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USER'S GUIDE TO

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TF-SIGNAL
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The Fortran95 Program Package
for Computation of Time-Frequency Representations
of Time Signals

by

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Bratislava, June 2006

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Purpose: Program package TF-SIGNAL is designed for computation and visualization of time-frequency representations of time signals using one or more of seven alternative methods of time-frequency analysis

Availability and use of the program:

The latest version of program package is downloadable from
http://www.nuquake.eu/Computer_Codes/

Reference to the program:

A user is asked to make reference to
Kristekova M., 2006. Time-frequency analysis of seismic signals. PhD. Thesis, Geophysical Institute, Slovak Academy of Sciences, Bratislava, in case that he/she publishes results obtained with the program package because the program package is a part of the Thesis and has not been published separately.

Acknowledgements:

The program package has been developed in cooperation between the Geophysical Institute, Slovak Academy of Sciences, and DAPEM, Faculty of Mathematics Physics and Informatics, Comenius University, Bratislava, Slovak Republic, within the EU FP5 projects SESAME and EUROSEISRISK, and EU FP6 SPICE.

Short introduction:

Program package TF-SIGNAL allows computing time-frequency (TF) representations of a signal using the following methods:

- Windowed Fourier Transform (WFT),
- Windowed Fourier Transform combined with Reassignment Method,
- Continuous Wavelet Transform (CWT),
- Continuous Wavelet Transform combined with Reassignment Method,
- Matching Pursuit Decomposition (MPD),
- Linear Matching Pursuit Decomposition (linear MPD),
- Quadratic Matching Pursuit Decomposition (quadratic MPD).

WFT is suitable only for relatively simple signals. The main drawback of this method is that the choice of the analyzing window (mainly the choice of its length) can significantly affect the results (see example in Fig. 1a-c).

The CWT is a proper tool for the time-frequency analysis of complex nonstationary signals.

Combination of WFT or CWT with the reassignment method allows one to better identify “ridges” in the TF representations.

The MPD method decomposes signal into elementary functions (TF atoms), chosen from a large set (dictionary) of the functions. We use three types of dictionaries: original Gabor, linear generalized Gabor and quadratic generalized Gabor dictionary. The original Gabor dictionary is a subset of the linear Gabor dictionary and the linear Gabor dictionary is a subset of quadratic Gabor dictionary. Each TF atom is a simple signal with an analytical description of its instantaneous frequency in dependence on time. For the original Gabor dictionary $\omega_{inst} = const.$ , for the linear dictionary $\omega_{inst} = a + bt$ , and for the quadratic dictionary $\omega_{inst} = a + bt + ct^2$ . Other advantages of the MPD method are simple reconstruction of the chosen parts of the signal, and clear and sharp maxima in the TF representation (Wigner distribution without cross-terms is used to calculate the TF representation for the obtained signal decomposition). The method requires more computational time than the other methods do. MPD method is still in development.

For a comparison of different methods of TF analysis see Figs. 1-2.

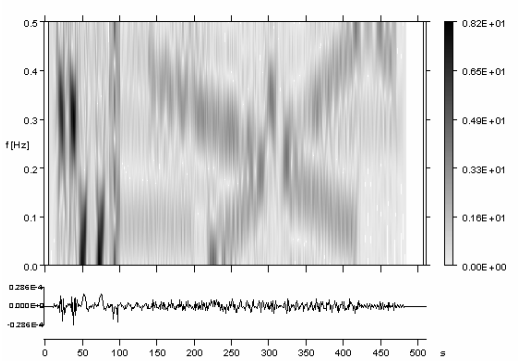

Fig.1a: $|WFT|^2$ (window length 10 s)

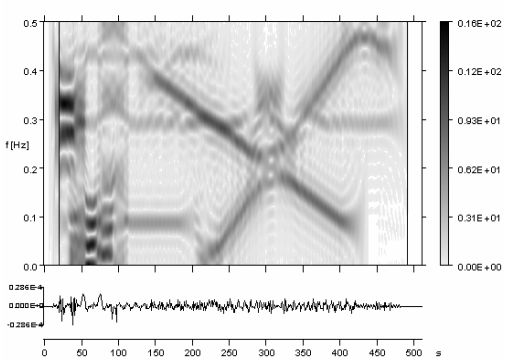

Fig. 1b: $|WFT|^2$ (window length 40 s)

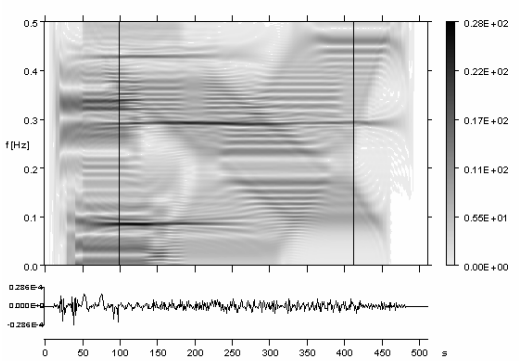

Fig.1: $|WFT|^2$ (window length 200s)

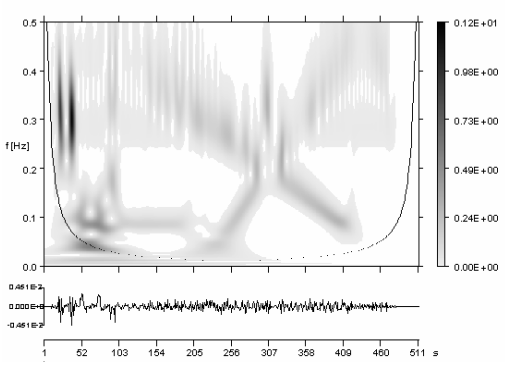

Fig. 1d: $|CWT|^2$ with Morlet wavelet

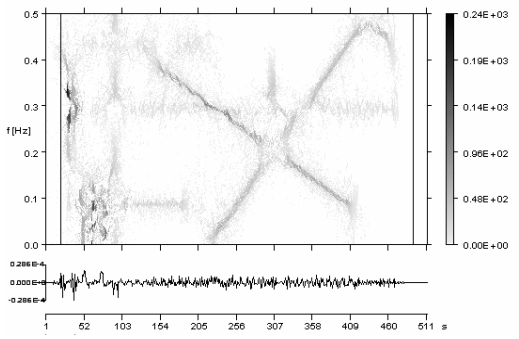

Fig. 1e: $|WFT|^2$ (40s) + reassignment

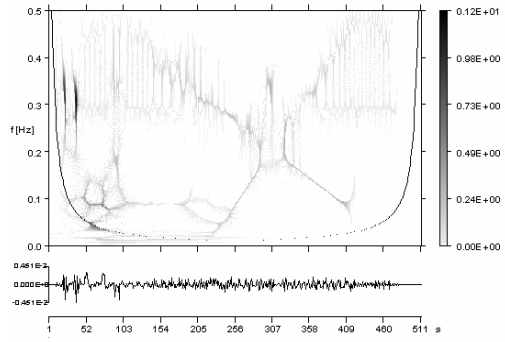

Fig. 1f: $|CWT|^2$ + reassignment

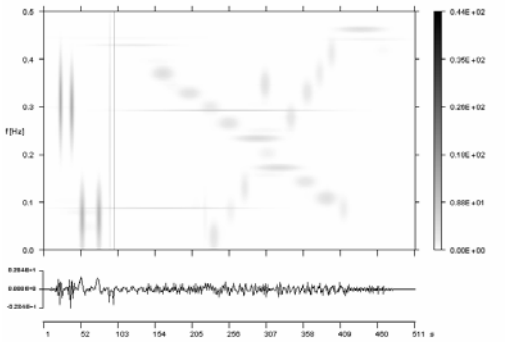

Fig.1g: original MPD

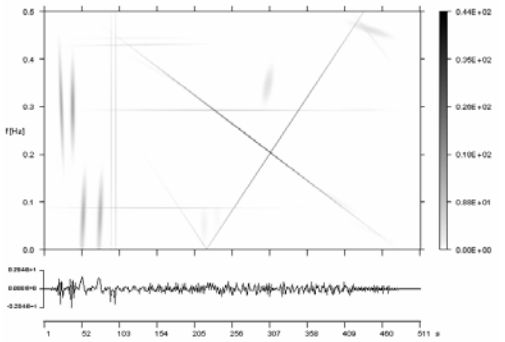

Fig. 1h: linear MPD

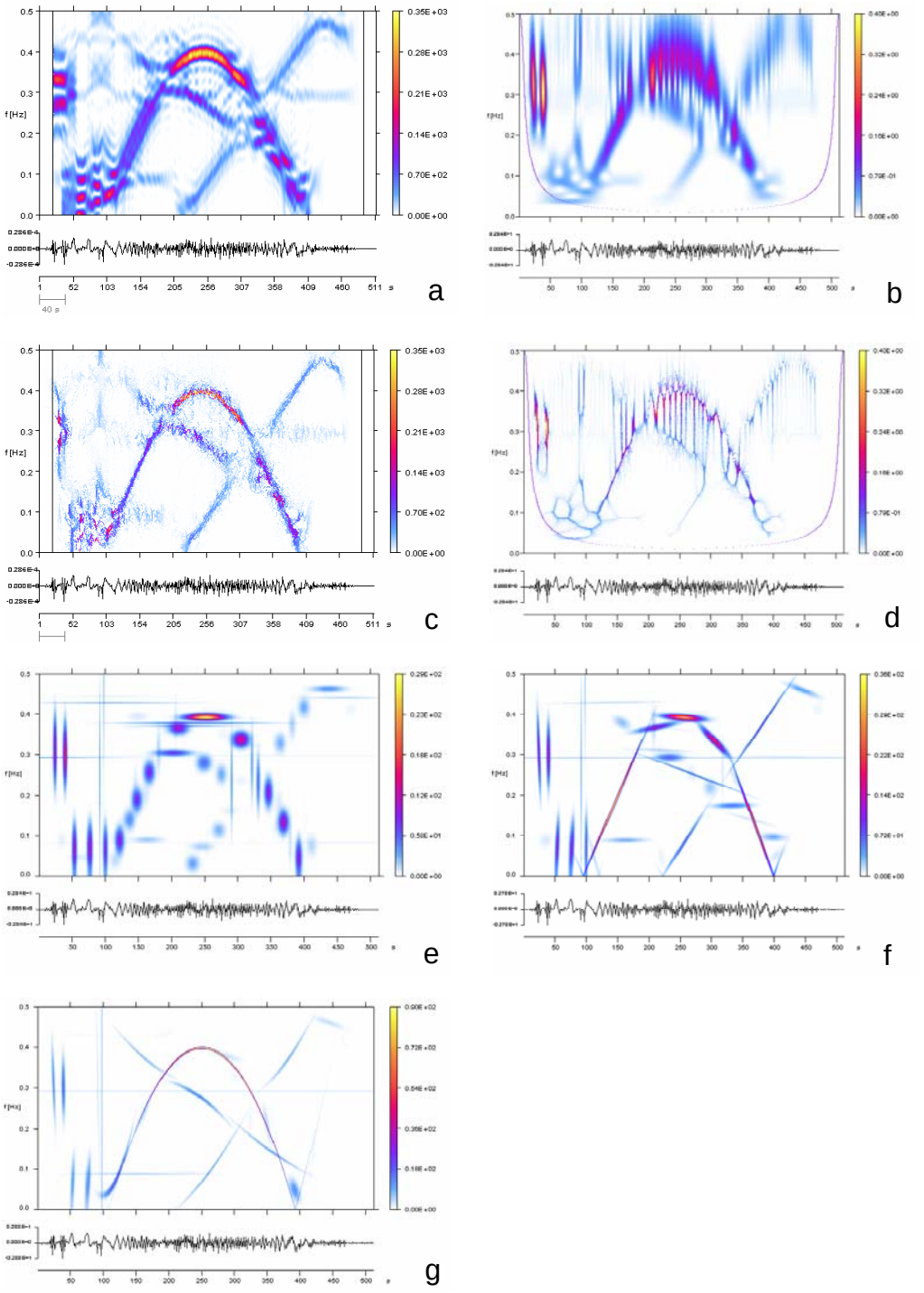


Fig. 2. TF representations of a complicated nonstationary signal, containing components with linear and nonlinear dependence of instantaneous frequency on time. a) $|WFT|^2$ with 40 sec window, b) $|CWT|^2$ with Morlet wavelet ($\omega_0 = 6$), c) $|WFT|^2$ with 40 sec window and application of the reassignment method, d) $|CWT|^2$ with Morlet wavelet ($\omega_0 = 6$) and application of the reassignment method, e) original MPD, f) linear MPD, g) quadratic MPD

# Program RWFT

Program RWFT computes time-frequency representation of a signal using the Windowed Fourier Transform (WFT) with an optional application of the Reassignment Method.

## Input files

Program RWFT requires two input files:

- help-file containing control parameters
- input file containing the time signal

### Help-file 'HFRWFT'

File type is ASCII and the file contains control parameters grouped into two FORTRAN namelists.

```
NAMELIST /CONTROL_DATA/ INP_FILE, TB, TE, DT, NT, &
                        FMIN, FMAX, KEY_LOG, WTW, TW_TYPE, NF, &
                        KNFFT, K1, K2, K3, K4
```

| *Name* | *Type* | *Description* |
|---|---|---|
| INP_FILE | A20 | Name of the input file containing the time signal. Program appends extension '.DAT' to the name. |
| TB | real | The time of the first sample of an input time signal [sec].<br>(default: 0) |
| TE | real | The time of the last sample of the input signal [sec].<br>(default: $(NT-1)\cdot DT$ ) |
| DT | real | The time step [sec]. |
| NT | integer | The number of samples of the input time signal. |
| FMIN, FMAX | real | The minimum and maximum frequencies for computation of WFT [Hz].<br>(default for FMIN:<br>0 if KEY_LOG = F ,<br>FMAX/1000 if KEY_LOG = T<br>default for FMAX: the Nyquist frequency) |

| *Name* | *Type* | *Description* |
|---|---|---|
| KEY_LOG | logical | TRUE: computation performed for frequencies with equidistant step in the logarithmic scale.<br>FALSE: computation realized for frequencies with equidistant step in the linear scale.<br>(default: FALSE) |
| WTW | real | The width of the time window used for WFT [sec]. |
| TW_TYPE | integer | The type of the time window:<br>1 – Cosine tapered rectangular time window.<br>(default: 1) |
| NF | integer | The number of frequency samples in the computed TF plane.<br>(default: 500) |
| KNFFT | integer | $2^{KNFFT}$ = the number of samples for the fast Fourier transform.<br>(default: 15) |
| K1 | logical | TRUE: the reassignment method is applied to the results of WFT in both the time and frequency domains, and the result is written into the file.<br>(default: TRUE) |
| K2 | logical | TRUE: the reassignment method is applied to the results of WFT in the time domain and the result is written into the file.<br>(default: FALSE) |
| K3 | logical | TRUE: the reassignment method is applied to the results of WFT in the frequency domain and the result is written into the file.<br>(default: FALSE) |
| K4 | logical | TRUE: the result of WFT (without application of the reassignment method) is written into the file.<br>(default: TRUE) |

NAMELIST /TYPE_1/ PERC

| *Name* | *Type* | *Description* |
|---|---|---|
| PERC | real | PERC $\in \langle 0,1 \rangle$, cosine-tapered portion of the time window. |

**Input file INP_FILE + '.DAT'**

The file type is ASCII and the file contains NT lines describing the input time signal. There is one value in each line. The first value corresponds to time TB , the last value to time TE.

## Output files

According to the values of variables K1, K2, K3 and K4 program RWFT stores results into the following output files. These files can be visualized using program TFplot.

**Output file INP_FILE + 'o.GRD'**

The file is generated only if K4 = .TRUE. The file type is binary and contains the following variables (written sequentially):

| *Name* | *Type* | *Description* |
|---|---|---|
| TFA | A3 | Type of the TF analysis: 'WFT' |
| WTW, TW_TYPE, PERC, NT, DT, TB, TE, FMIN, FMAX, NF, KEY_LOG | *The same as the input parameters* | |
| V(1:NT) | real, dimension (NT) | The input time signal |
| abs ( WV (1:NT+1,1:NF) ) | real, dimension (NT+1, NF) | The array containing the time-frequency representation of the input signal. The vector WV(NT+1, :) contains information about the border of the region affected by the edge effects. |

**Output file INP_FILE + 'r.GRD'**

The file is generated only if K1 = .TRUE. The file type is binary and contains the same variables (written sequentially) as file INP_FILE + 'o.GRD' does.

**Output file INP_FILE + 't.GRD'**

The file is generated only if K2 = .TRUE. The file type is binary and contains the same variables (written sequentially) as file INP_FILE + 'o.GRD' does.

**Output file INP_FILE + 'f.GRD'**

The file is generated only if K3 = .TRUE. The file type is binary and contains the same variables (written sequentially) as file INP_FILE + 'o.GRD' does.

# Program RCWT

Program RCWT computes time-frequency representation of a signal using the Continuous Wavelet Transform (CWT) with an optional application of the Reassignment Method.

## Input files

Program RCWT requires two input files:

- help-file containing control parameters
- input file containing the time signal

### Help-file 'HFRCWT'

File type is ASCII and the file contains control parameters grouped into two FORTRAN namelists.

```
NAMELIST /CONTROL_DATA/ INP_FILE, TB, TE, DT, NT, &
                        FMIN, FMAX, KEY_LOG, WVLT_TYPE, PCOI, NF, &
                        KNFFT, K1, K2, K3, K4
```

| *Name* | *Type* | *Description* |
|---|---|---|
| INP_FILE | A20 | Name of the input file containing the time signal. Program appends extension '.DAT' to the name. |
| TB | real | The time of the first sample of an input time signal [sec].<br>(default: 0) |
| TE | real | The time of the last sample of the input signal [sec].<br>(default: $(NT-1)\cdot DT$ ) |
| DT | real | The time step [sec]. |
| NT | integer | The number of samples of the input time signal. |
| FMIN, FMAX | real | The minimum and maximum frequencies for computation of CWT [Hz].<br>(default for FMIN:<br>0 if KEY_LOG = F ,<br>FMAX/1000 if KEY_LOG = T<br>default for FMAX: the Nyquist frequency) |

| *Name* | *Type* | *Description* |
|---|---|---|
| KEY_LOG | logical | TRUE: computation performed for frequencies with equidistant step in the logarithmic scale.<br>FALSE: computation realized for frequencies with equidistant step in the linear scale.<br>(default: FALSE) |
| PCOI | real | The parameter for estimation of the Cone of Influence (COI).<br>(default: $e^{-2}$) |
| WVLT_TYPE | integer | Wavelet type:<br>1 – Morlet, 2 – Paul, 3 – Mexican hat |
| NF | integer | The number of frequency samples in the computed TF plane.<br>(default: 500) |
| KNFFT | integer | $2^{KNFFT}$ = the number of samples for the fast Fourier transform.<br>(default: 15) |
| K1 | logical | TRUE: the reassignment method is applied to the results of CWT in both the time and frequency domains, and the result is written into the file.<br>(default: TRUE) |
| K2 | logical | TRUE: the reassignment method is applied to the results of CWT in the time domain and the result is written into the file.<br>(default: FALSE) |
| K3 | logical | TRUE: the reassignment method is applied to the results of CWT in the frequency domain and the result is written into the file.<br>(default: FALSE) |
| K4 | logical | TRUE: the result of CWT (without application of the reassignment method) is written into the file.<br>(default: TRUE) |

NAMELIST /TYPE_1/ W0

| *Name* | *Type* | *Description* |
|---|---|---|
| W0 | real | Parameter $\omega_0$ of the Morlet wavelet. |

NAMELIST /TYPE_2/ M

| *Name* | *Type* | *Description* |
|---|---|---|
| M | integer | The order of the Paul wavelet. |

NAMELIST /TYPE_3/ M

| *Name* | *Type* | *Description* |
|---|---|---|
| M | integer | The order of the Mexican-hat wavelet. |

**Input file INP_FILE + '.DAT'**

The file type is ASCII and the file contains NT lines describing the input time signal. There is one value in each line. The first value corresponds to time TB, the last value to time TE.

## Output files

According to the values of variables K1, K2, K3 and K4 program RCWT stores results into the following output files. These files can be visualized using program TFplot.

**Output file INP_FILE + 'o.GRD'**

The file is generated only if K4 = .TRUE. The file type is binary and contains the following variables (written sequentially):

| *Name* | *Type* | *Description* |
|---|---|---|
| TFA | A3 | Type of the TF analysis: 'CWT' |
| WVLT_TYPE,<br>W0 or M,<br>NT, DT, TB, TE, FMIN, FMAX, NF, KEY_LOG | *The same as the input parameters* | |
| V(1:NT) | real, dimension (NT) | The input time signal |

| *Name* | *Type* | *Description* |
|---|---|---|
| abs ( WV (1:NT+1,1:NF) ) | real, dimension (NT+1, NF) | The array containing the time-frequency representation of the input signal. The vector WV(NT+1, :) contains information about the border of the region affected by the edge effects (COI). |

**Output file INP_FILE + 'r.GRD'**

The file is generated only if K1 = .TRUE. The file type is binary and contains the same variables (written sequentially) as file INP_FILE + 'o.GRD' does.

**Output file INP_FILE + 't.GRD'**

The file is generated only if K2 = .TRUE. The file type is binary and contains the same variables (written sequentially) as file INP_FILE + 'o.GRD' does.

**Output file INP_FILE + 'f.GRD'**

The file is generated only if K3 = .TRUE. The file type is binary and contains the same variables (written sequentially) as file INP_FILE + 'o.GRD' does.

# Program MPD_2

Program MPD_2 performs Matching Pursuit Decomposition (MPD) of a signal using time-frequency atoms from the original/linear/quadratic Gabor dictionary. The decomposition can be optionally performed in one of three ways. The computation can be interactively terminated by creating the file with the name 'STOP' in the same directory where the program MPD_2 is running. Otherwise, the computation finishes when the L2 norm of the residuum is less than the value of EPSILON. The time-frequency representation of the obtained decomposition can be calculated using the program BK2WD.

## Input files

Program MPD_2 requires two input files:

- help-file containing control parameters
- input file containing the time signal

**Help-file 'HFMPD'**

File type is ASCII and the file contains control parameters grouped into FORTRAN namelist.

```
NAMELIST /CONTROL_DATA/  INP_FILE, TB, TE, DT, NT, EPSILON, &
                         TYPE_D
```

| *Name* | *Type* | *Description* |
|---|---|---|
| INP_FILE | A20 | Name of the input file containing the time signal. Program appends extension '.DAT' to the name. |
| TB | real | The time of the first sample of an input time signal [sec]. (default: 0) |
| TE | real | The time of the last sample of the input signal [sec]. (default: $(NT-1)\cdot DT$ ) |
| DT | real | The time step [sec]. |
| NT | integer | The number of samples of the input time signal. |
| EPSILON | real | The minimum desired value of the L2 norm of the residuum. (default: 0.001) |

| *Name* | *Type* | *Description* |
|---|---|---|
| TYPE_D | A1 | Type of MPD<br>o – original, l – linear, q – quadratic<br>(default: q) |

**Input file INP_FILE + '.DAT'**

The file type is ASCII and the file contains NT lines describing the input time signal. There is one value in each line. The first value corresponds to time TB , the last value to time TE.

## Output files

Program MPD_2 may generate a large number of output files:

- file containing the parameters of decomposed time-frequency atoms,
- files containing decomposed time-frequency atoms,
- file containing the residuum after decomposition.

**Output file 'BOOK.ORI'**

The file type is ASCII and the file contains as many lines as the number of decomposed TF atoms. It corresponds to the so-called 'structure book' of MPD. There are 9 values written in each line:

| *Name*<br>*in the header of file* | *Description* |
|---|---|
| N | A sequential number of a TF atom. |
| <RnF,G_gama,fi> | Coefficient $\left\langle R^n x, g_{\gamma_n} \right\rangle$. |
| scale [s] | Parameter $s$ of the TF atom. |
| position [s] | Parameter $u$ of the TF atom. |
| frequency [Hz] | Parameter $\xi$ of the TF atom. |
| Fi [rad] | A phase of the complex scalar product $\left\langle \hat{R}^n x, g_{\gamma_n} \right\rangle$. |

| *Name in the header of file* | *Description* |
|---|---|
| K_gamma,fi | Variable $K_{\gamma,\phi}$ used during the MPD (after *Mallat & Zhang 1993*). |
| - | The parameter $\xi_1$ of the TF atom (only if the linear or quadratic MPD is used). |
| - | The parameter $\xi_2$ of the TF atom (only if the quadratic MPD is used). |

**Output files 'VECxxx.DAT'**

The file type is ASCII and contains two columns of data. The first one corresponds to time, the second to the TF atom. xxx stands for a sequential number of the TF atom.

**Output file 'VECRES.DAT'**

The file type is ASCII and contains two columns of data. The first one corresponds to time, the second to the residuum.

# Program BK2WD

Program BK2WD performs the so-called back projection, which reduces the approximation error of the MPD and computes the energy distribution of the analyzed signal using the Wigner distribution. The results can be visualized using program TFplot.

## Input files

Program BK2WD requires three input files:

- help-file containing control parameters
- the file BOOK.ORI containing the results of MPD
- input file containing the time signal (the same as for program MPD_2)

### Help-file 'HFBK2WG'

The file type is ASCII and the file contains control parameters grouped into FORTRAN namelist.

```
NAMELIST /CONTROL_DATA/  OUT_FILE, TB, TE, DT, FMIN, FMAX, &
                         NT, KEY_LOG, DICT, INP_FILE
```

| *Name* | *Type* | *Description* |
|---|---|---|
| INP_FILE | A20 | Name of the input file containing the time signal. Program appends extension '.DAT' to the name. |
| OUT_FILE | A10 | Name of the output file containing the time signal reconstructed from the TF atoms found in decomposition. (Only atoms with positive sequential number in the file BOOK.ORI are used.) |
| TB | real | The time of the first sample of an input time signal [sec]. |
| TE | real | The time of the last sample of the input signal [sec]. |
| DT | real | The time step [sec]. |
| NT | integer | The number of samples of the input time signal. |

| *Name* | *Type* | *Description* |
|---|---|---|
| FMIN, FMAX | real | The minimum and maximum frequencies for computation of the time-frequency representation [Hz].<br>(default for FMIN:<br>0 if KEY_LOG = F ,<br>FMAX/1000 if KEY_LOG = T<br>default for FMAX: the Nyquist frequency) |
| KEY_LOG | logical | TRUE: computation performed for frequencies with equidistant step in the logarithmic scale.<br>FALSE: computation realized for frequencies with equidistant step in the linear scale.<br>(default: FALSE) |
| NF | integer | The number of frequency samples in the computed TF plane.<br>(default: 500) |
| DICT | integer | The type of MPD:<br>1 – original, 2 – linear, 3 – quadratic |

**Output files**

Program BK2WG, similarly as MPD_2, may generate a large number of output files:

- file ‘BOOK.NEW‘ containing new parameters of the decomposed time-frequency atoms obtained by the back projection,
- files 'VNxxx.DAT' containing the decomposed time-frequency atoms obtained by the back projection,
- file 'VNRES.DAT’ containing the residuum obtained by the decomposition and back projection,
- file OUT_FILE containing time signal reconstructed from TF atoms obtained by decomposition and back projection
- file ‘OUT.GRD‘ containing time-frequency representation of the signal

**Output file 'BOOK.NEW'**

The file has the same structure as file ‘BOOK.ORI‘ created by program MPD_2. It contains the new structure book from the back projection.

**Output files 'VNxxx.DAT'**

The file type is ASCII and contains two columns of data. The first one corresponds to time, the second to the TF atom from the back projection. xxx stands for a sequential number of the TF atom.

**Output file 'VNRES.DAT'**

The file type is ASCII and contains two columns of data. The first one corresponds to time, the second to the residuum from the back projection.

**Output file 'OUT.GRD'**

The file type is binary and contains the following variables (written sequentially):

| *Name* | *Type* | *Description* |
|---|---|---|
| TFA | A3 | Type of the TF analysis: 'MPD' |
| DICT,<br>NT, DT, TB, TE, FMIN, FMAX, NF, KEY_LOG | *The same as the input parameters* | |
| V(1:NT) | real, dimension (NT) | The input time signal |
| abs ( WV (1:NT+1,1:NF) ) | real, dimension (NT+1, NF) | The array containing the time-frequency representation of the input signal. |

# Program TFplot

Program TFplot interactively displays the results of the time-frequency analysis obtained using any of the TF-SIGNAL programs. Program reads the file with results of the time-frequency analysis and plots the resulting time-frequency representation together with other parameters of visualization. The visualization parameters can be interactively changed (Fig. 3). The program works under the operating system Windows XP and is optimized for the screen resolution 1280 x 1024 pixels.

## Input files

Program TFplot requires four input files:

- help-file containing control parameters of visualization
- file containing the time-frequency representation
- file containing the definition of the color scale

### Help-file 'HFTFPLOT'

The file type is ASCII and contains control parameters grouped into two FORTRAN namelists. All parameters could be changed interactively.

NAMELIST /INPUT/ INP_FILE

| *Name* | *Type* | *Description* |
|---|---|---|
| INP_FILE | A20 | Name of the input file containing the time-frequency representation of the signal. |

NAMELIST /CONTROL_DATA/ KEY_SC, TMIN, TMAX, FMIN, FMAX, KEY_GRID, KEY_SUMT, KEY_AMPLOG, DES_FILE, CG, NDDT, NDT, NDDF, NDF, TMINTIC, DTTICS, FMINTIC, DFTICS, MAG, COMMENT

| *Name* | *Type* | *Description* |
|---|---|---|
| KEY_SC | logical | MAXSC defines the value corresponding to the maximum on the color scale.<br>TRUE: MAXSC value is defined in the line below this namelist.<br>FALSE: MAXSC is the maximum value in the displayed portion of the time-frequency plane, i.e., a local scaling is applied.<br>(default: FALSE) |

| *Name* | *Type* | *Description* |
|---|---|---|
| TMIN, TMAX | real | The minimum and maximum time for plotting of the time-frequency representation [sec].<br>(default: minimum and maximum time in the TF computation) |
| FMIN, FMAX | real | The minimum and maximum frequencies for plotting of the time-frequency representation [Hz].<br>(default: minimum and maximum frequencies in the TF computation) |
| KEY_GRID | logical | TRUE: The grid-lines will be plotted in the TF plane<br>(default: FALSE) |
| KEY_SUMT | logical | TRUE: The average value of the TF representation over the whole chosen frequency range is computed for each time sample.<br>(default: FALSE) |
| KEY_AMPLOG | logical | TRUE: Logarithmic amplitude scale<br>FALSE: Linear amplitude scale<br>(default: FALSE) |
| DES_FILE | A12 | The name of the file containing the definition of the color scale.<br>(default: scale.decoi4) |
| CG | real | CG $\in \langle 0,1 \rangle$, defines the color of the grid. The value 0 corresponds to the color of the minimum on the color scale, 1 corresponds to the color of the maximum on the color scale.<br>(default: 0.88) |
| NDDT | integer | The number of decimal digits for numbers on the time axis.<br>(default: 0) |
| NDT | integer | The number of digits (including the decimal point) for numbers on the time axis.<br>(default: 5) |
| NDDF | integer | The number of decimal digits for numbers on the frequency axis.<br>(default: 0) |
| NDF | integer | The number of digits (including the decimal point) for numbers on the frequency axis.<br>(default: 5) |

| *Name* | *Type* | *Description* |
|---|---|---|
| TMINTIC | real | Defines time of the first tick on the time axis. [sec] (default: TMIN) |
| DTTICS | real | Defines the increment of the tics on the time axis [sec]. (default: -9999., i.e. automatically computed) |
| FMINTIC | real | Defines frequency of the first tick on the frequency axis. [Hz] (default: FMIN) |
| DFTICS | real | Defines the increment of the tics on the frequency axis. [Hz] (default: -9999., i.e. automatically computed) |
| MAG | real | The value of the magnification of the plot. (default: 0.64 ) |
| COMMENT | A80 | The user-defined comment which will be displayed. (default: -) |

MAXSC

| *Name* | *Type* | *Description* |
|---|---|---|
| MAXSC | real | MAXSC defines the value corresponding to the maximum on the color scale. |

**Output files**

Program TFplot creates bitmap file OUT.BMP with the actually displayed time-frequency representation. The displayed figure can be stored also using the menu File-Save.

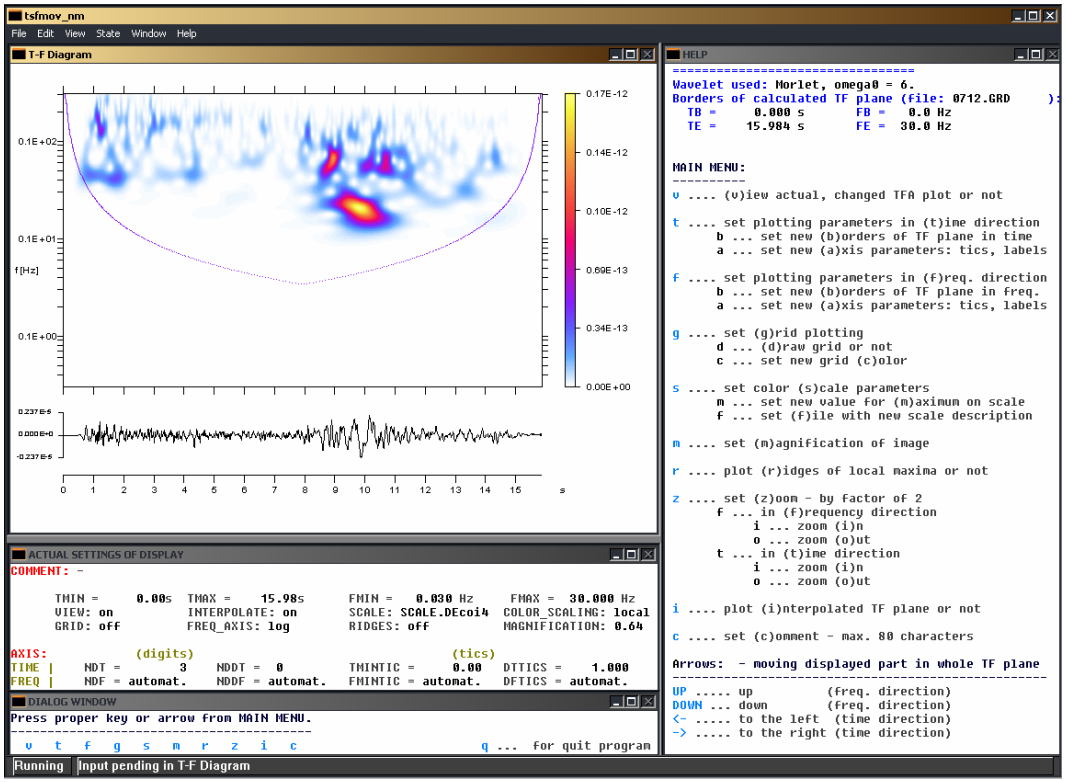


Fig. 3 Interactive environment of program TFplot