Blind Recognition of (2,1,m) Convolutional Code Based on Simulated Annealing Algorithm

Jianxiong Wang [1,a], Limin Zhang[1,b] ,Zhao-Gen ZHONG[1,c]

[1]Department of Electronic Information Engineering, Naval Aeronautical and Astronautical University, Yantai, 264001, China

[a]xiong3339509@163.com, [b]iamzlm@163.com, [c]zhongzhaogen@163.com

Keywords: simulated annealing algorithm; convolutional code; blind recognition

Abstract. For the blind recognition problem of $(2,1,m)$ convoluntional code, a new method based on simulated annealing algorithm is proposed. Firstly, the mathematical model is given based on code features. Then the basic principle and realization process is described in details, also the method to choose parameters is given. Finally, the performance is simulated by Monte Carlo method. Simulation results show the excellence of the method, and the recognition of $(2,1,m)$ convolutional code can be easily achieved even when bit error rate is as high as 10^{-2}.When compared with other methods, the algorithm's performance and computational complexity reach a compromise.

Introduction

In digital communication, channel coding is often used to improve the reliability of information transmission. For its simplicity and compilation advantages, convolutional code is often used in satellite communication and deep space exploration. Therefore, it's of great significance to address the identification blind recognition of convolutional code.

Current identification methods of convolutional codes are all have some disadvantages: Gaussian elimination[1] and Euclidean algorithm[2,3] can only works in low error rate conditions; Matrix analysis method[4,5] requires a large amount of data; Walsh-Hadamard transform method[6] becomes very complex with the increase of encoding memory. Thus, an effective method which is based on simulated annealing algorithm is proposed.

Identification method based on simulated annealing algorithm

For $(2,1,m)$ convolutional codes, the coding equation can be expressed as

$$\boldsymbol{V}(D)=\boldsymbol{u}(D)\boldsymbol{G}(D) \tag{1}$$

where $\boldsymbol{u}(D)$ is information sequence, $\boldsymbol{V}(D)$ is codeword sequence, $\boldsymbol{G}(D)$ is generator matrix, and

$$\boldsymbol{u}(D)=u_0+u_1D+\mathbf{L}+u_jD+\mathbf{L} \tag{2}$$

$$\boldsymbol{V}(D)=\left[\boldsymbol{v}^{(1)}(D)\quad \boldsymbol{v}^{(2)}(D)\right] \tag{3}$$

$$\boldsymbol{v}^{(i)}(D)=v_0^{(i)}+v_1^{(i)}D+\mathbf{L}+v_j^{(i)}D+\mathbf{L},i=1,2 \tag{4}$$

$$\boldsymbol{G}(D)=\left[\boldsymbol{g}^{(1)}(D)\quad \boldsymbol{g}^{(2)}(D)\right] \tag{5}$$

$$\boldsymbol{g}^{(i)}(D)=g_0^{(i)}+g_1^{(i)}D+\mathbf{L}+g_m^{(i)}D^m,i=1,2 \tag{6}$$

Let $\boldsymbol{H}(D)$ be the parity check matrix, then

$$\boldsymbol{G}(D)\boldsymbol{H}^{\mathrm{T}}(D)=0, \tag{7}$$

where

$$\boldsymbol{H}(D)=\left[\boldsymbol{h}^{(1)}(D)\quad \boldsymbol{h}^{(2)}(D)\right]^{\mathrm{T}}. \tag{8}$$

The following expression can be derived from equation (1) and (7):

$$\boldsymbol{V}(D)\boldsymbol{H}^{\mathrm{T}}(D)=\boldsymbol{u}(D)\boldsymbol{G}(D)\boldsymbol{H}^{\mathrm{T}}(D)=0. \tag{9}$$

Let $\boldsymbol{e}^{(i)}(D)=e_0^{(i)}+e_0^{(i)}D+\mathbf{L}+e_N^{(i)}D^N(\ i=1,2\ )$be the error polynomial, the receive sequence can be expressed as

$$\sum_{j=0}^{N-1}c_j^{(1)}D^j\sum_{k=0}^{m}g_k^{(2)}D^k+\sum_{j=0}^{N-1}c_j^{(2)}D^j\sum_{k=0}^{m}g_k^{(1)}D^k=0 \tag{10}$$

Formula includes $2(m+1)$ unknown numbers, which can be solved by building the following equations to solve if N is large enough.

$$\left[\boldsymbol{C}_0\quad \boldsymbol{C}_2\quad \mathbf{L}\quad \boldsymbol{C}_n\right]^{\mathrm{T}}\boldsymbol{g}=\begin{bmatrix} c_0^{(1)} & c_0^{(2)} & \mathbf{L} & c_m^{(1)} & c_m^{(2)} \\ c_1^{(1)} & c_1^{(2)} & \mathbf{L} & c_{m+1}^{(1)} & c_{m+1}^{(1)} \\ \mathbf{M} & \mathbf{M} & \mathbf{O} & \mathbf{M} & \mathbf{M} \\ c_n^{(1)} & c_n^{(2)} & \mathbf{L} & c_{n+m}^{(1)} & c_{n+m}^{(2)} \end{bmatrix}\begin{bmatrix} g_0^{(2)} \\ g_0^{(1)} \\ g_1^{(2)} \\ g_1^{(1)} \\ \mathbf{M} \\ g_m^{(2)} \\ g_m^{(1)} \end{bmatrix}=\boldsymbol{0}, \tag{11}$$

where $\boldsymbol{C}_i=\left[c_i^{(1)}\quad c_i^{(2)}\quad \mathbf{L}\quad c_{i+m}^{(1)}\quad c_{i+m}^{(2)}\right]$, $\boldsymbol{g}=\left[g_0^{(2)}\quad g_0^{(1)}\quad g_1^{(2)}\quad g_1^{(1)}\quad \mathbf{L}\quad g_m^{(2)}\quad g_m^{(1)}\right]^{\mathrm{T}}$.

Simulated annealing algorithm] derived from statistical thermodynamic physics. Compared with traditional linear inversion method, it doesn't depend on the selection of initial model, and can find the global optimal solution without falling into the local minimum.

Let $f(\boldsymbol{g})$ be the objective function of $\boldsymbol{g}$, then implemen- tation for the algorithm can be expressed as follows:

STEP1 Choose an initial solution $\boldsymbol{g}_0$ arbitrarily and set starting temperature t_{max}.

STEP2 Define a series of vectors $\boldsymbol{e}_i=(0,0,\mathbf{L},1,\mathbf{L},0),1\le i\le 2(m+1)$, which the i-th position is 1, while other positions are 0. At temperature t, let $\boldsymbol{g}_i=\boldsymbol{g}+\boldsymbol{e}_i$, compute $\Delta f_i=f(\boldsymbol{g}_i)-f(\boldsymbol{g})$, if $\Delta f_i\le 0$, then $\boldsymbol{g}=\boldsymbol{g}_i$; otherwise if $exp(-\Delta f_i/t)>random(0,1)$, $\boldsymbol{g}=\boldsymbol{g}_i$. After the cycle, if the inner loop stop condition is satisfied, then end the operation; otherwise, go to STEP3.

STEP3 Decrease the temperature under control of $t=d(t)$, if the termination condition is met, the operation is terminated; otherwise, return to STEP2.

For solution vector $\boldsymbol{g}$, if $\boldsymbol{C}_i\boldsymbol{g}=0$, then the i-th equation is correct.So, objective function $f(\boldsymbol{g})$ can be choosed as $w=\sum_{j=0}^{n}\boldsymbol{C}_j\boldsymbol{g}$. The optimal solution satisfies the following condition:

$$\boldsymbol{g}=\left\{\boldsymbol{g}\middle|min(w)\right\}$$

Temperature parameters include the initial temperature, the temperature decreasing method and the stopping temperature. The initial temperature should meet the condition of $exp\left(-\frac{\Delta f_i}{t_0}\right)\approx 1$, thus it can be setted as $t_0=K\Delta_0$, where K is a sufficiently large number and $\Delta_0=max(w)-min(w)$. Assuming the worst case, the value of K is 20, while Δ_0 is choosed as $2(m+1)$.As for the

temperature decreasing method, it can be setted as $t' = a\,t$,while $a = 0.99$. The stopping temperature is $t_{\mathrm{f}} = 0.001$.

As for solution vector $\boldsymbol{g}_k$,when the number of equations n is large enough, the number of tenable equations obeys an approximate Gaussian distribution. According to the literature [7], the confidence level can be calculated as fellows:

$$a_k = \frac{n_k - (n - n_k)}{\sqrt{n}} = \frac{2n_k - n}{\sqrt{n}}$$

$|a_k| \geq 3$ is often called the impossible event in mathematics, So if $a_k \geq 3$, the error does not exist and $\boldsymbol{g}_k$ is the solution of the target.

Simulation

Firstly, feasibility of the algorithm is verified. The simulation uses $(2,1,4)$ convolutional code, with its generating polynomial matrix of $G(D) = \left[1 + D^3 + D^4 \quad 1 + D + D^3 + D^4\right]$.Under the bit error rate of 3%, the intercepted sequence is 1011000110100110 ... 11110110010110. Since the memory length m is unknown, it may be set to 6 (in practical application, it's generally less than 7). Construct equation sets according to equation (11). After getting the two solution vectors, simplify them to relatively prime to get the desired polynomial. The solution of the equation sets is $\boldsymbol{g} = [11010101000011]$, namely, $g^{(1)}(D) = 1 + D + D^2 + D^3 + D^6$, $g^{(2)}(D) = 1 + D^6$ .Thus the utility of the proposed algorithm is demonstrated.

Then the effect of the encoding memory length on algorithm performance is researched. Using Monte Carlo method to calculate the recognition probability under different bit error circumstances with the value of memory length ranging from 3 to 6, the results are shown in figure 1. The simulation results show that with the increasing of memory length, recognition probability will reduce gradually. When bit error rate is less than 3% , the recognition probability of four different convolutional codes can stay above 90%, which shows excellent performance.

At last, the recognition performance is compared between Walsh-Hadamard transform algorithm, Euclidean algorithm, Gaussian elimination algorithm, and the method proposed in this paper based on Monte Carlo simulations. The results are shown in figure 2, from which can be concluded that performance of the proposed method is better than Euclidean algorithm and Gaussian elimination algorithm, but weaker than Walsh-Hadamard transform algorithm. However, consider the calculation complexity of Walsh-Hadamard transform algorithm, the proposed method is relatively more efficient when under circumstances of low error rate and little memory length.

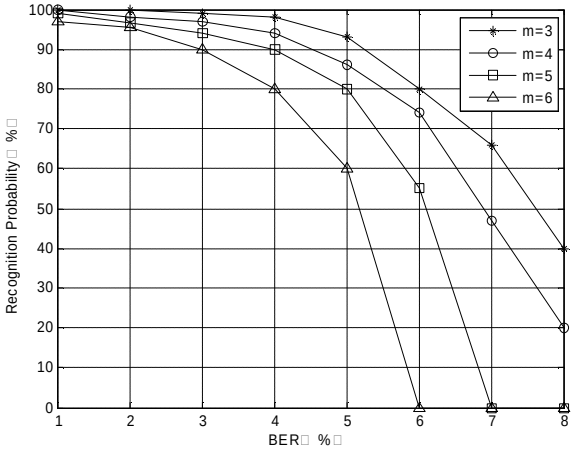

Fig.1 Comparation of permormance under different memory length

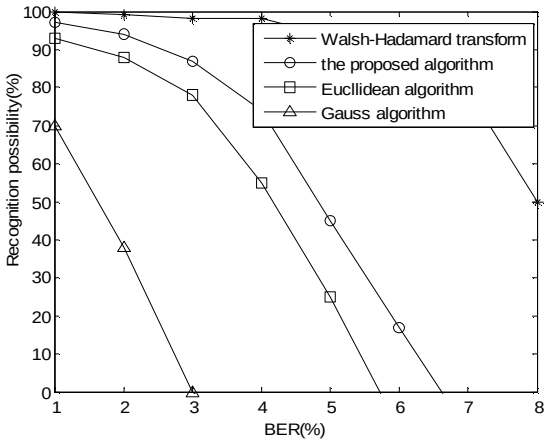

Fig.2 Comparation of permormance between different methods

Conclusions

An effective identification method for $(2,1,m)$ convoluntional code is given in this paper. According to the annealing thought in statistical physics thermodynamic, the elements in the solution space is tested through iterative calculation to make the equation solution tend to actual value and avoid the interference of local optima. The method has high data utilization and fault tolerance. When compared with other methods, the algorithm's performance and computational complexity reach a compromise.

Acknowledgement

This research was financially supported by the Natural Science Foundation of China and Taishan Scholar Special Foundation (ts201511020).

References

[1] ZOU Yan. Research on Fault-tolerant technology in information interception and processing[D].Fudan University,Shanghai,2006:9-11.

[2] WANG Fenghua, HUANG Zhitao, ZHOU Yiyu. A method for blind recognition of convolution code based on Euclidean algorithm [C]. IEEE Inter Conference on Wireless Communications, Shanghai: IEEE Press.2007: 1414-1417.

[3] XIE Hui, WANG Fenghua, HUANG Zhitao. A fast method for blind recognition of convoluntional codes based on improved Euclidean algorithm. Journal of National University of Defense Technology, Vol.34 (2012), p. 2364, in Chinese.

[4] LIU Jiancheng, YANG Xiaojing. Blind recognition of (n,1,m) convolutional code based on solving check-sequence. Journal of Electronics & Information Technology, Vol.34 (2012), p. 2364, in Chinese.

[5] XUE Guoqing, CHANG Fengjia, LIU Weiping. Blind identification of 1/n convolutional codes. Wireless Communication Technology, Vol.38 (2009), p. 39, in Chinese

[6] LIU Jian,WANG Xiaojun, ZHOU Xiyuan. Blind recognition of convolutional coding based on Walsh-Hadamard transform. Journal of Electronics & Information Technology, Vol.32 (2010), p. 884-888, in Chinese.

[7] YOU Ling, ZHU Zhongliang. Application of Walsh function in resolving of F(2) equations. Signal Processing, Vol.16 (2000), p.28, in Chinese.