Eng Int Syst (2021) 4: 217–223

Engineering
Intelligent Systems

Automatic Recognition Method of Digital Communication Signal Under Strong Electromagnetic Interference

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In the current automatic recognition method of digital communication signals based on entropy features, approximate entropy and norm entropy constitute an eigenvector to achieve signal recognition. Without signal filtering, it takes longer time for feature extraction, the recognition accuracy of signal is low, and the energy consumption of signal recognition is high. An automatic method for recognising digital communication signals based on complex features is proposed in this paper. The median filter and a posteriori Wiener filter are used to filter the digital communication signals in the presence of strong electromagnetic interference. The signal denoising result is applied to enhance the digital communication signal, achieving further separation of signals. Meanwhile, the dimensionality of the signal is reduced and the result of this dimensionality reduction is substituted into digital communication signal recognition, and the automatic recognition of digital communication signals under strong electromagnetic interference is achieved. Experimental results show that the proposed method can enhance the signal filtering effect, improve the efficiency and accuracy of signal recognition, reduce the energy consumption of recognition, and has strong reliability.

Keywords: Strong electromagnetic interference; digital communication signals; automatic identification

1. INTRODUCTION

Electromagnetic interference (EMI) is an electronic noise that interferes with the cable signal, thereby reducing its integrity. EMI is usually generated by electromagnetic radiation sources such as motors and machines [1]. Electromagnetic interference is an electromagnetic phenomenon that was discovered long ago, almost simultaneously with the phenomenon of electromagnetic effect. In 1981, British scientists published an article on interference, marking the beginning of the research on interference [2]. In 1989, the British Post Office researched the problem of interference in communication, so that the research of interference entered the engineering and industrialization domains [3]. Digital communication is used to transmit messages with the digital signal as the carrier, or the communication mode of the digital carrier modulated by a digital signal and then transmitted [4]. It can transmit digital signals such as telegraph and digital data, and also analog signals such as voice and image after digital processing. It is the transmission of messages in digital form or the modulated carrier signals in digital form. The conventional telephone and television belong to analog communication [5]. The analog signals of telephone and TV are digitalized and then modulated and transmitted by digital signals, that is, digital telephone and digital television[6]. The data communication between computer terminals is digital

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communication because the signal itself is a digital form. The recognition of digital communication signals under strong electromagnetic interference has become a major problem for experts and scholars in this field [7]. To address this problem, several researchers have conducted in-depth analyses.

Xue et al. [8] researched the role of the clustering method in signal modulation recognition to address the problem of avoiding inter-symbol interference in short-wave communication. A classification method using breadth-first search neighbor (BFSN) clustering to process the feature of cyclic statistics is proposed. In this method, the feature peak value of the cyclic statistics is considered as the input object of clustering. Through BFSN clustering analysis, the singularity peaks caused by delay signal and noise are eliminated, and the effect of inter symbol interference caused by multipath effect is overcome. Then automatic recognition of six modulation signals such as 2FSK, 4FSK, BPSK, QPSK, π/4-QPSK, and 8PSK is realized. Experimental results show that although the feature parameters extracted by the clustering method have a strong ability to suppress multipath interference, the recognition accuracy is low [9]. In this paper, we propose an automatic method for recognising digital communication signals based on complex features under strong electromagnetic interference. The details of the process are given below.

2. AUTOMATIC RECOGNITION METHOD OF DIGITAL COMMUNICATION SIGNAL UNDER STRONG ELECTROMAGNETIC INTERFERENCE

2.1 Digital Communication Signal Filtering

To filter the digital communication signal, the discrete form of the signal must be determined, which is obtained by

$$s(k) = \sum_{i=0}^{\infty} A_i g(k - i * T_b) + n(k) \tag{1}$$

where A_i is the level value of the information symbol, $g(k - i * T_b)$ is the symbol pulse waveform, which is rectangular when the signal bandwidth is not limited, T_b is the symbol width, $n(k)$ is the additive noise.

Before automatic classification, in order to eliminate as much as possible the influence of noise on the classification process, digital filtering is needed for communication signals [10]. The filtering method is divided into linear filtering and nonlinear filtering. For signal reconnaissance, the commonly-used linear filters include mean filter, posteriori probability Wiener filter, and wavelet filter. Generally speaking, the edge of the digital communication signal contains more important information than does the flat part. Hence, with linear filter processing, although the noise is suppressed, the loss of the high frequency component leads to the blurred edge of the signal, which is not conducive to the recognition and classification of the signal. In the nonlinear filtering method, the median filter, the near mean filter, the Lee filter, and the gradient reciprocal weighted filter can protect the edge of the signal while filtering the noise, so that it is not blurred [11]. The method of nonlinear filtering is more suitable for the denoising of digital communication signals, enabling a more effective identification of signals.

In this paper, the median filter and the posteriori Wiener filter are used to filter the digital communication signals under strong electromagnetic interference. The main properties of the median filter allow it to protect the edge of a signal and make it unambiguous. When the width of the window is, $2N + 1$ the pulse width greater than N in the signal sequence will be cleared by median filter. For noise sequence, assume the input $n(k)$ satisfies independent distribution (i, i, d) and has the same distribution function $F(x)$. When the window width is $L = 2N + 1$, the distribution function of the output sequence distribution function is given by

$$F_y(x) = \sum_{i=N+1}^{L} C_i^L \tag{2}$$

and the probability density function is given by

$$f_{n'}(x) = LC_N^{L-1} f(x) \tag{3}$$

where $F_y(x)$ is the distribution function value, C_i^L is the probability function, and $f(x)$ is the probability density function of the input signal. When $L \to \infty$, $f_{n'}(x)$, obeys the normal distribution with zero mean and the variance σ_m^2, where $\sigma_m^2 = 1/[4Lf^2(a)]$ and the constant a satisfies $F(a) = 1/2$. This characteristic of the median filter helps to achieve signal classification. Compared with the median filter, the near mean filter has a better effect on Gaussian white noise suppression, although the computation is heavy. Therefore, the median filter is used in this paper.

When the filter is used to filter the digital communication signal under strong electromagnetic interference, the width L of the window must be determined first. Assume the system sampling rate is f_s, the relationship $N = (L - 1)/2 < f_s \cdot T_b$ should be satisfied, and then

$$L < 2f_s \cdot T_b + 1 \tag{4}$$

Thus, according to the symbol width T_b and the above equation, the signal can be filtered and the signal quality can be improved.

In a digital communication network, the transmitted information is often required to form a frame structure according to a certain protocol, such as the physical layer structure defined by the 802.11 protocol cluster of the wireless LAN [12–13]. During communication, the frame structure remains unchanged in the short term, and the intercept receiver can acquire data approximately at the beginning of a frame using the energy detection method. Signal sampling technology can also be used to start sampling for hopping and DSSS systems at a certain frequency hopping point. For multiple sets of the collected data at the beginning of a frame, a posteriori Wiener filter can be used to improve SNR. Assume the same type of the intercepted digital communication signal has K groups, and each group has N samples. Hence, the average power spectrum of the K groups of signals is given by

$$E\{\bar{P}_s(f)\} = S(f) + N(f) \tag{5}$$

where $S(f)$ and $N(f)$ are the power spectrums of signal and noise. The power spectrum of the average value of the K groups of samples is given by

$$E\{P_s - (f)\} = S(f) + N(f)/K \tag{6}$$

Then the filtering result of the posterior filter of the K groups of signal samples is given by

$$H(f) = \frac{S(f)}{S(f) + N(f)/K} \tag{7}$$

According to the filter, the signal-to-noise ratio can be improved, and the parameters of digital communication signals under strong electromagnetic interference can be automatically identified under any conditions.

2.2 Automatic Recognition of Digital Communication Signal under Strong Electromagnetic Interference Based on Complex Features

In the automatic recognition of digital communication signals based on complex features under strong electromagnetic interference, signal enhancement is achieved by filtering the result given in Section 2.1 to improve the accuracy of signal recognition. To achieve signal enhancement, the dimensionality of the signal is reduced, the operational complexity of signal recognition process is decreased, and the number of steps required for signal recognition is reduced.

The detailed process of signal enhancement based on signal filtering is described as follows:

The filtered result $H(f)$ obtained in Section 2.1 is composed of a $L' \times M'$ sampling sequence A' according to the digital communication working cycle, where L' is the sampling points of a cycle and M' is the number of the cycles. Singular value decomposition is used to obtain the singular value spectrum $\{\varepsilon_i'\}$ of the sampling sequence A'. Singular value spectrum is a kind of signal division rule in time domain. Singular value spectral entropy h'' is defined by

$$h'' = \frac{\sum_{i=1}^{L'\times M'} \log q_i''}{\{\varepsilon_i'\}} \cdot A' \cdot H(f) \tag{8}$$

where q_i'' is the ratio of the ith singular value to the entire signal spectrum.

According to Eq. (8), the discrete Fourier transform of signal y_i'' is used to obtain the signal intensity $Y''(w)$. Then the signal power spectrum $a''(w)$ is expressed as

$$a''(w) = \frac{1}{4\pi}|Y''(w)| \cdot h'' \tag{9}$$

When the signal is transferred from the time domain to the frequency domain, the energy is conserved. Then

$$\sum a''(w)\Delta T'' = \sum |Y''(w)|^2 \tag{10}$$

where $\Delta T''$ is the conservation factor. Eq. (10) represents the conservation of energy when digital communication signals are converted from the time domain to the frequency domain under strong electromagnetic interference.

The power spectral entropy h_f' of a signal is a criterion for signal division in the frequency domain, which is defined by

$$h_f' = -\sum_{i=1}^{L'\times M'} q_i'' \log q_i'' \tag{11}$$

Eq. (11) can be used to calculate the time-frequency information entropy, which is given by

$$E(a''(w)) = \frac{\int_{-\infty}^{+\infty} |e(c'', d'')|^2}{h_f'} \tag{12}$$

where $e(c'', d'')$ is the wavelet coefficient, which represents the energy of the signal in the local time-frequency domain. According to the calculation of signal time-frequency information entropy, the enhancement result of digital communication signals under strong electromagnetic interference can be obtained as

$$h_{we} = -\frac{\sum q_i'' \log q_i''}{E(a''(w))} \tag{13}$$

where h_{we} is the result of an enhanced digital communication signal.

After obtaining the result of signal enhancement, rough set is used to reduce the initial signal and the time consumption of signal recognition and extraction.

Generally speaking, the number of initial features of a digital signal is usually large under strong electromagnetic interference. For example, for 4-level signal enhancement decomposition, 4 times sub-segments are processed four times to obtain 64 bands of local energy features. Feature dimensionality reduction helps to achieve higher signal recognition efficiency. All the components in the initial feature sequence are mapped to the attributes of the information system. Then, the rough set method is used to complete attribute reduction, so as to achieve feature reduction [14–15]. It is noted that the local energy of the frequency band in the initial feature sequence is continuous data. It must be normalized before the rough set method is applied; this process can be completed by the method based on attribute clustering.

The enhanced initial feature sequence information data set is discretized to form a signal system $\{u'', q''', v'', F''\}$, where u'' is the set of all objects in the signal set, q''' is the set of conditional attributes and decision attributes, v'' is the set of attribute values, and F'' is the mapping of the object in u'' and the value in v''.

In rough set theory, assume $Ind(l'')$ is an undiscernible relation on u'', where $l'' \subseteq q'''$ and $q_i''' \in l''$. If $Ind(l'') = Ind(l'' - \{q_i'''\}) \cdot h_{we}$, q_j''' is the omission attribute in l''. That is to say, when the attribute q_j''' is removed from l'', the remaining attributes can keep the same classification generated by l'', otherwise q_j''' is the necessary attribute of l''. If every attribute in l'' is a necessary attribute, it is called l'' independent, that is, classification on l'' must be made up of all attributes independently. If $z'' \subseteq l''$ is independent and $Ind(z'') = Ind(l'')$, z'' is called a reduction of l'', denoted as $red(z'')$. The intersection of all the reductions of l'' is called as the kernel of l'', denoted as $core(l'')$, that is, $core(l'') = \cap red(z'')$.

According to the basic concept of attribute reduction, the following definitions can be further given.

Assume $\{u'', q''', v'', F''\}$ is a signal system, $Ind(l'')$ is an undiscernible relation on u'', $z'' \subseteq l'' \subseteq q'''$. $q(l'')$ and $q(z'')$

are the classification results of the attribute sets l'' and z'' on u'' m, respectively. Assume the similarity between $q(l'')$ and $q(z'')$ is $cs(q(l''),\ q(z''))$. According to Eq. (14), the final reduction value is obtained.

$$cs(q(l''), q(z'')) = g_1 \cdot \frac{(q(l'') \cap q(z''))}{(q(l'') \cup q(z''))} + g_2 \cdot \frac{(q(l'') \cap q(z''))}{q(l'')} + g_3 \cdot \frac{(q(l'') \cap q(z''))}{q(z'')} \tag{14}$$

where $g_1,\ g_2$ and g_3 are the weights of the support, the confidence, and the inclusion degree of $q(l'')$ relative to $q(z'')$. If $cs(q(l''), q(z''))$ is larger than the given threshold $\vartheta,\ z''$ is called as a reduction of l'', denoted as $red(z'')$. This reduction can effectively reduce the energy consumption of signal recognition.

Using the above reduction results, the automatic recognition of digital communication signal under EMI is realized. The reduction result $red(z'')$ is reconstructed, which is the key to the extraction of effective digital communication signal. The detailed steps are shown as follows.

Assume the reduction result $red(z'')$ is a signal time sequence $\{k''(i)\}$ with the length of $L'' + 2$, then

$$\iota(k'') = \frac{|\{k''(i)\} - \{k''(i+1)\}|}{cs(q(l''), q(z''))} \tag{15}$$

where $\iota(k'')$ is a new sequence. Eq. (15) can further improve the automatic recognition accuracy of digital communication signal under strong electromagnetic interference.

$\iota(k'')$ is quantized and encoded. Assume the quantization level is $\eta'',\ b''' = \max\ \iota(k'')$. The $\iota(k'')$ is divided into L'' layers in the interval of $(0, b''']$. Then

$$\begin{cases} \rho(k'') = 1,\ \text{if} \frac{b'''}{L''} < M\iota(k'') \\ \rho(k'') = 0,\ \text{if}\ \iota(k'') = 0 \end{cases} \tag{16}$$

Based on the above, a reconstructed digital sequence $\rho(k'')$ with L'' symbols is obtained.

According to the obtained $\rho(k'')$, the complexity feature $v(L'')$ of digital communication signal under strong electromagnetic interference is defined by

$$v(L'') = \frac{\rho(k'') \log(L'')}{L''} \tag{17}$$

The result obtained with Eq. (17) is the automatic recognition result of digital communication signals based on complex features under strong electromagnetic interference.

3. EXPERIMENTAL RESULTS AND ANALYSIS

To verify the proposed method, an experimental platform is set up with Simulink. An actual satellite burst signal is used as the source of experimental data. The signal data contain 40000 samples, the sampling frequency is 448 kHz, 20000 points are processed simultaneously, and the noise is Gaussian white noise. The proposed method is verified is this experimental environment.

The experimental indexes include:

(1) The filtering effect of digital communication signal under strong electromagnetic interference.

(2) The time required for feature extraction of digital communication signal under strong electromagnetic interference.

(3) The recognition precision of a digital communication signal under strong electromagnetic interference.

(4) The energy consumption of digital communication signal recognition under strong electromagnetic interference.

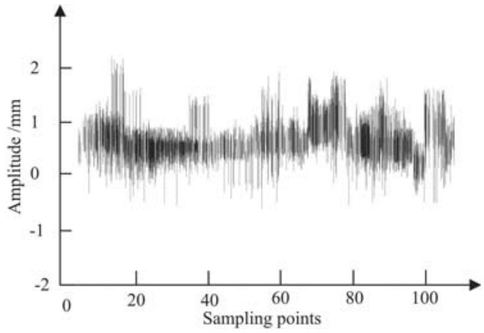
Fig. 2 shows the waveform of the digital communication signal under a strong electromagnetic interference. The locations of the feature points of the digital communication signal are marked with white crosses. The feature points are extracted by different methods to observe the extraction time required by the different methods.

In Fig. 3, the noise signal under strong electromagnetic interference is marked with the pentagram, and the digital communication signal under strong electromagnetic interference is marked with a six-pointed star. The digital communication signal is identified by different methods to observe the accuracy of each one.

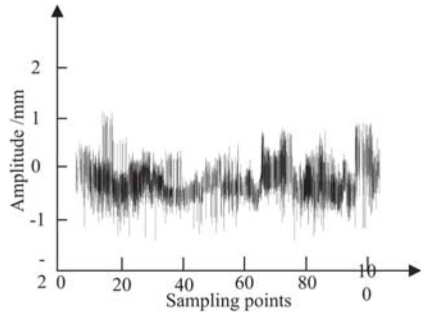
By comparing the energy consumption of different methods, we can verify the automatic identification method of communication signals based on complex features in the presence of strong electromagnetic interference.

The analysis of the experimental results shows that the proposed method has definite advantages over methods reported in the literature in terms of digital communication signal filtering under the strong electromagnetic interference, signal feature extraction, and signal recognition accuracy. In this paper, in the process of signal recognition, through the analysis of the current filtering method, it is known that the current filtering methods are generally divided into linear filter and nonlinear filter. For signal reconnaissance, the commonly-used linear filters include a mean filter and a posteriori probability Wiener filter. For the method of linear filter processing, although the noise is suppressed, the loss of the high frequency component leads to the blurred edge of the signal, which is not conducive to its recognition and classification. However, the median filter in the nonlinear filtering method not only filters the noise, but also protects the edges of the signal. In order to recognize the signal effectively, the denoising processing of the digital communication signal is combined with a median filter and a posteriori Wiener filter to achieve efficient filtering. It not only filters out the noise under strong electromagnetic interference, but also effectively improves the efficiency and accuracy of signal recognition.

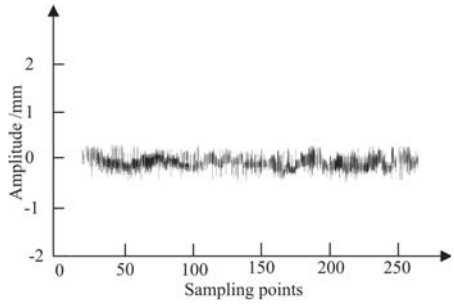
In the automatic recognition method of digital communication signal under strong electromagnetic interference based on complex features, signal enhancement is used to further improve the accuracy of signal recognition. Signal recognition energy consumption is reduced by decreasing the dimensionality of the signal. The proposed method, through signal filtering, enhancement, and dimensionality reduction, can effectively solve the problems existing in the current related methods and lay the foundation for the development of this field.



(a) Experimental model



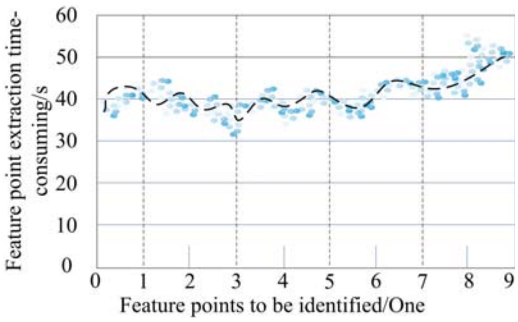
(b) Signal filtering effect of breadth-first search neighbor clustering method



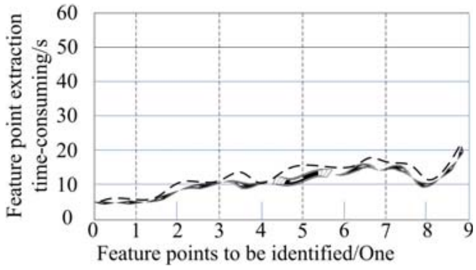
(c) Signal filtering effect of complex feature-based method

Figure 1 Comparison of Filtering Effect Between Different Methods.

(a) Experimental model



(b) Time consumption of breadth-first search neighbor clustering method



(c) Time consumption of complex feature-based method

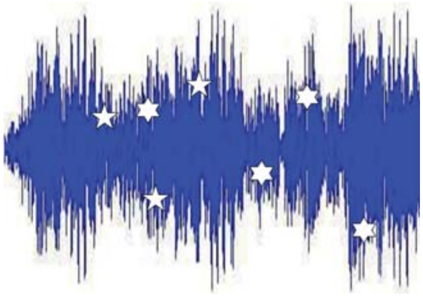
Figure 2 Comparison of Feature Extraction Time Required by Different Methods.

4. CONCLUSIONS

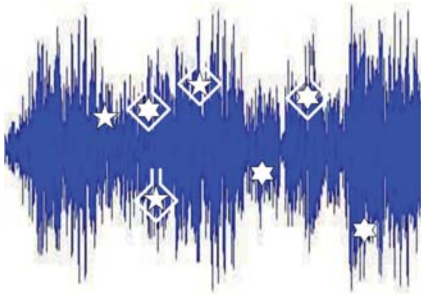
In this paper, we have conducted a useful exploration in the research field of digital communication signal recognition in the presence of strong electromagnetic interference. However, much work remains to be done in future particularly in regard to finding an efficient feature selection method and designing a high-performance classifier. There are two specific problems that require further research:

(1) how to extract the specific physical meaning of an automatic identification method and guide the separation and recognition of communication signals; and

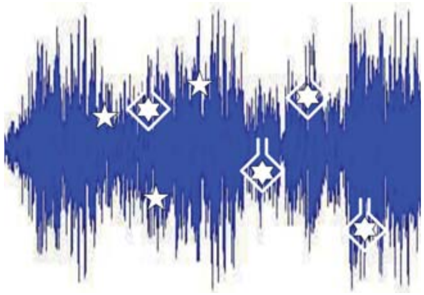
(2) how to apply the automatic modulation recognition results of the digital communication signal to the research of multi-carrier modulation recognition.



(a) Experimental model

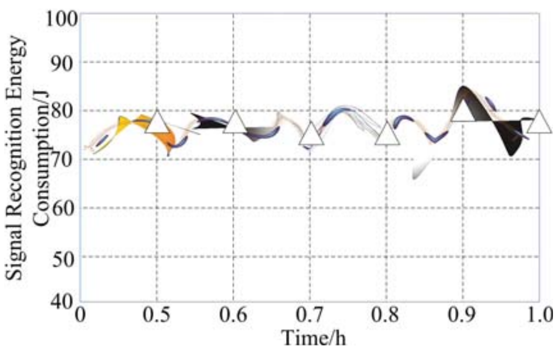


(b) Recognition precision of breadth first search neighbor clustering method

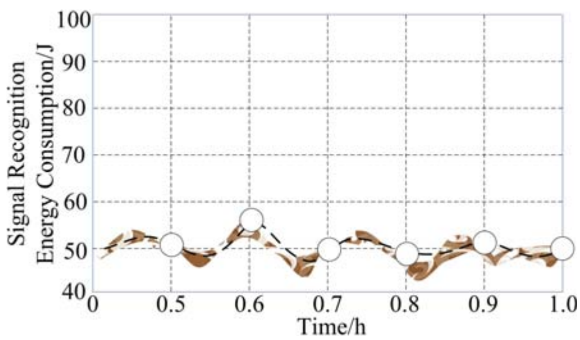


(c) Recognition precision of complex feature-based method

Figure 3 Comparison of Signal Recognition Precision of Different Methods.



(a) Energy consumption of signal recognition based on breadth first search neighbor clustering



(b) Energy consumption of signal recognition based on complex features

Figure 4 Comparison of Energy Consumption of Signal Recognition Between Different Methods.

The rapid development of digital technology has made possible its application to a wide range of real-life situations. Hence, future research is very worthwhile.

ACKNOWLEDGEMENTS

This study was supported by the Henan Science and Technology Research Project (172102210606) and other key scientific research projects of Henan higher education institutions (17B520040).

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