

ORIGINAL RESEARCH ARTICLE

Realization of Spectrum Analysis of Speech Signal Based on

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ABSTRACT

MATLAB is a very powerful engineering and practical software for data analysis and processing. It is very convenient to analyze and deal with it. This paper introduces how to collect the speech signal and voice signal acquisition in MATLAB environment, and analyze the MATLAB of speech signal processing by an example. The basic principle and basic process of texture image analysis based on Fourier transform spectrum are described by MATLAB simulation of sinusoidal texture image and spectral characteristic analysis of sinusoidal texture image. The program is written, and the spatial texture image with ideal sine distribution is obtained, and its spectral characteristics are analyzed. According to the definition of discrete Fourier transform DFT, a method of calculating the amplitude spectrum of discrete signal by DFT is deduced. The effectiveness of the method is verified by MATLAB simulation.

KEYWORDS: MATLAB; spectrum analysis; Fourier transform; speech signal; signal analysis

1. Introduction

1.1. Background

With the advent of the information age and the digital world, digital signal processing has become an extremely important subject and technology field. Digital signal processing has been widely used in many fields such as communication, voice, image, automatic control, medical and household appliances. Any signal has a time domain and frequency domain characteristics, the signal spectrum completely represents the signal, so the signal spectrum is equal to the study signal itself. It is easy to get a deep understanding of the characteristics of the signal usually from the frequency domain of the signal analysis and processing. Therefore, the spectral analysis of the signal is a more important tool in digital signal processing technology [1-3].

In the field of engineering, MATLAB is a language that is favored by program developers. For some complex applications that need to do a lot of data processing and some complex spectrum analysis algorithms, MATLAB is well equipped [4].

1.2. Research significance

Signal processing involves almost all of the engineering technology, and spectrum analysis is a very important means of signal processing. General spectrum analysis is to rely on the traditional spectrum analyzer to complete, expensive, bulky, not easy to carry the engineering and technical personnel. The virtual spectrum analyzer changed the overall design of the original spectrum analyzer, replacing the hardware with software, so that engineers and technicians can use a laptop to the scene can easily complete the signal acquisition, processing and spectrum analysis [5-6].

1.3. The contents of this study

The spectrum analysis of the signal is to use the Fourier analysis method to find the time domain description corresponding to the frequency domain description, from which to find the signal spectrum changes in order to achieve the purpose of feature extraction. The theory and method of Fourier analysis of different signals are introduced in the relevant professional books.

But the actual signal to be analyzed is generally not analytic, the Fourier analysis is very difficult to use the formula directly. TFFT is a Fourier transform of discretization in time domain and frequency domain, suitable for numerical calculation and fast algorithm, a powerful tool for the signal.

DFT and FFT are important aspects of digital signal processing. DFT is the basis of FFT, FFT is a fast algorithm for DFT, in the MATLAB function FFT can be used to calculate the sequence of discrete Fourier transform DFT. Based on this, we first introduce the MATLAB software. Secondly, we give the method of DFT and FFT spectrum analysis based on MATLAB software. The Matlab software method is used to make the design convenient and fast, and the workload is greatly reduced. Finally, the simulation results are given.

This article will focus on the spectrum analysis and design based on MATLAB, including:

- (1) Audio signal spectrum analysis;
- (2) Image signal spectrum analysis;
- (3) Discrete signal / sequence spectrum analysis.

2. Spectrum analysis and MATLAB

2.1. Spectrum analysis technology

2.1.1 Time Domain Sampling Theorem

The time domain sampling theorem gives the constraint condition that the signal is not distorted during the continuous signal sampling. For the baseband signal, the signal sampling frequency is greater than or equal to twice the maximum frequency of the signal. Time domain sampling is a continuous signal into a discrete system suitable for digital system processing. For the continuous signal at interval T sampling, the available discrete sequence is. [7]

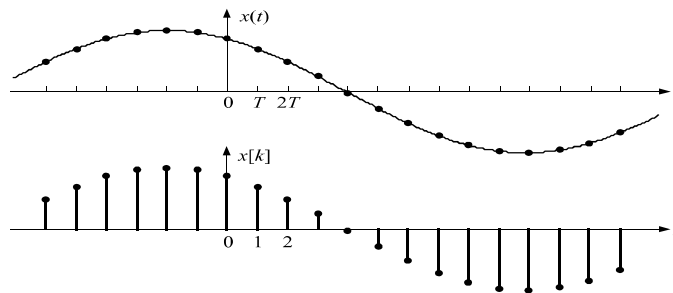


Figure 1. Discrete sequence of continuous signal sampling

If $X[k] = X(kT)|_{t=kT}$ there is a signal between the spectrum $X(t)$ and the $X[k]$ existence of:

$$X(e^{j\Omega}) = \frac{1}{T} \sum_{n=-\infty}^{\infty} X(j(\omega - n\omega_{sam}))$$

Among them, $X(e^{j\Omega})$ the spectrum is $X(j\omega)$, $X[k]$ the spectrum is $X(e^{j\omega})$.

It can be seen that the signal time domain sampling leads to the periodicization of the signal spectrum. $\omega_{sam} = 2\pi/T$ (Rad / s) for the sampling angle frequency, $f_{sam} = 1/T$ for the sampling frequency. The relationship between the digital angular frequency Ω and the simulated angular frequency ω is: $\Omega = \omega T$.

2.1.2 Discrete Fourier Transform (DFT)

The finite - $x(n)$ length sequence of discrete Fourier transform (DFT) is

$$X(k) = DFT[x(n)] = \sum_{n=0}^{N-1} x(n)W_N^{-kn}, \quad 0 \leq n \leq N-1$$

Inverse transformation[8]

$$x(n) = IDFT[X(k)] = \frac{1}{N} \sum_{k=0}^{N-1} X(k)W_N^{-kn}, \quad 0 \leq n \leq N-1$$

2.1.3 Fast Fourier Transform (FFT)

In a variety of signal sequences, the finite length sequence occupies an important position. The finite length sequence can be analyzed using discrete Fourier transform (DFT). DFT not only can well reflect the spectral characteristics of the sequence, but also easy to use fast algorithm (FFT) on the computer for analysis. [9]

The DFT of a finite-length sequence is an isometric sample of its z-transform on a unit circle, or an equidistant sample of the sequence Fourier, and thus can be used for spectral analysis of the sequence. FFT is a fast algorithm for DFT, which is a sub-decomposition of the transformation, making it a combination of several small data points, thereby reducing the amount of computation.

MATLAB provides a series of rich mathematical functions for calculating the discrete fast Fourier transform of data, mainly Fft, Ifft, Fft2, Ifft2, Fftn, Ifftn and Fftshift, Ifftshift and so on. When the length of the processed data is 2, the computational speed is increased by the base-2 algorithm. So, as far as possible to make the data to be processed by the length of 2 or add the zero way to fill the data to make it a power of 2.

Fft function call:

- (1)Y=fft(X);
- (2)Y = fft(X,N);
- (3)Y = fft(X,[],dim)or Y = fft(X,N,dim).

The parameter application of the function Ifft is exactly the same as the function Fft.

2.1.4 Spectrum analysis principle

Time domain analysis can only reflect the signal amplitude with the change of time, in addition to the simple single frequency component of the waveform, it is difficult to clear hint signal of each frequency component of the frequency composition, and size, and spectrum analysis can be a very good solution to this problem. Since frequency information is mainly obtained from the frequency domain, this section mainly introduces the estimation of frequency (period) and the generation of the spectral graph. [10]

1. Frequency, period estimation

For $Y(k\Delta f)$, if when $k\Delta f = f$, Y take maximum $Y(k\Delta f)$, f as frequency estimate, due to the error of the sampling interval, f there is error, the error of the maximum $\Delta f / 2$.

Period $T = 1 / f$.

In principle, you can see that if in the standard signal mixed with noise, using the above method is still able to accurately estimate the original standard signal frequency and cycle, the validation will be made in the next chapter

2. Spectrum

In order to visually represent the frequency characteristic of the signal, the result of the Fourier transform is often represented in the form of a graph, the spectral graph.

So the frequency f is the x-coordinate, so $|Y(f)|$ is the y-coordinate, and you get the amplitude spectrum;

In terms of frequency f , the $\arg Y(f)$ is the vertical coordinate, and you get the phase spectrum;

If you take the frequency f as the x-coordinate, and $\text{Re } Y(f)$ is the y-coordinate, you get the real spectrum;

In the case of f , the frequency f is the y-coordinate, and I can get the imaginary spectrum.

According to the sampling theorem, only the frequency of no more than the $F_s / 2$ signals can be collected correctly, that is the result of the Fourier transform of frequency is greater than the $F_s / 2$ parts is not correct, therefore, not shown in the spectrum. That's the x-coordinate f , the f , the f , the zero, $F_s / 2$

2.2. Introduction of MATLAB

2.2.1 MATLAB software development

MATLAB is the scientific computing system environment for numerical computation and graphic processing by Mathworks corporation [11]. MATLAB is an abbreviation for MATrix LABoratory (MATrix LABoratory). Its first edition (DOS version 1.0) was released in 1984, and after more than a decade of improvement, it now has its Windows 98 / NT version (version 6.1). The new version focuses on the various functions of daily digital processing, including efficient numerical calculations, matrix operations, signal processing and graphical generation. In the MATLAB environment, the user can integrate the program design, numerical calculation, graphical drawing, input output, file management and so on. MATLAB provides a human-computer interaction mathematical system environment, the system is the basic data structure of matrix, the generator matrix object, does not require a specific dimension. MATLAB can save a lot of programming time by using MATLAB compared to program design using c or FORTRAN. In some universities in the United States, MATLAB is becoming to the numerical calculation, algorithm design and verification, and some special matrix computing applications, such as automatic control theory, statistics, digital signal processing (spin-off) time series, etc. The MATLAB system was originally designed by Cleve Moler in FORTRAN, and the algorithms for matrices came from the LINPACK and the EISPACK project. Now MATLAB program is developed with C language MathWorks company, the first hosted by Steve Bangert compilation explanation program development, Steve Kleiman complete graphical capabilities of design, John Little and Cleve Moler sub-modules taking charge of the development of various kinds of mathematical analysis, writing the user guide and most M files. Since its release version 1, there have been many scientific and technical workers to join ATLAB development team, and to form today's MATLAB system made great contributions, MATLAB in the form of goods, only a few years, with its good openness and reliability of the control in the field of original sealed package (UMIST, such as Britain and Sweden's LUND, Germany KEDDC) are eliminated, which based on MATLAB platform to rebuild them. In the 1990s, MATLAB became an internationally recognized standard computing software. By the early 1990s, MATLAB was the dominant figure in numerical computing in 30 international mathematical applications.

2.2.2 Composed MATLAB

The MATLAB system is composed of five main parts.

1. MATLAB language system. MATLAB is a high-level matrix/array language with conditional control, function call, data structure, input and output, object-oriented programming language features. The use of it can be either for small-scale programming, algorithm design and experiment of basic task, also can undertake large-scale programming, development of complex applications.

2. MATLAB environment. This is the general term for the management functions that are improved to the user using MATLAB. This includes the means and methods for managing variable input and output in the workspace, as well as various tools for developing, debugging, and managing M files.

3. A graphic sentence system. This is the basis of MATLAB graphics system, including the complete 2 d and 3 d data graphic and image processing, animation, graphics, and other functions of high-level MATLAB command, also includes the user to control the wild graphics image objects such as low-level MATLAB command, a GUI application and development of a variety of tools.

4. MATLAB mathematical function library. This is the general term for the mathematical algorithms used in MATLAB. The algorithms of all kinds of elementary functions include matrix arithmetic, and matrix analysis.

5. MATLAB application interface (API). This is the MATLAB to provide users with a function library, allows users to use C program in the MATLAB environment or FORTRAN programs, including the caller from MATLAB (dynamic connection), read and write the function of the MAT files. It can be seen that MATLAB is a very powerful system, which is a combination of numerical calculation, graphics management and program development. On top of that, MATLAB has a strong ability to expand, with its system, with a variety of toolkits.

2.3. The summary of this chapter

This chapter introduces the basic principle of spectral analysis, and introduces the development and composition of MATLAB software.

3. Programs and examples

3.1. Voice signal spectrum analysis

Matlab language is a kind of data analysis and processing functions very powerful computer application software, it can sound file conversion into discrete data file, and then take advantage of its powerful matrix capable of handling the data, such as digital filter, the Fourier transform, the time domain and frequency domain analysis, sound playback and analysis of the present and so on. In this paper, the method of the realization of Matlab in speech signal processing is illustrated by analyzing the waveform of speech signal, spectral graph and inverted spectrogram.

The program code:

```
S = wavread (' 1.wav ');
Subplot (3,1,1); The plot (S); Title (' waveform diagram ')
N = size (S);
D = 100;
L = 512;
K = L - d;
T = fix (n/k);
Frame_length = 512;
R = (rectwin (frame_length));
For a = 1: t
N1 is equal to L minus d times a minus 1 plus 1;
N2 = (l-d) * (a-1) + frame_length;
Y = S (n1, n2);
Sf = FFT (y' . * r', 512);
X1 (n1: n2) = sf (1: frame_length);
The end
FFTSIZE = 8000;
Y = zeros (FFTSIZE, 1);
Y is equal to 20 times log of 10.
Subplot (3,1,2); Plot (Y (1:40)), title (' spectrum ');
T1 = length (X1);
T1 = fix (t1 / L);
For I = 1: t1
Z = ifft (X1 ((I - 1) * L + 1: I * L), 512);
Z = real (z. / r);
Y (I - 1) * k + 1: I * k = z (1: k);
end
Subplot (3,1,3); Plot (y), title (' inverted diagram ')
```

3.2. Image signal spectrum analysis

The spectrum of the texture image can be obtained through the discrete Fourier transform (DFT). Using the representation of a spatial texture image, the spectrum of the image, the size of the image is M by N, and the mass check can be calculated by the DFT, and the formula is as follows:

$$F(u, v) = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) e^{-2\pi j \left(\frac{xu}{M} + \frac{yv}{N} \right)}$$

$$u = 0, 1, \dots, M-1; v = 0, 1, \dots, N-1$$

The formula for the energy spectrum can be used:

$$S(u, v) = |F(u, v)|^2$$

Based on the analysis of the texture image analysis of the Fourier energy spectrum, the premise is that the grain has different sine waves. Ideal sinusoidal texture image, it is one of the most typical texture image, discussed below ideal sine distribution analysis of the simulation of texture image and its frequency spectrum characteristics.

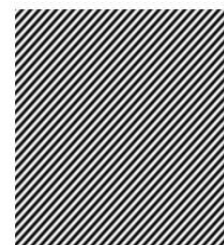
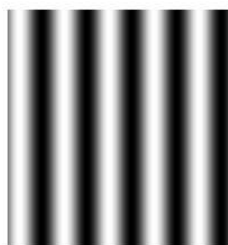
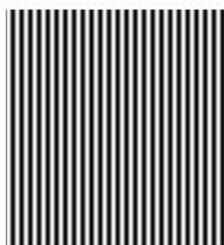
Write the following program has the ideal sinusoidal airspace texture image, A is the amplitude of sine texture, uf0, vf0 respectively (vertical) x axis and y axis direction (horizontal) simulation frequency, M, N, respectively the x, y axis of the sampling points, the Tsu, Tsv sampling interval of x and y, respectively, to facilitate the observation and treatment, Tsu = 1 / M, Tsv = 1 / N, the sampling frequency of x axis and y axis M and N, respectively, so that in the range of 0 ~ 1 airspace of texture image (if consider into the time domain sampling signal, sampling between 0 ~ 1 s).

```
A = 1;
Uf0 = 0;
Vf0 = 25;
M = 200;
N = 200;
Tsu = 1 / M;
Tsv = 1 / N;
R = 0: M minus 1;
C equals 0: N minus 1;
[C, R] = meshgrid (C, R);
G = A * sin (2 * PI * uf0 * R * t.
F = mat2gray (g);
figure
Imshow (f)
```

The output variable g returns in the program is the actual ideal sine function, and f returns the result of the g translation (the value is limited to 0 to 1).

In Matlab, a set of texture images obtained by simulation of the ideal sinusoidal distribution:

The direction or period of the texture in figure 3-2 is different. Which (a) and (b) are distributed in texture in the vertical direction (horizontal direction), (a) the frequency of the y direction is 25 hz, (b) y frequency of 5 hz, namely for (a) (b) diagram is cycle figure 5 times of vertical texture, so within the scope of the entire image (the equivalent of a second) (a) and (b) there are 25 and five cycles, respectively. (c) the graph texture is both x and y and the frequency is 25Hz.



(a) (b) (c)

Figure 2. ideal sinusoidal texture image

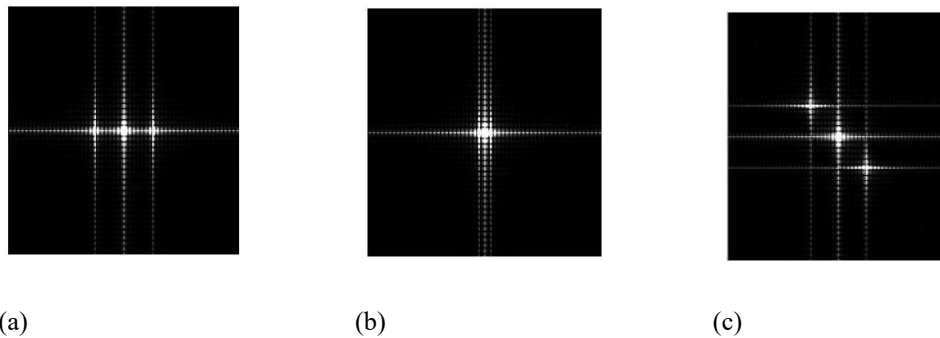
The FFT algorithm is then used to analyze the spectrum of the three images.

Program code:

```
I = imread ('1. Tif');
I = rgb2gray (I);
Imshow (I);
FftI = fft2 (I);
SfftI = fftshift (fftI);
RR = real (sfftI);
II = imag (sfftI);
A = SQRT (RR ^ 2 + II ^ 2);
A = (a-min (A))/(Max (A) -min (min (A))).
```

Figure;

Figure 3-3 for each figure in the corresponding figure of Fourier spectrum energy diagram (in Matlab to perform the FFT (fast Fourier transform), the use of fftshift function adjustment, so that the spectrum of the image the origin (0, 0), from the starting point to the center of the image (M / 2, N / 2)). Can be seen from the figure 3-3: vertical ideal single frequency sine distribution of texture spectrum energy is concentrated in the horizontal direction on the three points of the horizontal single frequency sine distribution of texture spectrum energy is concentrated in the vertical direction of three point; Ideal for a single frequency sine distribution of texture image, its texture direction and its frequency spectrum energy diagram of perpendicular to the direction of point of attachment as shown in figure for figure (b) (c) texture lines rationalize clockwise tilted 45 degrees, the figure medium frequency spectrum energy points also tilted 45 degrees clockwise accordingly; The spectral energy diagram of the superimposed image of vertical texture and horizontal texture is shown in five points of horizontal and vertical direction; Texture cycle is smaller, the corresponding frequency spectrum center point to 0) (central point, namely the frequency the greater the distance, as shown in figure 3-3 (a) texture frequency point the distance to the center of figure 3-3 (b) five times as texture.

**Figure 3.** spectral energy diagram of the ideal sinusoidal texture image

3.3. Discrete signals/sequences

The $x(t) = 1 + 2 \sin(2\pi * 10t) + 3 \sin(2\pi * 15t)$ sampling frequency 100Hz, sampling 100 points, forming discrete signals, using MATLAB for spectrum analysis.

Procedure is as follows:

$N = 100; F_s = 100; T = ((N - 1))/F_s;$

$X_n = 1 + 2 * \sin(2 * \text{PI} * 10 * t) + 3 * \sin(2 * \text{PI} * 15 * t).$

$XK = \text{abs}(x_n, N); F = (0: N / 2) * F_s/N;$

$XK(1) = XK(1)/N$; $XK(2(N/2 + 1)) = XK(N/2 + 1) = XK(N/2 + 1) = XK(N/2 + 1) * 2/N$;
 Stem(f, XK(1:(N/2 + 1))); Axis([-1, N/2, 0, 5]);
 The grid on; Xlabel('f (Hz)'); So, ylabel('|X(f)|');

Program run result:

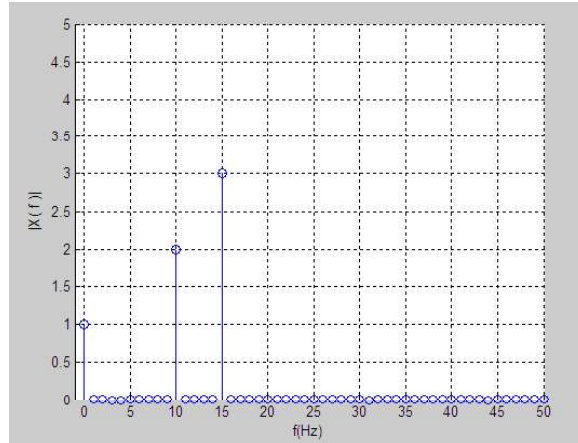


Figure 4. N = 100 amplitude spectrum

As you can see from figure 3-4, the analysis of the DFT method is very consistent with the actual signal, indicating that the method is effective.

However, it is important to note that the discrete Fourier transform in frequency domain is discrete, the restrictions on the fundamental frequency integer times, only get signal K time harmonic amplitude spectrum, and for the K time harmonic spectrum is unable to detect, and because the fence effect and spectral leakage, to other K also has effect on the amplitude of harmonics.

If you change N = 100 from the above program to N = 50, the result is shown in figure 3-5.

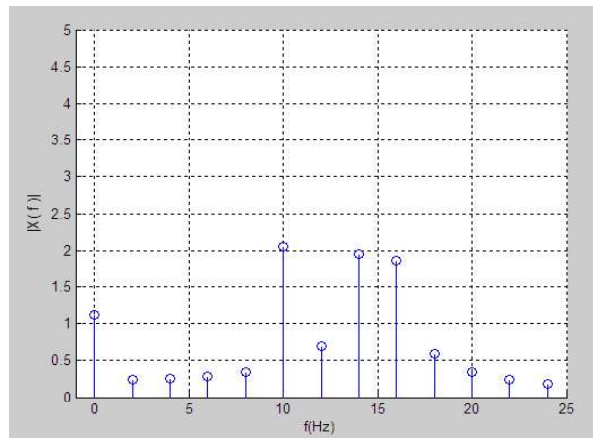


Figure 5. N = 50 amplitude spectrum

Can be seen from figure 3-5, as the base rate is $100/50 = 2$ hz, 15 hz component of $x(t)$ is not detected, there have been other frequency component amplitude error and the fence effect is also one of DFT inevitable problems in the application. To reduce the barrier effect and spectral leakage, can reduce the sampling frequency, increase the sampling points, to reduce the fundamental frequency value, make the line, that miss some of the original spectrum component can be detected, but pay attention to the sampling frequency must meet the requirements of the sampling theorem, increase the sampling points will increase system calculate DFT overhead.

3.4. The summary of this chapter

In this chapter, the spectral analysis of sound signal, image signal and discrete signal/sequence is analyzed by MATLAB, and the results of the spectrum analysis are obtained and the results are analyzed.

4. Conclusions

This paper is based on the basic characteristics of the advanced object-oriented development language MATLAB, and the powerful toolbox function of MATLAB, the preprocessing and spectral analysis of the signal.

(1) MATLAB can be used to analyze the spectrum of speech signals.

(2) The method of spectral analysis can be used to extract the basic characteristics of the texture, such as the orientation characteristic and the period characteristic. Based on the ideal sine distribution of texture image of Matlab simulation and sine texture image spectrum characteristics analysis, for example, describes the texture image based on Fourier energy spectrum analysis of the basic principle and basic process.

(3) Through the method of discrete Fourier transform and Fourier series, the definition of periodic signal clearly $X(k)$ is deduced and the relationship between the signal amplitude, puts forward a kind of effective computing discrete signal amplitude spectrum method/sequence.

References

1. Huang Zhigong. A continuous signal spectrum analysis based on MATLAB [J]. Guangxi Physics, 2009, (03).
2. Liu Xiaobo, Zhou Yunbo. Based on Matlab DFT and FFT spectrum analysis [J]. Shanxi Electronics Technology, 2010, (04).
3. Dong Jingwei, Yu Guangyan. Based on Matlab FFT spectrum analysis and IIR digital filter design [J]. Software Guide, 2008, (10).
4. Zhao Shumin. Based on MATLAB for speech signal spectrum analysis [J]. Jiangxi communication technology, 2010, (01).
5. Zeng Shangcui, Shen Hua, Yu Zhenli. Based on the Matlab signal FFT spectrum analysis and display [J]. Technology Bulletin, 2000, (04).
6. Zeng Xiulian, Cheng Baosheng, Xue-Feng Pan. Continuous time signal spectrum analysis and MATLAB [J]. China Water Transport (academic), 2006 (05).
7. Yang Feng, Su Yuping, Yu Dongju. MATLAB simulation for digital signal modulation and spectral analysis [J]. Computer Learning, 2008, (04).
8. Wang Zhan. The application of spectral analysis techniques in practice [J]. Heilongjiang Technical Information, 2009, (27).
9. Zhao Shumin. Based on MATLAB for speech signal spectrum analysis [J]. Information Communication, 2010, (04).
10. Li Yuanyuan, Xu Yan, Wang Jingyue. The spectrum analysis of digital signal for MATLAB [J]. Communication technology, 2008, (01).
11. Wei Kexin. MATLAB language and automatic control system design. Beijing: Mechanical Industry Press. 2002:1-150