A NEW PSEUDO-NOISE GENERATOR FOR SPREAD SPECTRUM COMMUNICATIONS

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ABSTRACT

A new method to construct a chaotic generator is presented in this paper. It is based on the fact that sea clutter is chaotic, and it can be reconstructed by the use of a supervised neural network. The constructed chaotic sequence generator is then applied to the direct-sequence coherent BPSK communication system as a pseudo-noise generator. Experimental results are presented. The advantages and disadvantages of the new pseudo-noise generator are discussed.

1. INTRODUCTION

Generally speaking, spread spectrum modulation is a kind of modulation technique in which the modulated signal has a relatively wideband spectrum. A key device in a spread spectrum system is the pseudo-noise generator, which is used to generate the modulated signal. It is usually implemented by means of a feedback shift register. A shortcoming of this kind of generator is that the price paid for making the period of the pseudo-noise fairly long increases sharply, since a large amount of storage capacity and a large number of logic circuits are required. This imposes a practical limit on how large the period of the pseudo-noise can actually be made. This shortcoming can be overcome by the use of a digital chaotic sequence generator.

A chaotic sequence has the properties of a noise-like waveform, wideband spectrum, and most importantly, sensitive dependence on initial conditions. The length of a chaotic sequence can be infinitely long; this does not cost any more for its implementation. At present, there are only very few well-known chaotic systems defined by coupled deterministic differential or difference equations that may be considered for real applications. A recent study on radar clutter analysis and modelling has demonstrated that sea clutter is chaotic, and the underlying dynamics of sea clutter can be reconstructed by the use of a supervised neural network. This provides us with a new resource to construct a chaotic sequence for spread spectrum communications, which is different from any method known today. In this paper, we present a new pseudo-noise generator which is based on the fact that sea clutter is chaotic, and is implemented by a multilayer perceptron model.

2. DEFINING A CHAOTIC SEQUENCE GENERATOR

Given a time series $\{x(1), x(2), \ldots, \}$, which is an observation of an unknown chaotic dynamical system in its phase space $\mathcal{M}$ with dimension D, by the use of Takens' embedding theorem [4], there exists a nonlinear function f, such that, with $D_e > 2D + 1$,

$$x(n) = f(x(n-1), \cdots, x(n-D_e)) \qquad (1)$$

The reconstructed function f is equivalent to the original chaotic system up to a diffeomorphism. In other words, an equivalent chaotic system can be reconstructed directly from the observation data of the system. The problem that we have to resolve

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here is how to construct the nonlinear function f. In [5] we have proposed and demonstrated that a multilayer perceptron model trained with the backpropagation algorithm is able to successfully achieve the construction for the nonlinear modelling of sea clutter.

A chaotic sequence generator defined by the multilayer perceptron model (with two hidden layers) for the nonlinear modelling of sea clutter can be expressed as follows:

$$\begin{aligned} x_j(n) &= \phi(\textstyle\sum_{i=1}^{N} w_{ji}^{(1)} y(n-i) + b_j^{(1)}) \\ z_k(n) &= \phi(\textstyle\sum_{j=1}^{J} w_{kj}^{(2)} x_j(n) + b_k^{(2)}) \\ \hat{y}(n) &= \textstyle\sum_{k=1}^{K} w_{ok}^{(3)} z_k(n) + b_o^{(3)} \end{aligned} \quad (2)$$

where $j = 1, 2, \ldots, J$, $k = 1, 2, \ldots, K$, $y(n-1), y(n-2), \ldots, y(n-N)$ are the input data, and the $\hat{y}(n)$ is the one-step prediction at time n. The synaptic weights $w_{ji}^{(1)}$ and bias term $b_j^{(1)}$ refer to neuron j in the first hidden layer; the synaptic weights $w_{kj}^{(2)}$ and bias term $b_k^{(2)}$ refer to neuron k in the second hidden layer; and the synaptic weights $w_{ok}^{(3)}$ and bias term $b_o^{(3)}$ refer to the neurons in the output layer. Note that the output layer is linear, which is the customary practice in the design of nonlinear regression models. It is further assumed that all the neurons in the two hidden layers of the model use the same sigmoid nonlinearity described by the logistic function:

$$\phi(v) = \frac{1}{1 + \exp(-v)} \quad (3)$$

where v is the activation function.

The parameters of the model described in (2) are determined in accordance with the backpropagation algorithm acting on the actual sea clutter data. The generalization ability of the multilayer perceptron model is demonstrated by performing recursive (iterated) prediction on it with test data to confirm that the model has learned the underlying dynamics of the chaotic process. After all these procedures are finished, a chaotic sequence generator, therefore, is ready for application.

The generator operates in an autonomous fashion. Specifically, it uses N input samples $y(n-1), y(n-2), \ldots, y(n-N)$ to start the operation,

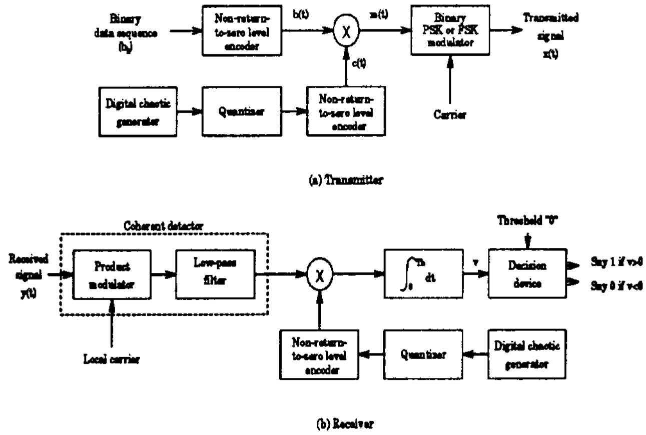

Figure 1: Direct-sequence spread coherent BPSK system, where the pseudo-noise generator consists of a digital chaotic generator, a quantizer and a non-return-to-zero level encoder.

then uses the predicted point to dispense with one of the input samples, and keeps the operation going. The output sequence is then defined by $\{\hat{y}(n) : n = 1, 2, \ldots\}$. Since the generator is the reconstruction of a chaotic system, the output sequence of the generator is, therefore, a chaotic process, which satisfies the property of sensitivity to initial conditions. Thus for the reconstructed model, we can vary the exact time-domain description of the chaotic signal generated by the model merely by changing the set of N input samples used to initialize the chaotic model.

3. AN APPLICATION FOR SPREAD SPECTRUM COMMUNICATIONS

As an application, we apply the chaotic sequence generator to a spread spectrum communication system. A block diagram of a direct sequence BPSK system is shown in Figure 1. In this system, the conventional PN sequence generator is replaced by a chaotic sequence generator. The chaotic sequence generators for both the transmitter and receiver are built identically.

To illustrate the spreading ability of the chaotic sequence generated by the chaotic generator, we present a simple computer experiment in the following. We consider a sinusoid as a message signal, which is shown in Figure 2 (a). The spreading PN

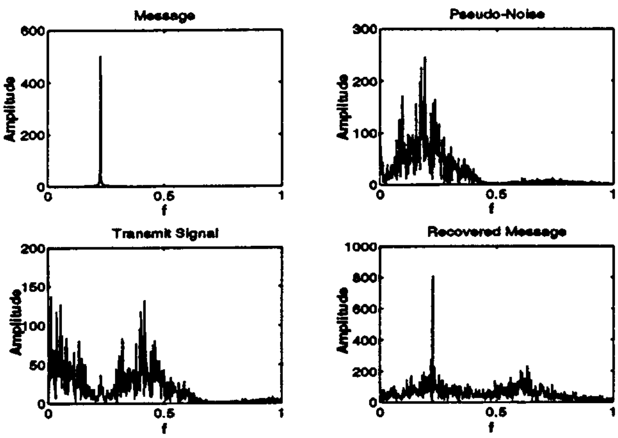

Figure 2: (a) A single sinusoid signal; (b) the modulated signal generated the chaotic sequence generator; (c) the transmitted signal; (d) the recovered sinusoid signal.

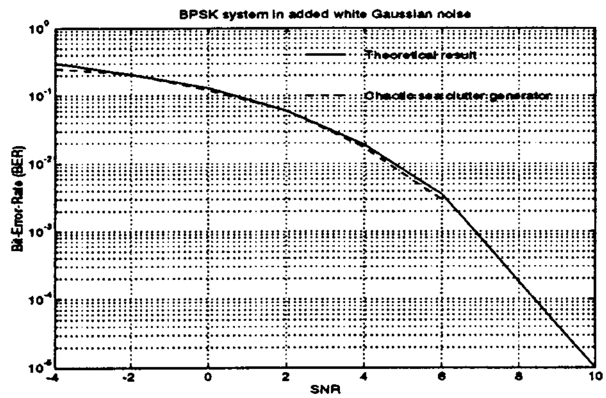

Figure 3: A plot of BER via SNR of a BPSK system in additive white Gaussian noise. The pseudo-noise is a chaotic sequence generated by the multilayer perceptron model.

sequence generated by the chaotic sequence generator has the spectrum shown in Figure 2 (b). The product of the message signal and the chaotic sequence represents the transmitted signal, which has the spectrum shown in Figure 2 (c). To recover the original message, the received signal is multiplied by an exact replica of the PN sequence produced by the chaotic sequence generator. The output spectrum of the multiplier is shown in Figure 2 (d). Clearly, the message signal can be easily recovered from the output of the multiplier. There are two observations from the above computer experiment: (1) The use of the chaotic (clutter) sequence as spreading code in the transmitter produces a wide-band transmitted signal that appears noise-like to a receiver that has no knowledge of the spreading code. (2) In the same way, the spreading nature of the chaotic sequence at the receiver forces the interference signal (*i.e.*, jammer) to spread its spectrum such that the detection of the message signal at the receiver output can be afforded increased reliability.

Next we show the performance of the chaotic sequence generator in a direct-sequence spread BPSK system, where we assume that the channel noise is additive white Gaussian noise, and both the transmitter and receiver are synchronized. In this experiment, the chaotic sequence generator is followed by a quantizer and a nonreturn-to-zero level encoder to get binary sequence stream. The clock time for starting the chaotic sequence generator at the receiver is recovered in a self-synchronized fashion, for which it is extracted directly from a noisy nonreturn-to-zero bit stream. Figure 3 shows a plot of bit-error-rate (BER) versus signal-to-noise ratio (SNR). The solid line in the figure shows the theoretical result, while the dashed line shows the experimental result of using the chaotic sequence.

4. DISCUSSION AND CONCLUSION

The use of chaos theory, applied to real-life radar data, tells us that sea clutter is a chaotic process, and the underlying dynamics responsible for the generation of the process can be reconstructed by the use of a multilayer perceptron model. In other words, the reconstructed model is capable of generating a random-like chaotic process that exhibits the statistical characteristics that are usually associated with actual sea clutter data [5]. The exact time-domain description of the process generated by the model can be varied merely by changing the set of input samples used to initialize the model.

In this paper, we have presented a method of defining a new chaotic sequence generator. We have described an application of the chaotic sequence generator to spread spectrum communications, in which the chaotic sequence generator acts as a pseudo-noise generator. The advantages of the chaotic sequence generated by the multilayer perceptron model for spread spectrum communications are listed as follows:

- it has a noise-like waveform and wideband spectrum, the implementation of which is made possible by using real-life radar clutter data that are known only to the system designer;
- it can be made arbitrarily long without increasing the complexity of the generator;
- it is sensitive to initial conditions, which is desirable from the viewpoint of secure communications;
- the generators for both the transmitter and receiver can be built identically, since they are digitally implemented;
- the exact time-domain description of the sequence can be varied simply by varying the limited data set used for initialization;
- the system lends itself to implementation using VLSI technology.

As mentioned before, the underlying dynamics of sea clutter is reconstructed by the use of a multilayer perceptron; the backpropagation algorithm is used to train it. Thus it has the shortcoming of a slow rate of convergence during the training session. However, once the training is done, the multilayer perceptron operates entirely in a feed forward fashion and can therefore be very fast. Another shortcoming of the chaotic sequence generator for spread spectrum communications is that the structure of the chaotic sequence generator is more complicated compared to the conventional feedback shift register. This may be overcome by the use of VLSI technology.

5. REFERENCES

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