A Research on DSSS based CNN
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Abstract: Chaos has been the focus of scientific research. The application of chaos theory in spread spectrum opens a new field for communications. This paper puts forward a new application of Cellular Neural Networks (CNN) in chaotic spread spectrum systems, that is, investigating the feasibility of implementing impulsive chaos synchronization with CNN and pointing out whether it can be synchronized or not is related to the energy of synchronization impulse. Furthermore, spread spectrum sequence is generated using CNN. By simulation, it is proved that CNN can be applied to spread spectrum system effectively.

Keywords Cellular neural networks (CNN), chaos, impulsive chaos synchronization, spread spectrum

I. Introduction

Cellular Neural Networks (CNN)[1] is a kind of large-scale non-linear analog circuit, which can process signal parallelly and rapidly. It has many advantages, for example, can be implemented easily with VLSI and process information rapidly and parallelly. At the same time, it is also a complex non-linear dynamical system. One can expect interesting phenomena (“bifurcations”) and complex (“chaotic”) dynamics to occur in such networks[2]. Because of the complex randomicity of chaotic signal, applying chaotic system in spread spectrum will have good landscape [3].

This paper discusses the application of three-cell CNN in the direct sequence spread spectrum communication system (DSSS), studies and proves the feasibility of implementing impulsive chaos synchronization with CNN, thus finds out a new circuit for impulsive chaos synchronization. Compared with Chua’s circuit, this circuit can be integrated easily and has its own characteristic. What is more, considering the disadvantages of previous digital chaotic spread spectrum sequence, this paper puts forward a new method of generating spread spectrum sequence with CNN. The simulation of QPSK spread spectrum system proves this method is an effective chaotic communication scheme. In Sec.2 we present the chaos generation and its synchronization in CNN, implement impulsive chaos synchronization with CNN and reach a useful conclusion. In Sec.3, we put forward a new method of generating spread spectrum sequence with CNN and analyze its performance. In Sec.4, we give a simulation of chaotic spread spectrum system which shows a good performance of CNN spread spectrum system. Sec.5 contains the conclusion.

II. CNN Chaotic Model

1. Chaos Generation Based on Three-Cell CNN

Cellular Neural Networks (CNN) consists of many regular circuit units named cell. Every cell can communicate with the neighboring cells. CNN has two good properties. (1)the good continuous time property meets the request of real-time digital signal processing. (2) the local interlinkage property makes it be implemented easily by VLSI. CNN can generate chaos under certain conditions, whether it can do or not is decided by Lyapunov exponent. A n-dimension discrete system has n Lyapunov exponents. As long as the maximal Lyapunov exponent exceeds 0, this system can generate chaos[4].

In this paper, we adopt three-cell CNN model as a
chaotic system. Its equation can be written as

\[ \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + [A] \begin{bmatrix} f(x_1) \\ f(x_2) \\ f(x_3) \end{bmatrix} \]  

(1)

In Equ. (1), A is an output feedback matrix, \( f(x) \) is the output function of every nerve cell. \( f(x) \) is described by Equ. (2)

\[ f(x) = \begin{cases} -1 & x \leq -1 \\ x & -1 < x < 1 \\ 1 & x \geq 1 \end{cases} \]  

(2)

Under certain conditions, such CNN can generate chaotic phenomena when choosing proper matrix A and initial values. In our simulation, we take

\[ [A] = \begin{bmatrix} 1.25 & -3.2 & -3.2 \\ -3.2 & 1.1 & -4.4 \\ -3.2 & 4.4 & 1.0 \end{bmatrix} \]  

(3)

CNN chaos phrase figure is shown in Fig.1

![Fig.1. CNN chaos phrase figure](image)

**2. CNN Chaos Impulsive Synchronization**

The synchronization in a communication system is very important. The synchronization of chaos system contains adaptive synchronization, OGY synchronization and impulse synchronization and so on. Impulsive synchronization is a research focus because of its simplicity and security. It has become a mainstream of investigating chaotic applications [5-6]. Now, we investigate the possibility of implementing impulsive chaos synchronization with CNN and prove the feasibility of this method by simulation, thus find out a new circuit for impulsive chaos synchronization. Compared with Chua’s circuit, this circuit can be integrated easily and has its own characteristic. Considering a n-dimension Chaos dynamical system, its differential equation can be described by Equ. (4)

\[ \frac{dx}{dt} = F(x, s_T) \]  

(4)

In Equ. (4), \( x \) is a vector, \( X(t,x_0) \) is a track while initial conditions is \( t=0 \) and \( x=x_0 \). Driving signal \( s_T \) is a m-dimension chaos impulse sequences: \( s(2T), s(2T), s(0), s(T), s(T) \).

Then \( x \) value is reset in time \( T \) by chaos impulse sequences \( s(2T), s(2T), s(T), s(T) \), that is, in time \( T \), the concussive chaos value is replaced by the certain \( s(T) \). \( s(t) \) can also be a function, in other time, system is in the state of concussion. We describe it as

\[ \frac{dx}{dt} = F(x) + \delta_T (s - x) \]  

(5)

In Equ. (5), \( s-x \) is a function consisting of driving signal and driven signal, whose simplest form is the difference of two signals and it can also be chosen as more complex forms. However, \( \delta_T \) cannot be ideal Dirac Delta impulse function obviously. It should be a rectangle function which has certain time width and limited amplitude. The condition of synchronization is the same as other methods, that is, Whether or not error function is \( 0 \) with the increase of time, described by Equ.(6)

\[ |x - x'| = 0 \]  

(6)

In Equ. (6), \( x \) is the driving system, \( x' \) is the driven system. Here, we choose the simplest error control function as \( x_1 - x_2 \). In three-cell CNN chaos system, we choose (1) as the driving system and \( x_1 \) as chaos driving signal, so get a chaos driven system, described by Equ. (7)

\[ \begin{bmatrix} \dot{y}_1 \\ \dot{y}_2 \\ \dot{y}_3 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} + [A] \begin{bmatrix} f(y_1) \\ f(y_2) \\ f(y_3) \end{bmatrix} + [K] \begin{bmatrix} x_1 - y_1 \\ x_2 - y_2 \\ x_3 - y_3 \end{bmatrix} \]  

(7)

where
\[
[K] = \begin{bmatrix}
a\delta_f(t) & 0 & 0 \\
0 & b\delta_f(t) & 0 \\
0 & 0 & c\delta_f(t)
\end{bmatrix}
\] (8)

In Equ.(8), we choose \(a=3.0, b=-1, c=3.5\), which will satisfy the following conditions: the eigenvalues of Jacobi matrix are negative ones. Then we can choose a proper synchronization error function to obtain synchronization. We define the synchronization time interval as the interval of two synchronized ranges. Between the synchronized ranges is the free oscillation range. In our simulation, we find out if the interval is too small, we can not synchronize the systems. Such synchronization interval is related to the impulse energy(energy=applitude multiplies duration ). In simulation, we take Euler method, whose step pace is 0.31, initial status is (0.02,0.02,0.02) and (-0.2,0.12,0.01), the results are shown as Fig. 2 and Fig.3. It can be seen from Fig.2 that CNN synchronization have a locking procedure, and Fig.3 represents the same procedure in the form of synchronization error. Simulation demonstrates either a too large interval or a too small aptitude will not lead to synchronization, which indicates whether or not the two systems can be synchronized is related to the energy of impulse.

III. CNN Spread-Spectrum

The spread spectrum sequence is the basis of the spread spectrum communications. But the traditional spread spectrum sequence have low complexity, poor

Fig.3 Synchronization Error

security, and the number of it is limited with good correlation. So generating spread spectrum sequence based on chaos have become the focus of recent research[7]. As a kind of non-linear dynamical systems, Chaos has the characteristic of high pseudo-randomicity. What is more, it is very sensitive to initial values and circuit’s parameters and can never appear repeatedly. So many chaotic sequences can share the same channel., which means we can take full advantage of the resource of frequency. In this paper, we use three-cell CNN to generate continuous pseudo-random signal, at that time, the CNN is under chaotic status. We can get chaotic circuit output by choosing proper parameters and initial values, and then get a series of analog sequence by sampling it with more lower impulse frequency. Finally, we can get desired chaotic spread spectrum sequence. Different initial values will generate different sequences, and they all have good correlation properties, so the number is theoretically infinite. Simulation shows that too high sampling frequency will result in poor correlation property sequences. While the time interval is long enough, CNN presents excellent randomicity. In simulation, we take a step pace as 0.01, sample per 4000 CNN time interval. For three-cell CNN, three status variable \(x_1, x_2, x_3\) have zero mean, thus the chaotic sequence has also zero mean, that is

\[
\bar{x} = \lim_{N \to \infty} \frac{1}{N} \sum_{i=0}^{N-1} x_i = 0
\] (9)

the auto-correlation is defined as:
\[ ac(m) = \lim_{N \to \infty} \frac{1}{N} \sum_{i=0}^{N-1} (x_i - \bar{x})(x_{i+m} - \bar{x}) \]

\[ = \lim_{N \to \infty} \frac{1}{N} \sum_{i=0}^{N-1} x_i x_{i+m} \]  

and the cross-correlation as:

\[ cc_{12}(m) = \lim_{N \to \infty} \frac{1}{N} \sum_{i=0}^{N-1} (x_i - \bar{x})(x_{2i+m} - \bar{x}) \]

\[ = \lim_{N \to \infty} \frac{1}{N} \sum_{i=0}^{N-1} x_i x_{2i+2m} \]  

which \( x_1 \) and \( x_2 \) are generated through different initial values.

According to the given equation above, we calculate the chaotic sequences’ auto-correlation and cross-correlation, which is showed as Fig.4 and Fig.5(N=512). Figures show that chaotic sequences based on CNN have a sharp auto-correlation (the maximum is 1 at \( t=0 \)), and also a small cross-correlation. Compared with m-sequence and Gold sequence, it has more better correlation property, and is closer to ideal white noise.

When sequence becomes longer, the correlation property of sequence becomes better (showed in Fig.6 and Fig.7). But the ideal sequence can’t be generated only by means of increasing the length of sequence because it is also very difficult to get so long sequence in practice[8]. Considering the departure (related to mean value 0) of Auto-correlation side-lobes and Cross-correlation function, that is, their mean square root

\[ \sigma_{AC} = \sqrt{\frac{1}{N} \sum_{m=1}^{N} [AC(m)]^2}, m \neq N \]  

\[ \sigma_{CC12} = \sqrt{\frac{1}{N} \sum_{m=1}^{N} [CC(m)]^2} \]  

In Equ.(12) and Equ.(13), \( N \) is the length of sequence. The two parameters represent respectively the ability of restraining multi-path interference and multi-address interference in CDMA communication system. Fig.8 and Fig.9 show the mean square root as the function of the length of sequence \( N \), we can see that the mean square root of Auto-correlation side lobe and Cross-correlation function is almost equal. From the tendency of curve, the longer sequence is, the smaller mean square root is and the correlation property is much closer to the theory value. But we can’t improve the property of correlation only by means of increasing the length of sequence because it is unpractical. In terms of Fig.8 and Fig.9, When the length of sequence \( N \) is exceed 4000, the correlation property will not be improved remarkably. So we suggest the length of sequence can be chosen as 2000~4000.
IV. CNN-DSSS Simulation

In order to test the performance of CNN based spread spectrum sequence in practical applications, we design a QPSK DSSS system as Fig.10. In this system, we take 31 bit CNN based spread spectrum sequence and impulsive synchronization. Finally, we give both Gold sequence and CNN sequence simulation results on bit error rate (BER) as a function of SNR, showed as Fig. 11.

V. Conclusion

In this paper, we discuss a new method of impulsive synchronization which is based on CNN, and find out a new circuit implementation. Simulation proves whether or not CNN can be synchronized depends on the energy of the sampling impulse, either a too large interval or a too small
aptitude will not lead to synchronization. Secondly, we discuss a new method of generating spread spectrum sequences based on CNN, which possesses better auto-correlation and cross-correlation properties, which will suit future large capacity communications.

References

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