
12/03/1935
masc
fem
Diagnosis
Diagnosis
Essential Tremor
Recording condition
Right
Left
500 g
rest
rest
posture
500 g
1000 g
Edit
Recording date
12/14/95
Comment
Recording time
12:04:44
Amplification
Acc. r
1000
Acc. r 2
3.0
Flex. r
0.03
Ext. r
0.10
Acc. l
1000
Acc. l 2
7.0
Flex. l
0.30
Ext. l
0.30
OK
Cancel

Figure 3

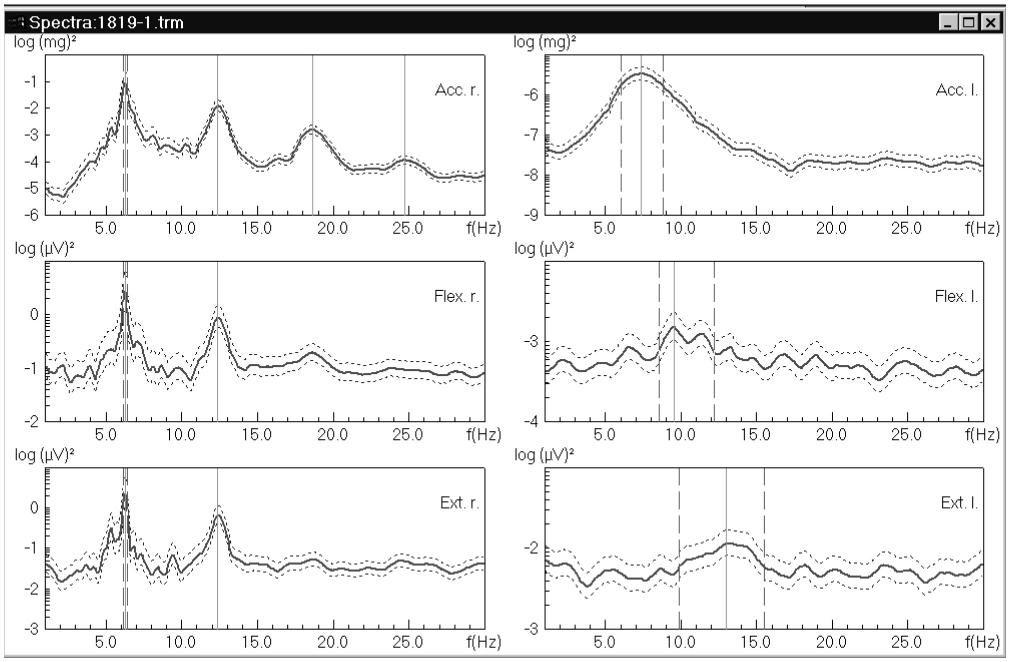
Spectra:1819-1.trm
log (mg)²
Acc. r.
Acc. l.
log (μV)²
Flex. r.
Flex. l.
Ext. r.
Ext. l.
f(Hz)
5.0
10.0
15.0
20.0
25.0

Figure 4

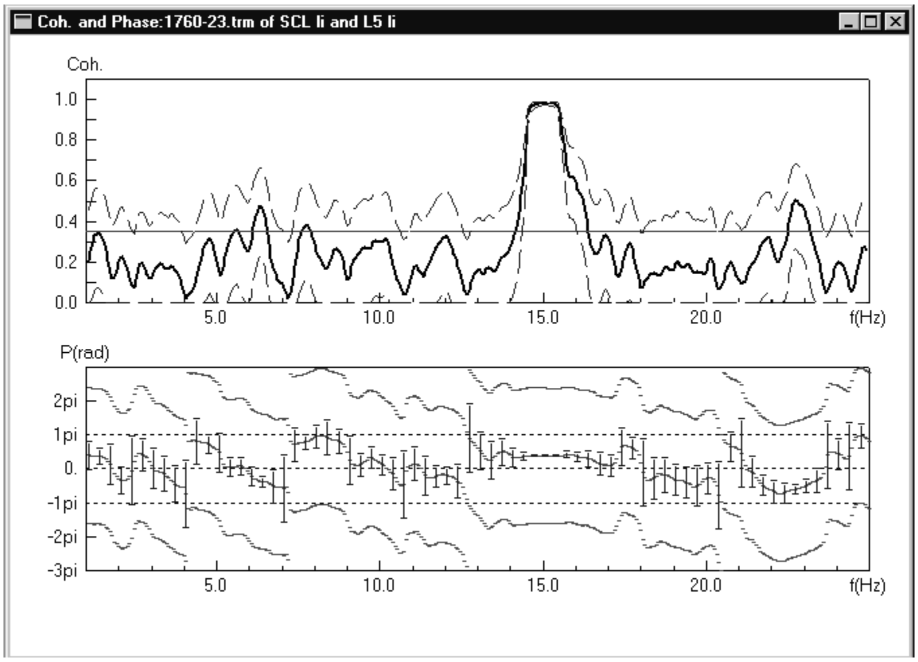
Coh. and Phase:1760-23.trm of SCL li and L5 li
Coh.
1.0
0.8
0.6
0.4
0.2
0.0
5.0
10.0
15.0
20.0
f(Hz)
P(rad)
2pi
1pi
0.
-1pi
-2pi
-3pi
5.0
10.0
15.0
20.0
f(Hz)

Figure 5

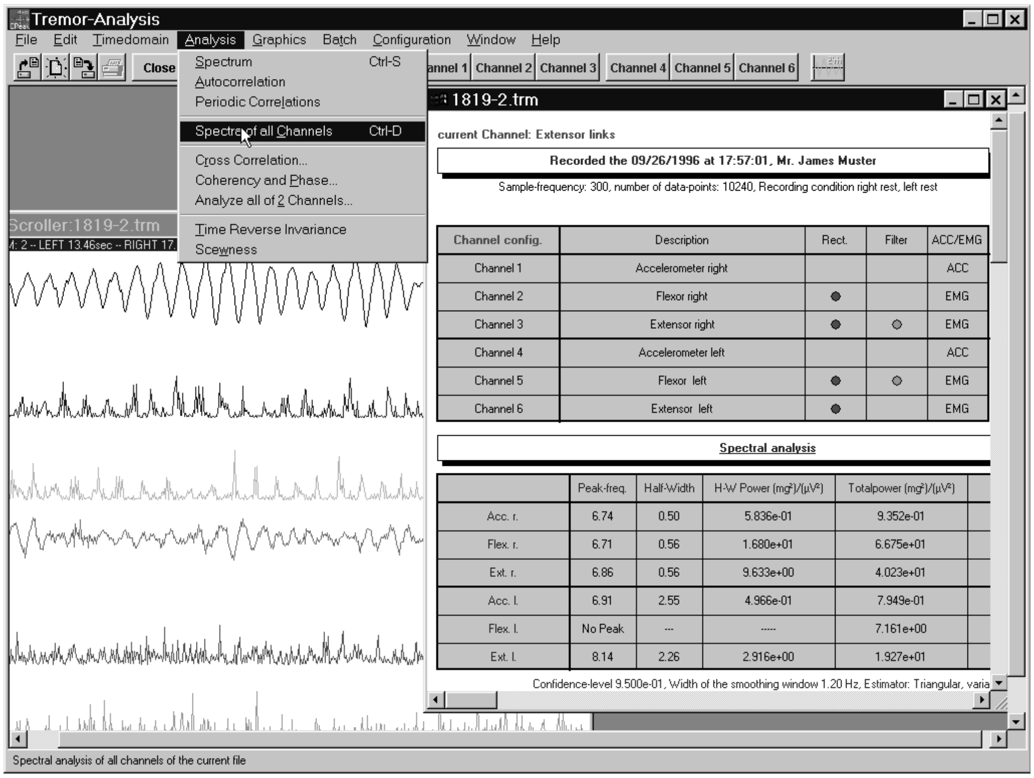
Tremor-Analysis
File Edit Timedomain Analysis Graphics Batch Configuration Window Help
Close
Spectrum Ctrl-S
Autocorrelation
Periodic Correlations
Spectra of all Channels Ctrl-D
Cross Correlation...
Coherency and Phase...
Analyze all of 2 Channels...
Time Reverse Invariance
Scewness
Channel 2 Channel 3 Channel 4 Channel 5 Channel 6
1819-2.trm
Scroller:1819-2.trm
current Channel: Extensor links
Recorded the 09/26/1996 at 17:57:01, Mr. James Muster
Sample-frequency: 300, number of data-points: 10240, Recording condition right rest, left rest
Channel config. Description Rect. Filter ACC/EMG
Channel 1 Accelerometer right ACC
Channel 2 Flexor right EMG
Channel 3 Extensor right EMG
Channel 4 Accelerometer left ACC
Channel 5 Flexor left EMG
Channel 6 Extensor left EMG
Spectral analysis
Peak-freq. Half-Width H-W Power (mg²)/(μV²) Totalpower (mg²)/(μV²)
Acc. r. 6.74 0.50 5.836e-01 9.352e-01
Flex. r. 6.71 0.56 1.680e+01 6.675e+01
Ext. r. 6.86 0.56 9.633e+00 4.023e+01
Acc. l. 6.91 2.55 4.966e-01 7.949e-01
Flex. l. No Peak --- ----- 7.161e+00
Ext. l. 8.14 2.26 2.916e+00 1.927e+01
Confidence-level 9.500e-01, Width of the smoothing window 1.20 Hz, Estimator: Triangular, varia
Spectral analysis of all channels of the current file

Figure 6