An Algorithm for Chaotic Masking and Its Blind Extraction of Image Information in Positive Definite System

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Abstract. According to the renewable and the noise-like characteristic of chaotic signal, the effective frequency band and the energy band of image information are used to carry out the chaotic masking transmission, so as to achieve the security transmission of image information. Chen chaos is selected as the carrier to carry out the chaotic masking transmission for the image information of the two time-frequency aliasing under the positive definite transmission model, and the blind extraction algorithm is used to restore it in the receiver. The influence of additive noise source on the extraction effect is analyzed, and a secure transmission method of image information under chaotic masking is proposed in this paper.

Keywords: Image information · Positive definite system
Masking transmission · Blind extraction · Chen chaos

1 Introduction

As one of the popular multimedia forms in today's society, digital image has been widely used in politics, economy, national defense and education. In some relatively special areas, such as military, commercial, digital image has a high confidentiality requirements [1, 2]. Since 1990, many researchers have made many kinds of image encryption algorithms by using the spatio-temporal property and visual perception of images [3]. Banerjee and Barrera use something similar to chaos to achieve encryption by improving and transforming chaos [4, 5]. Chaotic signal is the description of complex and irregular motion in a deterministic system. The chaotic masking technology uses the chaotic signals with statistical characteristics to hide the useful signals, so that the useful signal and the chaotic signal can be superimposed to achieve the communication security effect [6–8]. Blind source separation (BSS) is a subject developed in the middle and late 80s of last century, which can recover the target source signal from the observed aliasing signal, just using the statistical characteristics of the source signal, even the input signal and channel parameters are unknown. In recent years, blind source separation (BSS) technology has been widely used in wireless communications, biomedical engineering, speech processing and image

X. Gu et al. (Eds.): MLICOM 2017, Part II, LNICST 227, pp. 428–436, 2018.
https://doi.org/10.1007/978-3-319-73447-7_47

processing, etc. [9, 10]. On the basis of this, we combine the image information and the chaotic signal, and propose a method to cover the image information by using the chaotic signal and extract the image information through the blind source separation technique in the determined model, so as to achieve the effect of the secure communication.

2 The Mathematical Model of Blind Source Separation and Chaos Signal

2.1 The Mathematical Model

Positive definite hybrid system model is the system model which assuming that the source are independent and the number is n, and at the receiving end using n receive antennas to receive n signals. The mathematical model of the positive definite hybrid blind source separation system as shown in Fig. 1.

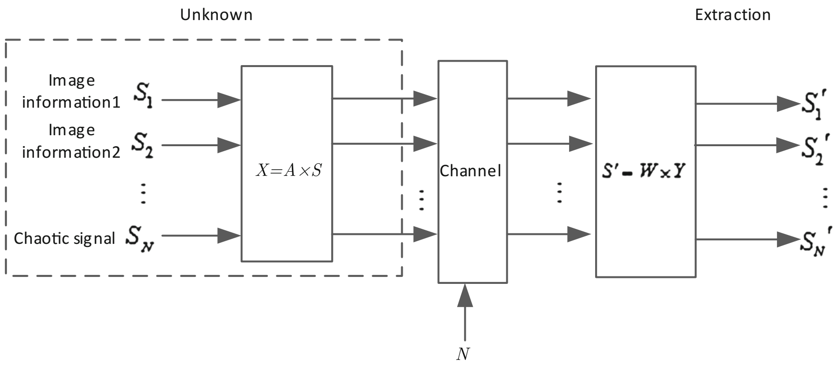

Fig. 1. Mathematical model of positive definite blind source separation

Given the vector quantity of original signal $S = [s_1(t), s_2(t), \cdots, s_N(t)]^T$, which means the number of unknown original signal is N. In order to transmit the signal in secrecy, one of vector quantity is chosen to as a chaotic signal, then the image information is hided in the chaotic signal effectively, then realize the secret transmission. A is an unknown channel hybrid matrix of order $N \times N$, which generated by system randomly. $N = [n_1(t), n_2(t), \cdots, n_N(t)]^T$ is the additive white gaussian noise of the channel. It can conclude that the vector formulation of the positive definite hybrid system observed signal is shown as follow:

$$Y = A \times S + N. \tag{1}$$

The key step of positive definite hybrid system for blind source separation is to solve the separation matrix W. $S' = \left[s_1'(t), s_2'(t), \cdots, s_N'(t)\right]^T$ is the original signal estimated from the observed signal. Through the matrix W, the target signals S' can be extracted from the observed signal Y, the output of the separation system or the extracted vector expression is

$$S' = W \times Y = W \times A \times S + W \times N. \tag{2}$$

ICA is the common method for blind signal processing. This paper adopts the algorithm for blind source separation to get the separation matrix W, due to the FastICA algorithm has good convergence, the short training time and small dependence on learning step factor.

2.2 Chaotic Signal

This paper based on chaotic signal to do the research of target signal blind extraction, so the Chen chaotic system is selected. The dynamic expression of Chen chaotic system [11] is given.

$$\begin{cases} \frac{dx}{dt} = a(y - x) \\ \frac{dy}{dt} = (c - a)x - xz + cy \\ \frac{dz}{dt} = xy - bz \end{cases}. \tag{3}$$

Where a, b, c are the system parameters. Chen chaotic system in a state of chaos when $a = 35, b = 3\,, c = 28$. x, y, z are the state variables of the system.

3 Algorithm Performance Index and Simulation Flow

3.1 Algorithm Performance Index

For the successful separation of the target signal can be evaluated by two aspects, qualitative and quantitative. For image information, qualitative analysis can visually contrast the image information before and after blind source separation so as to obtain an intuitive evaluation [12]. Quantitative analysis can evaluate the performance of the algorithm objectively through the performance evaluation function, the similarity coefficient [13] is the most commonly used evaluation criterion.

3.2 Simulation Flow

The detailed implementation steps and algorithm flow chart are given. The chaotic signal is used as the background to judge the validity and universality of the algorithm. The algorithm flow diagram is shown in Fig. 2.

Implementation steps:

Step 1: Select gray scale pictures from the standard test picture library and convert it from a two-dimensional image to one dimensional array data, making the one-dimensional array data into binary array data.

Step 2: Simulate the unknownness of the channel, randomly generate the mixed matrix. The observed signal is obtained after the source signal have passed by the

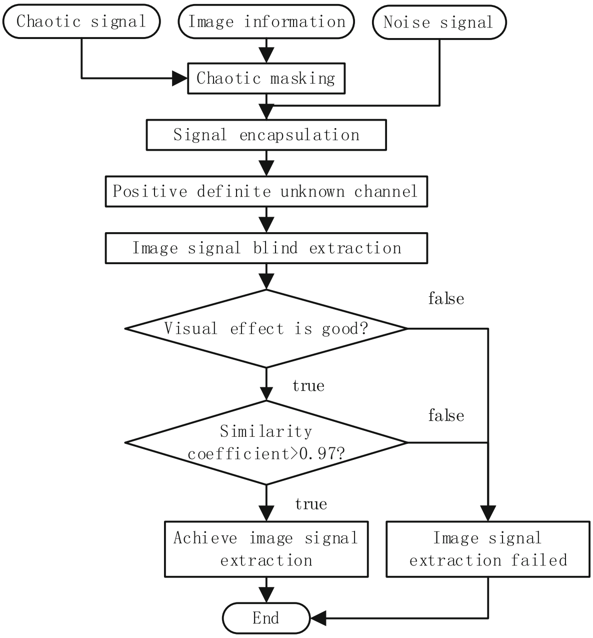

Fig. 2. Flow chart of positive definite blind source separation algorithm

hybrid matrix, then the observation signal is observed to see if the image information has been hidden by chaotic signals and can not be distinguished by human eyes.

Step 3: Use the FastICA algorithm to do blind source separation for the observed signal, and extract the target signal from it.

Step 4: Observe the image information before and after blind source separation through the visual system and view the similarity coefficients. If the extracted image information can be clearly recognized by the human eye, and the similarity coefficient is more than 0.97, the separation is considered to be successful.

Because this paper is based on the mathematical model of positive definite mixed system to realize blind source separation, the algorithm simulation process randomly generates a full rank square matrix.

4 Simulation Experiment and Performance Analysis

4.1 Blind Separation of Two Image Signals Without Noise

Select two gray scale pictures from the standard test picture library shown as Figs. 3 and 4 256×256 and convert it from a two-dimensional image to one dimensional array data, making the one-dimensional array data into binary array data. Then encapsulate it with Chen chaotic signals. A 3×3 matrix is generated randomly through the system, making into aliasing with encapsulated data to obtain three way observation signals. Then convert the data of the observation signal into a decimalization date and turn it into a two-dimensional date. The image information is shown in Figs. 5, 6 and 7. And then the matrix after aliasing was separated by FastICA algorithm to can get estimated value of each source signal. We convert the resulting estimates into a decimal and two-dimensional date. The image information can be shown in Figs. 8 and 9 (The image information after separating from source signal is displayed here).

The random generation of the hybrid matrix for this experiment is

$$A = \begin{bmatrix} 0.8694 & 0.1014 & 0.2086 \\ 0.4122 & 0.7794 & 0.8096 \\ 0.1678 & 0.1066 & 0.2961 \end{bmatrix}$$

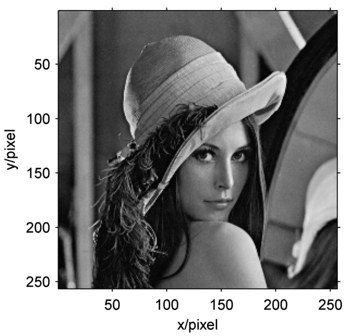

Fig. 3. Image information of first source signal

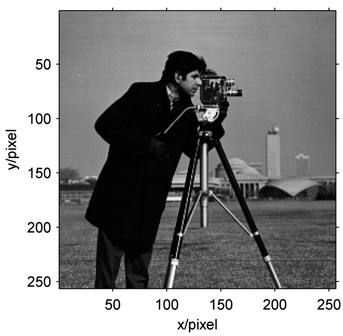

Fig. 4. Image information of second source signal

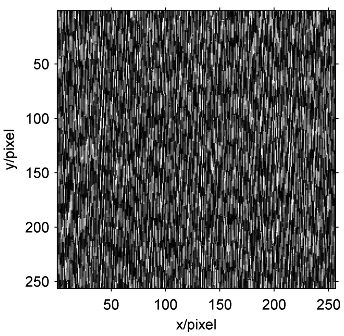

Fig. 5. Image information of the first observation signal in noise free model

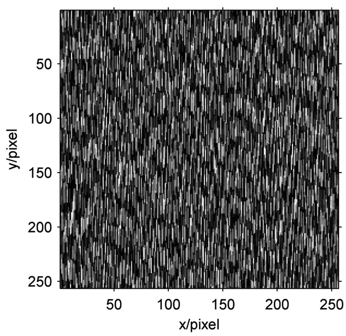

Fig. 6. Image information of the second observation signal in noise free model

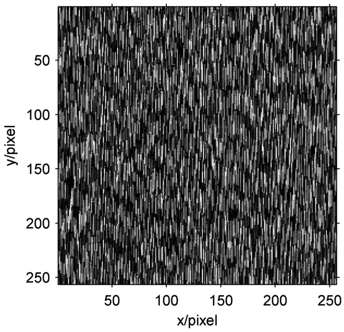

Fig. 7. Image information of the third observation signal in noise free model

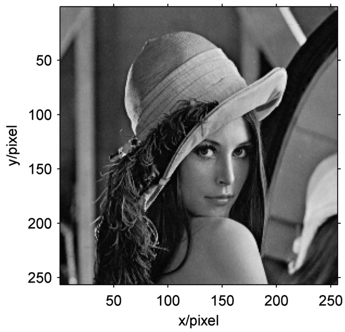

Fig. 8. Image information of the first extracting signal in noise free model

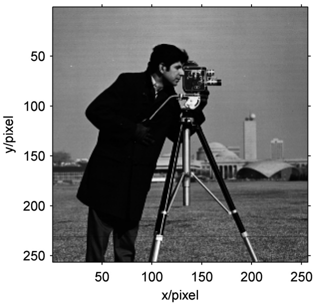

Fig. 9. Image information of the second extracting signal in noise free model

According to Figs. 5, 6 and 7 we can clearly find that the Image information reconstructed by observed signal could not be identified which shows that the image signals are obscured by Chen chaotic signals and cannot be recognized by human eyes. By comparing Fig. 3 with Fig. 8 and Fig. 4 with Fig. 9, we can clearly find that the similarity between the two images is high and almost no difference, and the image information can be easily seen with human vision. By calculation, the similarity coefficient between Figs. 3 and 8 is 0.9999, and the similarity coefficient between Figs. 4 and 9 is 0.9999. In summary, it can be concluded that the image information of the source signal is well separated, and the simulation has also achieved the desired results.

4.2 Blind Separation of Two Images with Superimposed Noise

We select two gray scale pictures from the standard test picture library, as shown in Figs. 3 and 4, and convert it from a two-dimensional image to one dimensional array data, then making the one-dimensional array data into binary array data. A Gaussian white noise is randomly generated by the system, and then the Gaussian white noise, the binary array data and the Chen chaotic signal are encapsulated. A 4×4 matrix is randomly generated by the system and mixed with the encapsulated data to obtain four channel observation signals. The data of the observation signal is converted into decimal and then the four channel image information which made by converting one-dimensional data into two-dimensional data can be shown in Figs. 10, 11, 12 and 13. And then the matrix after aliasing was separated by FastICA algorithm, we can get the estimated value of the source signal. Then the image information shown in Figs. 14 and 15 can be obtained by repeating the above steps.

The random generation of the hybrid matrix for this experiment is

$$A = \begin{bmatrix} 0.3935 & 0.5669 & 0.8033 & 0.5702 \\ 0.0788 & 0.8792 & 0.0240 & 0.4017 \\ 0.2789 & 0.7586 & 0.7554 & 0.9707 \\ 0.4431 & 0.4590 & 0.4078 & 0.1747 \end{bmatrix}$$

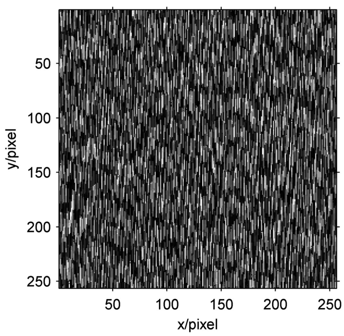

Fig. 10. Image information of the first observation signal in noise model

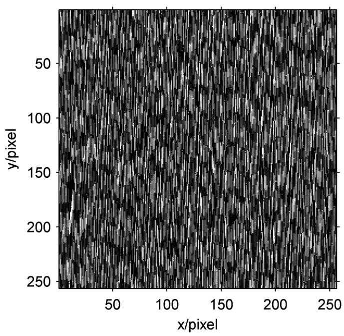

Fig. 11. Image information of the second observation signal in noise model

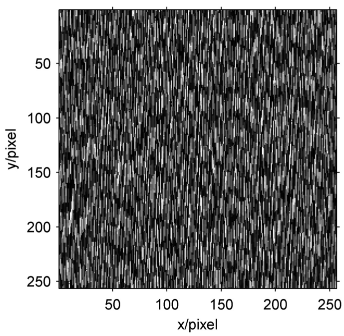

Fig. 12. Image information of the third observation signal in noise model

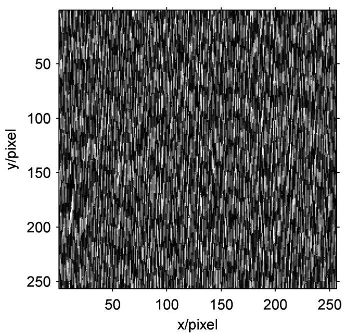

Fig. 13. Image information of the fourth observation signal in noise model

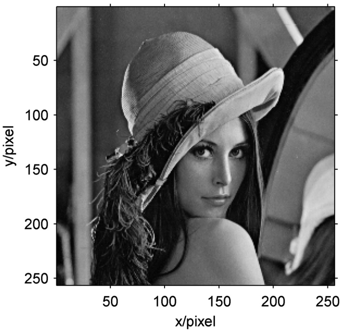

Fig. 14. Image information of the first extracting signal in noise model

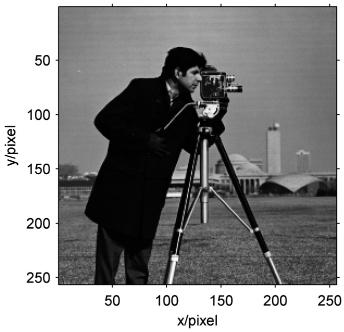

Fig. 15. Image information of the second extracting signal in noise model

In Figs. 10, 11, 12 and 13 observations can be found that the image information can't be identified only by the human eye. It shows that the image signal is covered well by the Chen chaos signal, which is not recognized by the human eye. Through the comparison between Figs. 3 and 14 and Figs. 4 and 15, it can be clearly seen that the extracted image information has a high similarity with the image information of the source signal, which shows that the content of the image information can be easily found. By calculation, the similarity coefficient between Figs. 3 and 14 is 0.9999, and the similarity coefficient between Figs. 4 and 15 is 0.9999. In summary, it can be basically concluded that the image information of the source signal is well separated, and the validity of the algorithm is also verified.

5 Conclusion

The secure communication transmission technology based on chaotic signals is widely used in various information security fields. Considering the importance of image information for secure transmission of the signal, this paper proposes that the signal of image information can be masked by Chen chaotic signal. After the channel transmission of determined system, the image information is extracted by blind extraction. The simulation results show that the method can obscure the image information and can extract the image information well. Even in the case of white Gaussian noise (WGN), better experimental results can be obtained, and the validity is verified as well. That will prepare for the secrecy and blind separation of the image information under the under-determined background.

Acknowledgments. This work was supported by the National Natural Science Foundation of China (grant 61571181), Postdoctoral Research Foundation of Heilongjiang Province (grant LBH-Q14136), and Graduate Student Innovation Research Project Fundation of Heilongjiang University (grant YJSCX2017-148HLJU).

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