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THE AUTOMATIC IDENTIFICATION OF A DIGITAL SIGNAL BASED ON CYCLIC SPECTRUM

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ABSTRACT

With the continuous development of the software radio technology, the mode of communication signal modulation recognition is becoming an important research direction. The article describes the spectrum of the digital signal modulation recognition method and takes advantage of some of the modulation signal when some modulation signal have the same power spectral density correlation function of the spectrum, but there is a significant difference in spectral correlation function. Low signal-to-noise ratio of the modulated signal can be identified by spectral correlation function. The article has computer simulation of Gaussian noise automatic identification of digital communication signals by the extraction of some of the parameters of the cyclic spectrum.The experimental simulation results show that signal average recognition rates can reach 95% or more, and good practial prospects when the signal-to-noise ratio is not less than 15dB.

Keyword: *Digital communications, Spectral Correlation, Automatic identification*

1. INTRODUCTION

In recent years, the communication signal automatic identification has attracted more and more attention and studied. Its applications will be increasingly widely .In the civilian aspects , the software radio receiver is based on the automatic identification of signal modulation mode; in the military aspects, the signal modulation recognition is one of the core technology of electronic warfare and signal interference[1,2] .

The signal modulation identification method of having existed mainly is divided into two categories. One is based on decision theory [1, 3] and the other is based on statistical pattern recognition method [4]. Due to every parameter of the method of decision theory has the optimal threshold , meanwhile both the parameter extraction and the order of the signal identification will affect the recognition rate parameter extraction .So the signal recognition based on decision theory methods tend to be more limited in real applications. But the statistical pattern recognition method is widely

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used because of its good performance. Cyclic spectrum has a high recognition rate, anti-interference ability and practical advantages so it gets more and more attention.

The paper has six sections and the section 6 is acknowledgment. The section 2 presents the spectral correlation's definition. In section 3, we propose the algorithm of the common digital signal's identification. We present the performance of the modulation identification in the section 4. Section 5 gives a conclusion to the whole paper and needs to solve questions in the future work.

2. ANALYSIS OF THE SPECTRAL CORRELATION

If x(t) is a non-stationary signal and its average is zero, so its time-varying auto-correlation function is defined as:

$$R_x(t;\tau) = E\left\{x\left[t+\frac{\tau}{2}\right]x^*\left[t-\frac{\tau}{2}\right]\right\}. \quad (1)$$

If the statistical properties of $x\left[t+\frac{\tau}{2}\right]x^*\left[t-\frac{\tau}{2}\right]$ are cyclical, its period is T_o. So the time-average of the auto-correlation function is defined as:

$$R_x(t;\tau) = \lim_{N\to\infty}\frac{1}{2N+1}\sum_{n=-N}^{N} x\left(t+nT_o+\frac{\tau}{2}\right)\bullet x^*\left(t+nT_o-\frac{\tau}{2}\right) \quad (2)$$

$R_x(t;\tau)$ has periodicity, so its Fourier series is:

$$R_x(t;\tau) = \sum_{m=-\infty}^{\infty} R_x^\alpha(\tau)e^{j\frac{2\pi}{T_o}mt} = \sum_{m=-\infty}^{\infty} R_x^\alpha(\tau)e^{j2\pi\alpha t} \quad (3)$$

Where α is m/T_o and the Fourier coefficients are:

$$R_X^\alpha(\tau) = \frac{1}{T_o}\int_{-T_o/2}^{T_o/2} R_x(t;\tau)e^{-j2\pi t}dt \quad (4)$$

Expression (2) substitutes expression (4),

$$R_X^\alpha(\tau) = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x\left(t+\frac{\tau}{2}\right)x^*\left(t-\frac{\tau}{2}\right)e^{-j2\pi\alpha t}dt = \left\langle \int_{-T/2}^{T/2} x\left(t+\frac{\tau}{2}\right)x^*\left(t-\frac{\tau}{2}\right)e^{-j2\pi\alpha t}\right\rangle_t \quad (5)$$

Where $R_X^\alpha(\tau)$ is called as cyclic autocorrelation function, the expression $\langle\cdot\rangle_t$ represents time average. We call the frequency α that makes $R_X^\alpha(\tau)\neq 0$ as cycle frequency of the signal. A cyclostationary signal may have many cycle frequency including ZF(zero frequency) and non zero frequency. The ZF corresponds stationary part of the signal and the non zero frequency corresponds cyclic stationary part of the signal.

When $\alpha=0, R_X^0(\tau)$ is autocorrelation function of the cyclostationary signal. When $\alpha\neq 0$, $R_X^\alpha(\tau)$ is period weighted form of $R_x(\tau)$ and is called as periodic autocorrelation function. It is called as cyclic autocorrelation function too. X(t)'s SCF can be obtained by Fourier transforming the cyclic autocorrelation function on as in(6):

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$$S_x^{\alpha}(f)=\int_{-\infty}^{\infty}R_x^{\alpha}(\tau)e^{-j2\pi f\tau}d\tau$$

(6)

$R_X^{\alpha}(\tau)$ substitutes expression (6), we have:

$$S_x^{\alpha}(f)=\int_{-\infty}^{\infty}\lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2}x\left(t+\frac{\tau}{2}\right)x^*\left(t-\frac{\tau}{2}\right)\cdot e^{-j2\pi\alpha t}e^{-j2\pi f\tau}dtd\tau=\lim_{T\to\infty}S_{xT}^{\alpha}(t,f)$$

(7)

Among the expression (7)

$$S_{xT}^{\alpha}=\frac{1}{T}X_T\left(t,f+\frac{\alpha}{2}\right)X_T^*\left(t,f-\frac{\alpha}{2}\right)$$

$$X_T(t,f)=\int_{t-T/2}^{t+T/2}x(\mu)e^{-j2\pi f\mu}d\mu$$

In the front, the article states spectral correlation density function's definition in theory. But we can only calculate discrete spectrum density function in the actual simulation. We calculate it by smoothing time domain and frequency domain smoothing [6].The article utilizes the frequency domain smoothing to calculate the spectral correlation density function of the signal. We have:

$$S_x^{\alpha}(f)_{\Delta f}=\frac{1}{M}\sum_{n=-(M-1)/2}^{(M-1)/2}\frac{1}{\Delta t}X_{\Delta t}\left(t,f+\frac{\alpha}{2}+nF_s\right)X_{\Delta t}^*\left(t,f-\frac{\alpha}{2}+nF_s\right),$$

(8)

$$X_{\Delta t}(t,f)=\sum_{k=0}^{N-1}W_{\Delta t}(kT_s)X(t-kT_s)e^{-j2\pi f(t-kT_s)}$$

(9)

Where $W_{\Delta t}(kT_s)$ is the function of data window; $\Delta f=M\cdot F_s$ is frequency domain smoothing width. M is called as spectral frequency resolution; Δt is the length of time of the data segment, so the cyclic frequency resolution is $1/\Delta t$; $F_s=1/(N-1)T_s$ is frequency increments; $N=\Delta t/T_s$ is length of the sample and T_s is periodically sampled length.

3. THE ALGORITHM OF AUTOMATIC RECOGNITION

According to having read document which calculates the parameter of digital signal recognition modulation and degree of computational complexity, the pros and cons of anti-noise immunity of every parameter, so the following parameters are choosed as identified parameter of the article. The article puts forward a new parameter to recognise BPSK and QPSK, meanwhile it is tested and verified its excellence by software simulation. We suppose that the pending identification of the digital modulation signal sample set is {2ASK、4ASK、2FSK、4FSK、BPSK、QPSK} in the article. The signal recognition step is in the following:

(1) To the normalized cyclic spectrum amplitude values for each axis as the object of study, we extract the cyclic spectral amplitude envelope of variance of $S_x^{\alpha}(0)$ and $S_x^{\alpha}(f_c)$, then they are taken as the parameter of recognition between classes. So they can put the digital modulation signal sample set into {2ASK、4ASK}、{2FSK、4FSK}、{BPSK、QPSK}.namely:

$$M_i=1/\sigma_i,\quad i=1,2 \qquad (10)$$

Where σ_i $(i=1,2)$ represents two-section cyclic spectrum amplitude envelope variance of $S_x^{\alpha}(0)$ and $S_x^{\alpha}(f_c)$ respectively. So we can make use of the parameter M_1 and t_1 that it is

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the reference threshold of M_1 dividing the digital modulation signal sample set into {2FSK、4FSK} and {2ASK、4ASK、BPSK、QPSK}.Meanwhile we can make use of the parameter M_2 and t_2 that it is the reference threshold of M_2 dividing the digital modulation signal sample set into {2ASK、4ASK} and {BPSK、QPSK}.So the parameter M_1 and M_2 can put the digital modulation signal sample set into {2ASK、4ASK}、{2FSK、4FSK}、{BPSK、QPSK}.

(2) To {2ASK、4ASK}, we can distinguish them by calculating the standard deviation of the absolute value of $a_{cn}(n)$ that it is the signal's normalized instantaneous amplitude of the center. And is defined as:

$$M_3=\left\{\frac{1}{N}\left[\sum_{i=1}^{N}a^2{}_{cn}(i)\right]-\left[\frac{1}{N}\sum_{i=1}^{N}|a_{cn}|\right]^2\right\}^{1/2} \tag{11}$$

On expression (11) $a_{cn}(n)=\frac{a(n)}{m_a}-1$, $m_a=\frac{1}{N}\sum_{i=1}^{N}a(i)$. We can distinguish two signals by comparing the parameter M_3 and its reference threshold t_3.If $M_3>t_3$, we can judge the signal as 4ASK; If not the signal is 2ASK.Figure 1 illustrates the simulation of the parameter M_3.

(3) Due to the differences of the number of peaks and margin, so the normalized mean of the cycle amplitude envelope must be different. We make use of the differences of the $S_x^{\alpha}(0)$'s amplitude envelope's mean to distinguish the signals: 2FSK and 4FSK. We have:

$$M_4=1/u \tag{12}$$

Where u is the amplitude envelope's mean of $S_x^{\alpha}(0)$.By comparing the parameter M_4 and its reference threshold t_4, we can distinguish 2FSK and 4FSK.If $M_4>t_4$, the signal is 2FSK. Otherwise the signal is 4FSK. Figure 2 illustrates the simulation of the parameter M_4.

(4) In theory, the recognition of the BPSK and QPSK is very hard. Because their function of power spectral density are similar and feature are approximate. Meanwhile the number of spectral peaks of them is zero and $S_x^{\alpha}(f)$'s the biggest decline in the normalized value is small on the f-axis. According to having read document the about the parameter that distinguish the two signals is very perplexed. The article makes use of the differences that is every signal's cyclic spectrum 3D map contours simulation figure and the BPSK and QPSK are especially different. So we can observe the signals' cyclic spectrum by the function "contour" in the Matlab and the parameter M_5 regards the number of dots in the cross-sectional view. The Figure 3 and Figure 4 represent respectively the three-dimensional map of cyclic spectrum of BPSK and QPSK and the Figure 5 and Figure 6 illustrate separately the sectional view of BPSK and QPSK by the function "contour".

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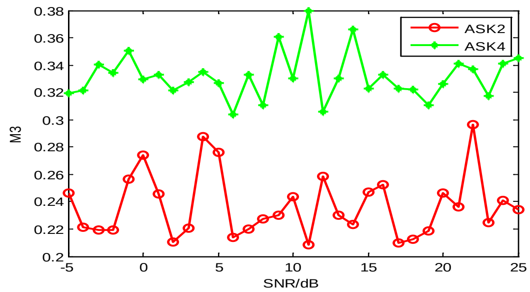

Figure1The simulation of the parameter M_3

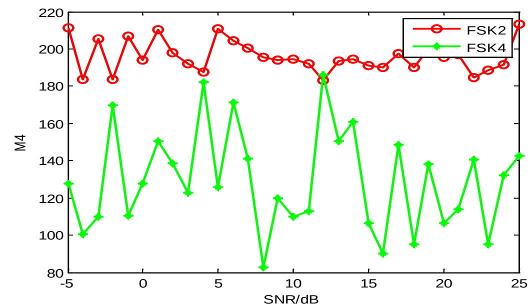

Figure 2 The simulation of the parameter M_4

The parameter M_5 of BPSK and QPSK are obviously different from the Figure 5 and Figure 6.When M_5 is four, the signal is judged as BPSK. When M_5 is two, the signal is judged as QPSK.

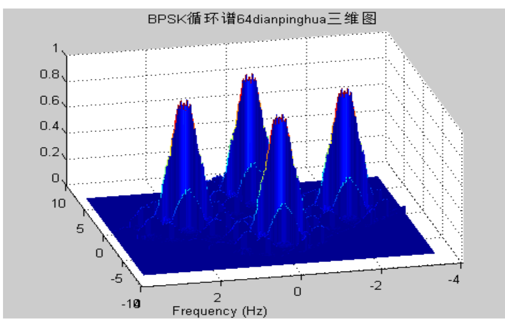

Figure 3 Three-dimensional map of BPSK

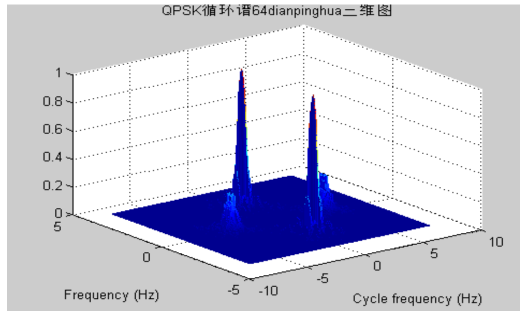

Figure 4 Three-dimensional map of QPSK

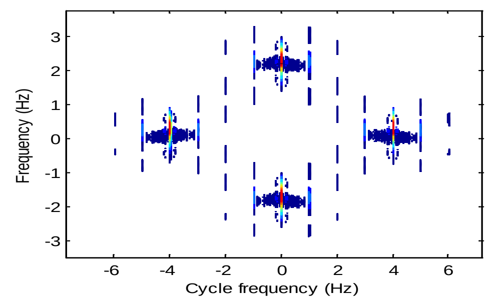

Figure 5 Cross-sectional view of the BPSK

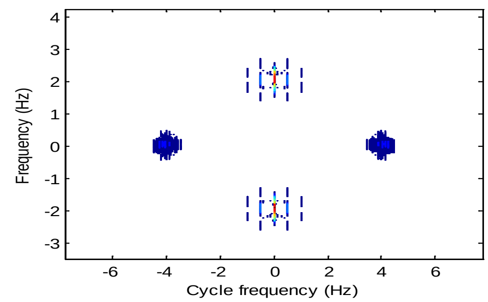

Figure 6 Cross-sectional view of the QPSK

Table 1 Common digital signal modulation type automatic recognition simulation results(%)

$\frac{S}{N}$ (dB)	Modulation type					
	2ASK	4ASK	2FSK	4FSK	BPSK	QPSK
5	93.5	93	85	85	92	91
10	94.5	94.5	89	89.5	96.5	94.5

15	95	100	94	98	98.5	94.5
20	96	100	95	98.5	98.5	95

4. ANALYSIS OF PERFORMANCE

The simulation environment of the article is in the Matlab 2011 and the digital modulation signal sample set is {2ASK、4ASK、2FSK、4FSK、BPSK、QPSK}.The parameter of simulation: carrier frequency is 200K, symbol rate is 10KB/s, the sampling frequency is 800K, the channel noise is Gaussian white noise, the sampling points is 1024.For simulating we used different SNRs varying between -5dB and 25dB and every 5dB produces 30 samples to simulate and identify. The result of modulation recognition is shown in table 1. According to the table 1: the signal automatic identification rate can reach above 96% when the SNR is 15dB and the signal automatic identification total rate can still reach 93% when the SNR is 10dB.The identification rate is improved to compare with the reference [9],especially in BPSK and QPSK.

5. CONCLUSION

This paper presents a recognition which is based on the SCF's feature as a solution to the

Problems of common digital modulation signals, the identification rate is improved especially in the recognition of BPSK and QPSK. The spectral correlation is a characteristic property of the cyclostationary and spectral correlation function is a popularization of the conventional power spectral density function. Then the power spectral density is only a special case of spectral correlation function theory. To signal's recognition of spectral correlation, the parameter's selection is the most important. Meanwhile its stability, its noise immunity, its calculation's complexity, all is recognition's emphasis and difficulty. They are needed to study thoroughly, meanwhile how to improve the speed of program running and how to reduce the amount of computation of the cyclic spectrum all are needed to optimize. These are practical research directions to real-time identification.

6. ACKNOWLEDGEMENT

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