

## Design and Implementation of a Time-frequency Analysis System for Non-stationary Vibration Signals Using Mixed Programming

Miaozhong Sun<sup>1</sup>, Shihai Cui<sup>2</sup> and Yuanli Xu<sup>3</sup>

<sup>1,2,3</sup>College of Mechanical Engineering, Tianjin University of Science & Technology  
No.1038 Dagu South Road, Hexi District, Tianjin City, Tianjin 300222, PR China  
<sup>1</sup>sunmzh66@sina.com, <sup>2</sup>shihaicui@tust.edu.cn, <sup>3</sup>xuyuanli2006@126.com

### Abstract

*At present, in the feature extraction of non-stationary vibration signals, many time-frequency analytic methods have emerged to meet the further need of non-stationary signal analysis such as Wavelet Transform (WT), Short Time Fourier Transform (STFT), Wigner-Ville Distribution (WVD), Empirical Mode Decomposition (EMD), Ensemble Empirical Mode Decomposition (EEMD) and so on. However, these time-frequency analysis methods can only be carried out on Matlab platform and the processes are of low efficiency, bringing a lot of inconvenience in signal analysis because they can not run on Windows system independently. According to the defects, a novel method of mixed programming which combines Matlab with Delphi based on COM (component Object Model) module technology is proposed to design a time-frequency analysis system for non-stationary vibration signals assembling fourteen methods. The advantages of two languages are shared with each other. In design of the system, a combined method which combines two or three analytic methods is put forward for relational analytic modules to make the analytic results more perfect and clearer, like WAVELET-FFT, EMD-WVD etc.. This paper uses the EMD-WVD combined method as an example to present the programming thoughts and processes. The effectiveness of the system is validated using a simulation signal and an experimental signal. The system can be executed separated from MATLAB environment.*

**Keywords:** Non-stationary vibration signal, COM module technology, Time-frequency analysis System, Combined method, Mixed programming

### 1. Introduction

In process of mechanical fault diagnosis, vibration signals are known usually to be non-stationary, for which the signal's parameters are time-varying. In order to acquire the characteristic information about the signal frequencies varying with time, joint time-frequency analytic methods are powerful tools such as WT, STFT, WVD etc.. These methods can extract the features of the non-stationary signals at different levels and have been widely used in different areas [1-3]. When they are used to solve actual problems, they have to be carried out only through Matlab platform and need to compile different M files that can not be executed in Windows, leading to difficult programming and low efficiency. At present, there are no developed analysis systems that assemble numerous time-frequency methods yet. Using Matlab platform to perform time-frequency methods brings a lot of inconvenience in the feature extract of the non-stationary vibration signals. Especially, when certain method is used in Matlab, only its own pure function is performed lacking profound result showing. Like the EMD method, it can decompose the original signal to get a series of intrinsic mode functions (IMFs) which vary with time, but can not deeply reveal the frequency characteristic

information. If other methods are employed to combine with the EMD method making a deeper analysis on this base, we name “the combined method” [4-5, 11], such as EMD-FFT, EMD-WVD *etc.*, the results will be clearer and more profound.

Matlab is a scientific computing language that possesses many powerful functions such as numerical calculation, time-frequency analysis, signal processing, graphics analysis and so on. Matlab can create oriented-object COM modules. It is effective highly to use Matlab to program for time-frequency analysis. But the programs can not be executed separated from Matlab environment and run slowly, furthermore their programming interfaces are too difficult to design and implement [6]. Delphi language is called the fourth programming language, and it is simple, efficient and powerful. Compared with VB and VC++, it is easier to grasp, and stronger to design the programming interface. Delphi has such functions: oriented-object style based on Windows, fast compiler, powerful database, mature component technology and so on [7-8]. If the two languages are mixed to program, their own advantages will be made best use of each other. A novel idea is proposed that Matlab builds up COM modules for different time-frequency methods and their graphics output, Delphi embeds the COM modules to connect the data between Delphi and Matlab and designs the system interface. In this paper a time-frequency analysis system assembling fourteen methods (including five combined methods) is deigned and implemented by using mixed programming based on COM module technology. New methods can be easily expanded to add in this system. This system can run on Windows separated from Matlab environment.

## **2. Mixed Programming Technology using Matlab and Delphi**

### **2.1. COM Technology**

COM is for short from Component Object Module which is a universal object interface and called by any other languages according to interface standards. M files with function top line will first be edited using the Matlab compiler, and then translated into corresponding COM modules that finally become Dynamic Link Library (DLL) files with the help of the external Matlab COM Builder. Delphi can directly call these COM modules to carry out the data exchange of the two languages.COM modules can not only separate from Matlab environment but also be called by Delphi not switching of the two environments and getting the best running speed. Programming experiments show that this method is easy and common to use, and can carry out any M function files of Matlab except Script M files which are not supported, and need to be changed into M function files [9, 10].

### **2.2 Building COM Modules in Matlab**

In the Matlab command window, input `mex -setup` to display different installed external Matlab compilers such as Borland (3-6), Microsoft Visual Studio (5.0, 6.0) and Microsoft Visual Studio.Net *etc.*. Microsoft Visual Studio 6.0 is chose in this paper. Firstly programming algorithms of signal analytic methods must be edited into M function files stead of script files using the Matlab M file editor. In M files, functions can receive parameters and also return them. The name of the M file must be as same as that of function. In the command window, input `comtool` or choose Start button in the left corner to pop out the main window of COM. Choose the item labeled MATLAB Builder for COM to translate the needed M files. Corresponding DLL files will be created after successful translation and registered automatically in Windows meantime. Two folders named `distrib` and `src` will be produced. `Disturb` folder includes the DLL executed files and `src` folder puts the exchanging C/C++ files.

### 2.3. COM Modules Called by Delphi

After the COM modules have been registered into Windows, Delphi can call them. Choose the item labeled Project Import Type Library on the main Delphi menus to pop out the next window. Then select the needed DLL files and click the Install button to install them. The corresponding components will be created in the ActiveX Control page later. Delphi programs can call them at any time.

## 3. Programming Implementation of the Time-frequency Analysis System

### 3.1. Flow Chart of Programming

The key point is that in the design of the system Delphi call COM modules which can carry out the data exchanging interface between Delphi programs and Matlab ones. The architecture of the system consists of six parts that are as following: signal sampling, M files, COM modules, main interface of time-frequency analysis system, signal analysis and graphics display.

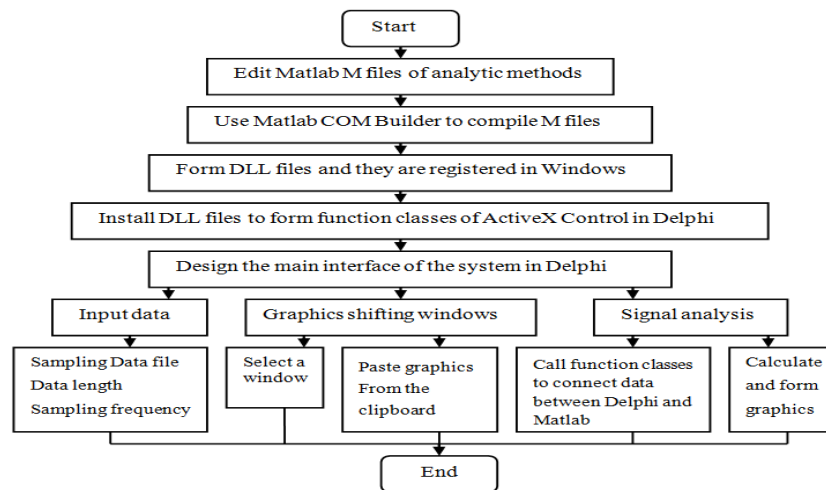
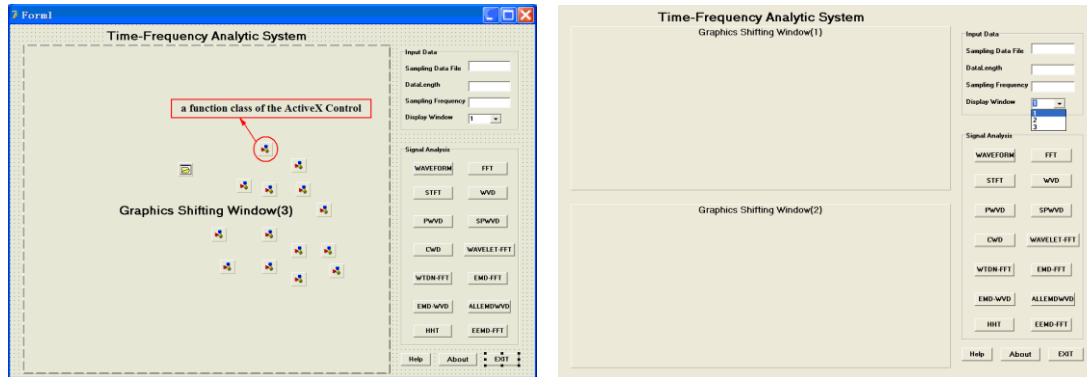


Figure 1. Framework of Time-frequency Analytic System

Figure 1 shows the framework of the system programming. Matlab M files perform different algorithms which depict corresponding signal analysis functions. Matlab COM Builder is used to translate these M files to create COM modules which finally become DLL files registered automatically in Windows. Delphi installs the DLL files to form corresponding function classes of ActiveX Control. When Delphi programs are running, they can call the function classes which finish the calculations in Matlab environment. Then the calculation results return to the Delphi function interfaces to output visual signal analysis graphics.

### 3.2. Design of the System Interface

Figure 2 displays the system programming window and the main starting interface respectively. The main interface is made up of three parts: Input data, Signal analysis and Graphics shifting windows (1-3).



**Figure 2. Programming Window of the System and Main Starting Interface**

(1)Input data module

In this module, a sampling data file must be input in the top blank, or the mouse can be also used to click the blank to open a file dialogue to choose the data file where to be deposited. Data length, sampling frequency and display window (1-3) need to be input in the next three blanks.

(2)Signal analysis module

Fourteen signal analysis functions including twelve time-frequency analysis functions have been exploited in this system. As the left Figure 2 seen, in the middle window, a red arrow is labeled to illustrate a installed function class of ActiveX Control. There embed fourteen ActiveX function classes that correspond to the fourteen methods: WAVEFORM (real-time waveform display), FFT (Fast Fourier Transform), STFT (Short Time Fourier Transform), WVD (Wigner-Ville Distribution), PWVD (Smoothed Wigner-Ville Distribution), SPWVD (Smoothed Pseudo Wigner-Ville Distribution), CWD(Choi-Williams Distribution), WAVELET-FFT(Wavelet Transform is first used to decompose the original signal, then FFT is used to analyze the decomposed components), WTDN-FFT (Wavelet is first used to de-noise the original signal, then FFT is used to analyze the de-noised signal), EMD-FFT (EMD is first used to decompose the original signal to get the IMFs, then FFT is used to analyze the each IMFs), EMD-WVD(EMD is first used to decompose the original signal to get the IMFs, then each IMF correlates with the original to achieve corresponding correlation coefficient. False IMFs are deleted if their coefficients are very small. Finally WVD is used to analyze the remanent IMFs to get thier time-frequency analytic spectrums.), ALLEMDWVD (Each WVD value calculated in EMD-WVD analysis is add together to get the total WVD time-frequency spectrum), HHT (Hilbert-Huang Transform) and EEMD-FFT (EEMD is first used to decompose the original signal, then FFT is used to analyze the IMFs).

(3)Graphics shifting window module

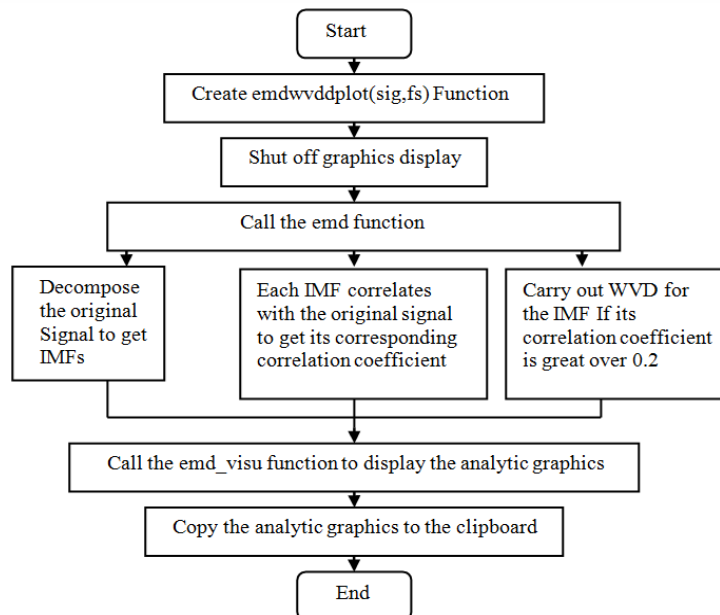
Three windows can be chose to present the analytic graphics. The main interface arranges two windows (1,2) to display Simultaneously two channel analytic results so as to be compared with each other easily. In order to depict complicate analytic results, for example EMD-WVD analysis, there sets up a big invisible window (3) behind the above two windows, see the main starting interface in the right Figure 2. In the analysis process, select window numbers to open or shift windows to display the analyzed results. At this time, the big window and the two windows are covered each other.

### 3.3. Programming of EMD-WVD Combined Method

**3.3.1. EMD-WVD Combined Method:** In this system aiming at better exacting the characteristic information of non-stationary signals, two or three methods are employed to be combined with during performing Wavelet transform, EMD and EEMD etc. In process of EMD analysis, three methods are combined with that are EMD, Correlation Coefficient Method and WVD.

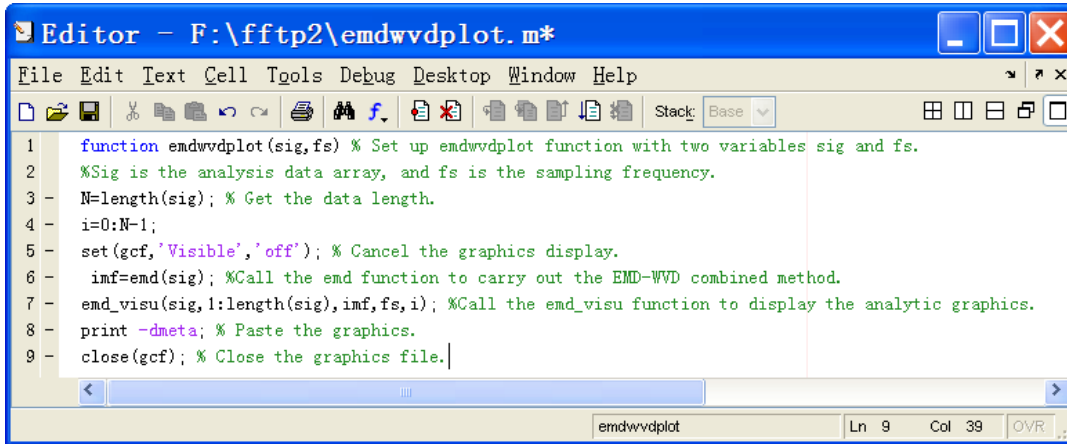
EMD is a kind of time–frequency analysis method with self-adaption according to the local time-varying characteristic to decompose the non-stationary signal into a set of complete and almost orthogonal components named intrinsic mode function (IMF) [11]. But in process of EMD, there exists over decomposition owing to some following causes: errors in the local average calculation, effect of boundary reaction and undemanding standard for ultimate filtration etc.. Over decomposition leads to additional IMFs that do not belong to those of the original signal. The additional IMFs are called “false IMFs” [12, 13]. Those false IMFs bring about the wrong results. In order to address the issue, each IMF is used to correlate with the original signal to gain the corresponding correlation coefficient. The false IMF is eliminated when the correlation coefficient is very small. Then WVD is used to analyze further the true remanent IMFs to obtain their time-frequency analytic spectrums making the results clearer because WVD is famous of the concentration and resolution [14]. We call the project “EMD-WVD combined method”.

**3.3.2. Programming Framework of EMD-WVD and Main Programming Codes:** In the platform of Matlab, a M file of the EMD-WVD method is first edited to set up a emdwvdplot function that calls two sub-functions named emd and emd\_visu. The emd function is exploited to carry out the combined method that uses EMD, Correlation Coefficient Method and WVD, and the emd\_visu one is developed to display the analytic graphics. The programming framework is presented in Figure 3.



**Figure 3. Programming Framework of EMD-WVD using a M File**

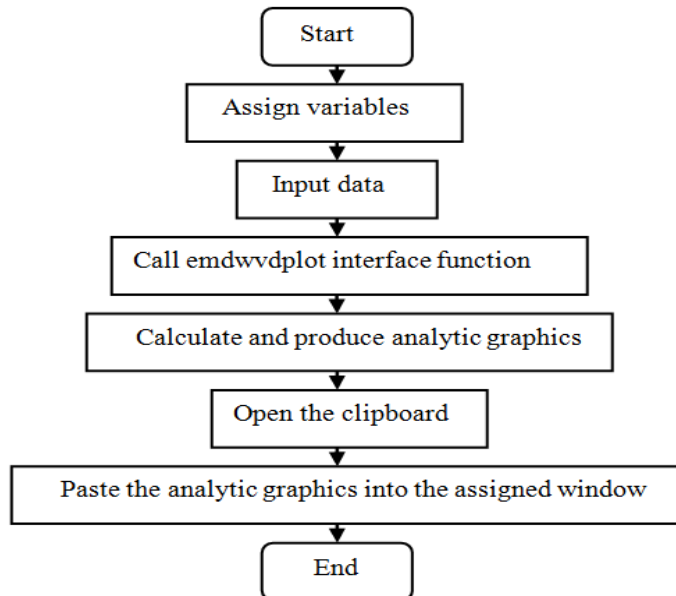
The Matlab programming codes of the EMD-WVD method are introduced as Figure 4:



```
1 function emdwvdplot(sig,fs) % Set up emdwvdplot function with two variables sig and fs.
2 %Sig is the analysis data array, and fs is the sampling frequency.
3 N=length(sig); % Get the data length.
4 i=0:N-1;
5 set(gcf,'Visible','off'); % Cancel the graphics display.
6 imf=emd(sig); %Call the emd function to carry out the EMD-WVD combined method.
7 emd_visu(sig,1:length(sig),imf,fs,i); %Call the emd_visu function to display the analytic graphics.
8 print -dmeta; % Paste the graphics.
9 close(gcf); % Close the graphics file.
```

**Figure 4. Matlab Programming Codes of the EMD-WVD Method**

The above M file is compiled to form a COM module that finally becomes a registered DLL file. This DLL file needs to be installed on Delphi platform to create the named fileemdwdclass class of the ActiveX Control page. The fileemdwdclass class can be inserted in the programming window (see the left Figure 2) to be called by the Delphi program. It can builds up a data link to the emdwvdplot function interface. The Delphi programming framework is depicted in Figure 5.



**Figure 5. Delphi Programming Framework of the EMD-WVD Method**

The Delphi Pascal programming codes of the EMD-WVD method are explained as Figure 6:

```

procedure TForm1.Button16Click(Sender: TObject); //EMD-WVD Function |
var
  // Assign variables
  fs,sig:olevariant;
  i,ndot:integer;
  fin:textfile;
  y:array[1..5000] of double;
  picture:Tmetafile;
  datafile:string;
begin
  ndot:=strtoint(edit2.Text); //Input the sampling dots.
  sig:=vararraycreate([1,ndot],vardouble); //Create the sampling data array.
  fs:=vararraycreate([1,1],vardouble); // Create the sampling frequency array.
  fs:=strtofloat(edit3.Text); //Input the sampling frequency.
  datafile:=opendialog1.filename; //Open the sampling data file dialogue.
  datafile:=edit1.text; // Input the data file
  assignfile(fin,datafile); // Assign the file handle.
  reset(fin); // Reset the file handle
  for i:=1 to ndot do //Circle the sampling dots.
  begin
    read(fin,y[i]); // Read the sampling data.
    sig[i]:=y[i]; //Transfer the data.
  end;
  closefile(fin); //Close the file.
  fileemdwvdclass1.emdwvdplot(sig,fs); //Call emdwvdplot function enclosed by
  //the fileemdwvdclass1 class to connect the data between Delphi and Matlab.
  if(Clipboard.HasFormat(cf_metafilepict))then//If there exists graphics in the clipboard
  begin
    picture:=Tmetafile.create; //Create the graphics file.
    picture.assign(Clipboard); //Assign the clipboard.
    image3.Picture.Assign(picture); // Paste the graphics into the shifting window.
    picture.free; //Release the graphics.
  end;
end;

```

Figure 6. Delphi Pascal Programming Codes of the EMD-WVD Method

#### 4. System Validation using a Simulation Signal

A simulation signal is defined as:

$$x(t) = t + \sin(2\pi \cdot 20t) + \cos(2\pi \cdot 50t + \sin(2\pi \cdot 20t)) + \sin(2\pi \cdot 200t) \quad (3-1)$$

It belongs to a non-stationary signal that consists of one linear trend  $t$ , two sine with 20Hz and 200Hz respectively and one 50Hz cosine modulated by a 20Hz sine in frequency domain. According to the modulated frequency of the expression, the angular velocity is calculated as:

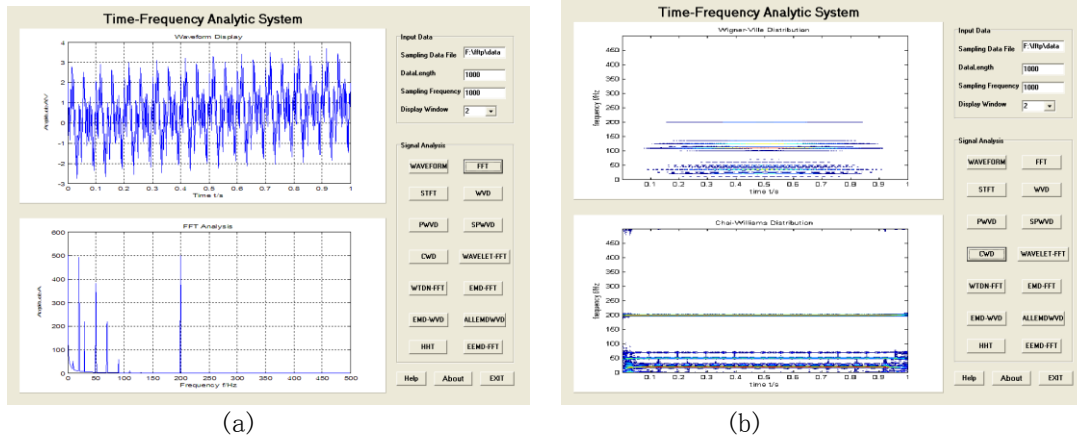
$$w(t) = \frac{d\theta(t)}{dt} = \frac{d(2\pi \cdot 50t + \sin(2\pi \cdot 20t))}{dt} \quad (3-2)$$

$$= 100\pi + 40\pi \cos(40\pi t)$$

$$f(t) = \frac{\omega(t)}{2\pi} = 50 + 20\cos(40\pi t) \quad (3-3)$$

According to (3-3), the frequency scope is  $30\text{Hz} \leq f(t) \leq 70\text{Hz}$ , and it changes regularly with the cosine wave.

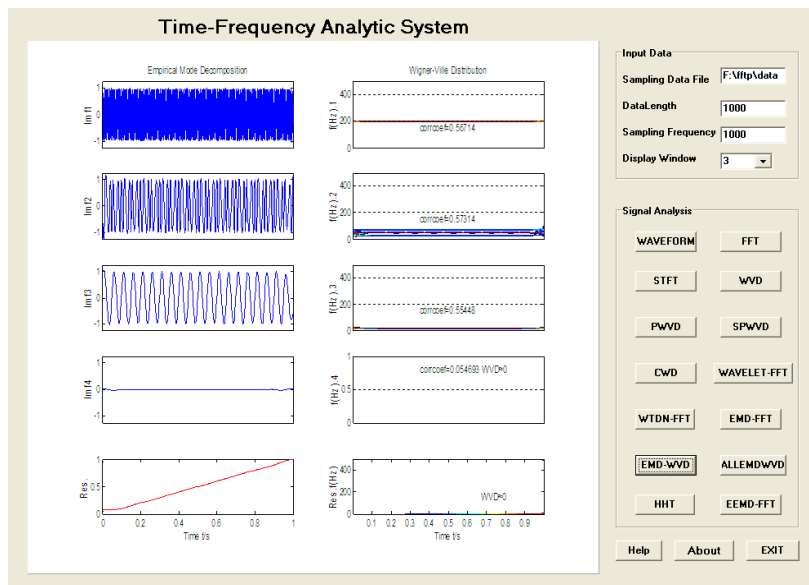
In the next work, we use most methods of the system to analyze the simulation signal in order to verify the effectiveness of the system. Figure 7(a) shows the simulation signal waveform and its FFT result respectively after using the system. The sampling dot is 1000 and the sampling frequency is 1000Hz. In the spectrum, 20Hz, 50Hz and 200Hz characteristic peaks are obvious to correspond to the original signal, but around the 50Hz characteristic peak, the 20Hz modulated frequency components are indistinct due to the deficiency of FFT in analyzing non-stationary signals.



**Figure 7. (a) Simulation Signal Waveform and its Spectrum (b) WVD Analysis and CWD Analysis**

Figure 7(b) depicts WVD and CWD results respectively. WVD exists obviously the cross-terms to be difficult to distinguish the characteristic frequencies. CWD presents the three base-frequency components clearly as it introduces a smoothed kernel window function. The modulated frequency components around the 50Hz base-frequency can still be seen, but in a poor resolution.

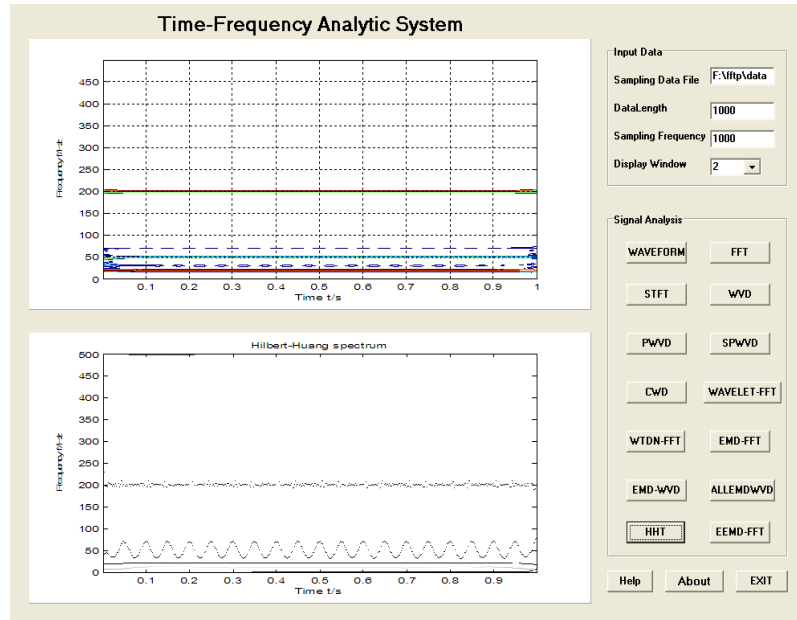
Figure 8 displays four IMFs, a trend using EMD to decompose the original signal and their corresponding time-frequency spectrums using WVD analysis respectively. In the right figure, the three correlation coefficients whose IMF1, IMF2 and IMF3 correlate respectively with the original signal are indicated, that are 0.5671, 0.5731, 0.5545, and the other IMF4 correlation coefficient is very small, that is 0.0547. So IMF4 is a false IMF to be deleted. We can see the 20Hz, 200Hz characteristic components and the 20Hz modulated frequency components around 50Hz in the right figure after WVD analysis.



**Figure 8. IMFs of the Simulation Signal using EMD Method and their Corresponding WVD Analysis**

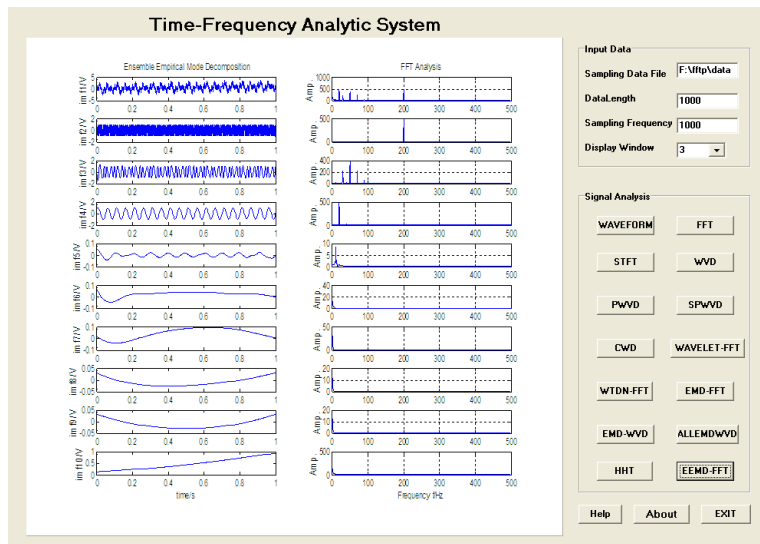


Figure 9 shows the total WVD time-frequency spectrum through adding last each WVD Value of true IMF and the Hilbert-Huang spectrum of the simulation signal respectively. Compared with the two results, HHT indicates more perfectly the feature extraction of the simulation signal than the ALLEMDWVD.



**Figure 9. ALLEMDWVD Analysis and Hilbert-Huang Spectrum**

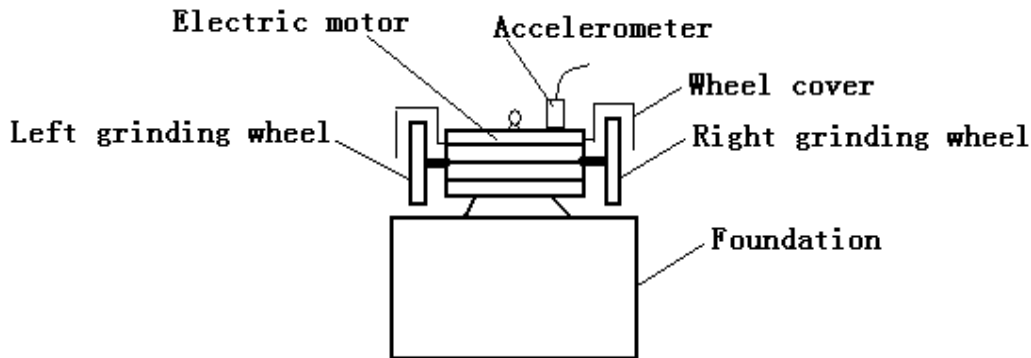
Figure 10 presents ten IMFs using EEMD to decompose the original signal and their spectrums using FFT analysis respectively. In the right figure, the top four spectrums explain clearly the own frequency components of the simulation signal, but the others belong to the false IMF spectrums to be ignored.



**Figure 10. IMFs of the Simulation Signal using EEMD Method and their Corresponding Spectrums**

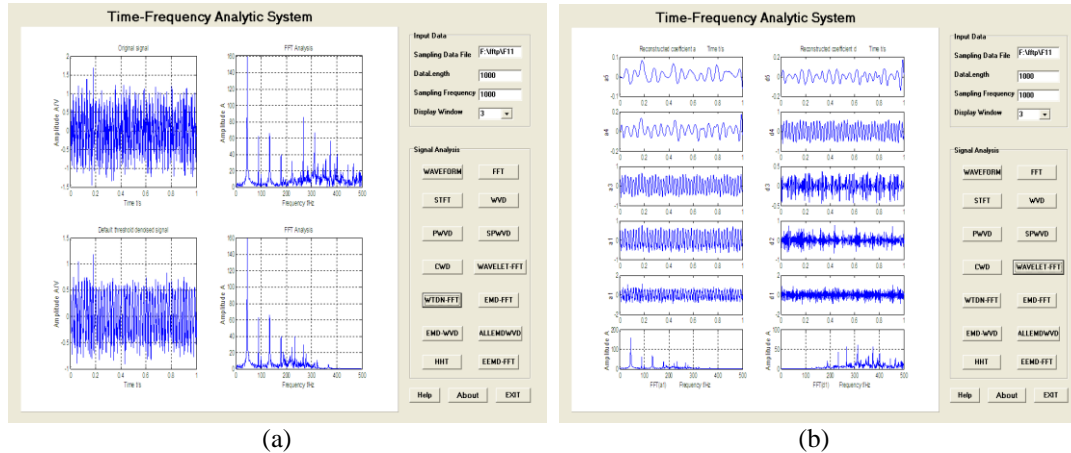
## 5. Experimental Validation

In order to further verify effectiveness of the designed time-frequency analytic system, a test is carried out in a type S3SL grinding machine which runs at a speed 2850 rpm/min (the rotating frequency  $f_0=47.5\text{Hz}$ ) with big vibration and noise (maximum 96.2dB). A vibration signal is picked up from its electric motor shell surface using type YD-12 accelerometers in the vertical direction. A testing system mainly consists of type YD-12 accelerometers, a type DHF-4 charge amplifier with filter, a type PCI2006 data sampling card, a computer and a software of vibration signal continuous large data acquisition and processing. The testing rig is presented as the Figure 11.



**Figure 11. Testing Rig of the Grinding Machine**

See the top of the Figure 12(a), a real time waveform with 1000Hz sampling frequency and 1000 sampling data dots is showed, and its corresponding spectrum using FFT analysis is also displayed. The spectrum explains that  $1f_0-5f_0$  characteristic values are obvious to indicate the sampled signal is modulated by some sine with 47.5Hz frequency multiplication. But bad characteristic information appears in the high frequency scope due to existence of noise. At the bottom of the Figure 12(a), a de-noised signal and its spectrum are presented using wavelet de-noised technology and FFT respectively.  $1f_0-5f_0$  characteristic values evidently emerge independently, on the contrary there exist no high frequency components after de-noising. Figure 12(b) depicts wavelet transform decompositions to the original signal using the daubechies mother wavelet and five orders wavelet decompositions. The two first order reconstruction coefficients  $a_1$  (the low frequency components of the signal) and  $d_1$  (the high frequency components of the signal) are selected to be analyzed by FFT to achieve the corresponding spectrums at the bottom of the Figure 12(b). The left spectrum extracts the signal feature of each frequency multiplication component, and the right one indicates the frequency components of the noise. According to above analysis, the grinding machine signal possesses  $1f_0-5f_0$  characteristic frequencies, especially  $1f_0$  amplitude value is biggest. This concludes that the grinding machine has a serious imbalance fault, particularly a bad eccentricity of the grinding wheel leading to big vibration and noise at the rotating speed [15].



**Figure 12. (a) Wavelet De-noising for the Vibration Signal (b) Wavelet Decomposition**

## 6. Conclusions

A multi-function time-frequency analysis system has been implemented by using mixed programming of Matlab and Delphi based on COM module technology in order to address the issue that all kinds of time-frequency methods are only carried out on Matlab platform with M files which cannot run on Windows Operation System separated from the Matlab environment. A novel combined method that combines with two or three methods together is proposed to perform some time-frequency analysis, leading to not only carrying out own analytic function but also making the results more profound and clearer. New methods will be easily expanded in this system to form a larger system later. This designed system has been employed to analyze a simulation signal and a vibration signal sampled from a grinding machine. The analytic results validate the effectiveness of the system.

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## Authors



**Miaozhong Sun**, he received the B.S., the M.S. degrees in mechanical engineering from Tianjin university of science and technology, Tianjin, China, in 1986, and Northeast university, Shenyang, China, in 1989, respectively. From 1989 to 1991, he was a tutor. From 1991 to 1997, he was a lecturer. From 1997 to now, he was associate professor. He has been working in Tianjin University of science and technology since 1989. His research interests include automotive testing system develop, vibration signal processing and intelligent Virtual Instrument, time-frequency theory and analysis.



**Shihai Cui**, he received the Ph.D. degree in automotive engineering from Beijing Jiaotong University, Peking, China, in 2006. From 2006 to 2011, he was a lecturer. From 2011 to now, He was a associate professor. He has been engaging in teaching in Tianjin University of science and technology since 2006. His research interests include automotive material, automotive safety and automotive part design.



**Yuanli Xu**, he received the Ph. D. degree in automotive engineering from Tianjin University, Tianjin, China, in 2009. From 2011 to now, He was an associate professor in Tianjin university of science and technology. His research interests include engine fuel injection condition and vehicle burning and emission control.