1090ES ADS-B Overlapped Signal Separation Research Based on Infomax Extension

Zhaoyue Zhang[1](✉), Hongyan Guo[2], Yongfei Zhang[3], and Jicheng Dong[3]

[1] Civil Aviation University of China, Tianjin 300300, China
zy_zhang@cauc.edu.cn
[2] Binzhou University, Binzhou 256603, China
[3] Harbin Engineering University, Harbin 150001, China

Abstract. 1090ES ADS-B is a new technology in civil aviation, mainly used to monitor dynamic condition of aircrafts and share the flight information. However, the ADS-B signals are often interfered with other overlapped signals during the signal transmission, causing signal overlap and bringing difficulties to signal processing afterwards. This article applies Blind Source Separation (BSS) into the separation process of ADS-B overlapped signals and constructs the ADS-B overlapped signal separation model using Infomax algorithm, in order to separate ADS-B overlapped signals into single-way ADS-B signals and improve signal decoding rate.

Keywords: ADS-B · Blind Source Separation · Infomax extension

1 Introduction

Automatic Dependent Surveillance-Broadcast (ADS-B) obtains aircraft's location information via onboard GPS and sends its location information via onboard communication equipments. People on the earth could receive situation information sent from the aircraft and realize aircraft surveillance. ADS-B improves security and efficiency of the airspace and runway, decreases the cost and reduces the harmful influence on environment. However, ADS-B signals will overlap in the practical transmission, causing giant influence on ADS-B receiver's decoding, leading to aircraft location information default and abnormal aircraft monitoring. In the context of unknown source signals, BBS separates the mixed signals observed and restores the source signals. FastICA algorithm, Infomax algorithm and Maximum Likelihood Estimate algorithm are the most commonly used and efficient algorithms of BSS. This article sets forth the ADS-B based on Infomax extension algorithm and verifies the feasibility of using Infomax extension algorithm for ADS-B overlapped signal separation on the MATLAB simulation platform. In 1995, A.J. Bell and T.J. Sejnowski put forward BSS algorithm based on information-maximisation (Infomax for short) principle. T.W. Lee developed traditional Infomax algorithm and put forward an Infomax extension algorithm which could separate the sub-gaussian source and super-gaussian source. It can realize the kurtosis variance of ICA, select the appropriate nonlinear function, and realize signal synchronization separation [2].

S. Liu and G. Yang (Eds.): ADHIP 2018, LNICST 279, pp. 99–107, 2019.
https://doi.org/10.1007/978-3-030-19086-6_11

2 ADS-B Signal Model

1090ES ADS-B information includes 4 leading pulses and 112-bit message sequence. The information data block format adopts pulse position modulation (PPM) code (Fig. 1). ADS-B information includes 4 identification pulses, each lasting 0.5 ± 0.05 μs.

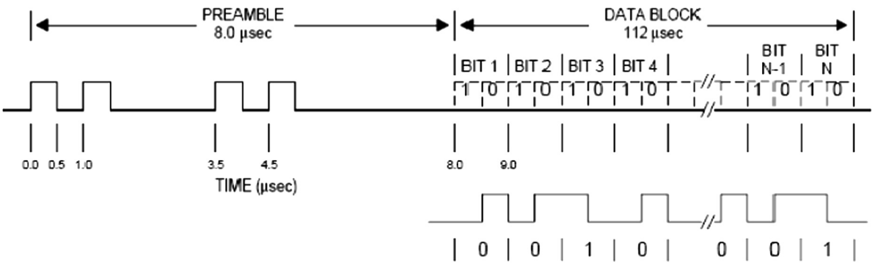

Fig. 1. ADS-B message transmission waveform

While several 1090ES ADS-B signals are transmitted in the mean time, there is the possibility that some parts of the pulse codes overlap. In Fig. 2, when signal 1(grey) and signal 2(white) are transmitted to the same ADS-B receiver, the signal power will overlap and wrong signal position will arise in PPM code, causing two-way or multipath signals can't be decoded correctly. When multipath signals overlap, it will cause that the position of one aircraft or several aircrafts can't be obtained and the messages will be lost. 1090ES ADS-B overlapped signal separation algorithm based on Infomax extension is to separate and restore ADS-B signals correctly with unknown 1090ES ADS-B source signals when 1090ES ADS-B signals overlap.

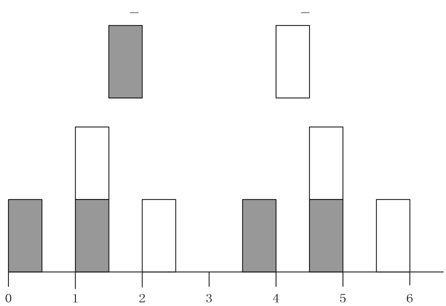

Fig. 2. ADS-B signal overlap model

3 BSS Principle

Supposing that we regard the multi-source data received from several 1090ES ADS-B base stations as observation signals, all the data received from each base station is the overlap of separated 1090ES ADS-B source signals. $s_1(t), s_2(t), s_3(t) \cdots s_n(t)$ is a observation signal vector from any N unit time, $x_1(t), x_2(t), x_3(t) \cdots x_m(t)$ show mixed vector signals received from m ADS-B base stations. In the mixture of ADS-B signals, we suppose that a_{ij} is an unknown constant matrix. The separation of ADS-B signals is how to separate the source signals $s_1(t), s_2(t), s_3(t) \cdots s_n(t)$ from the mixed observation signals received from the ADS-B receiver. So the ADS-B observation signals can be shown as:

$$X(t) = AS(t)$$

$X(t) = \{x_1(t), x_2(t) \cdots x_m(t)\}$ is the received observation signal from m dimension ADS-B base stations; $S(t) = \{s_1(t), s_2(t) \cdots s_n(t)\}$ is the n dimension vector formed by separated ADS-B source signals. In the mixed ADS-B model, a_{ij} is the separated component, and A is the mixture matrix formed by a_{ij}.

The algorithm model of ADS-B signal separation is to calculate the separated matrix W. Via the W, we can extract and restore ADS-B source signal $S(t)$ from the observation signal $X(t)$ mixed by ADS-B. Supposing that $Y(t)$ is the estimation signal of ADS-B source signal, so the separation system can be shown as:

$$Y(t) = WX(t)$$

3.1 The Principle of Infomax Extension Algorithm

The problem of blind signal separation is a process based on the maximum entropy of the separation system, using neural network or self-adaption algorithm and indirectly gaining high-order cumulants via nonlinear function. The framework of Infomax algorithm is shown as Fig. 3.

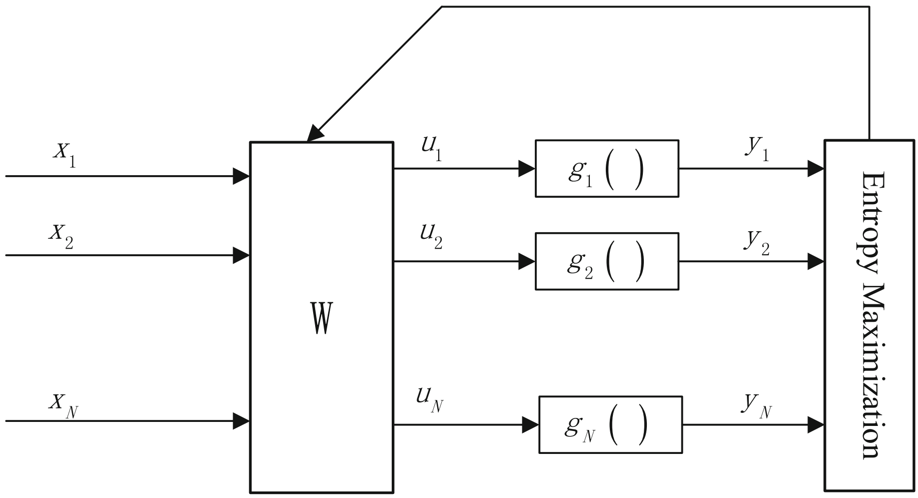

Fig. 3. Infomax algorithm

Among these, x is the multi-path ADS-B observation signal. It is mixed by N separated ADS-B source signals. The system output, $u = wx$, is the approach to true source s. $g_i()$ is a reversible monotone nonlinear function, and the nonlinear output is y_i. The maximum information transmission principle is used in the independence judgment of ADS-B signals, namely that making the interactive information $I(x, y)$ (or output entropy $H(y)$) between nonlinear output y and input x maximum, via adjustment on separation matrix W. According to the information above, the entropy $H(y)$ is defined as:

$$H(y) = H(y_1) + H(y_2) + \cdots + H(y_N) - I(y_1, y_2, \cdots y_{_N})$$

Among them, the interactive message $I(y_1, y_2, \ldots y_N)$ between nonlinear outputs is always non-negative. Only when nonlinear output y_i is separated from each other, there is $I(y_1, y_2, \ldots y_N) = 0$. At this time:

$$H(y) = H(y_1) + H(y_2) + \cdots + H(y_N)$$

So if $H(y)$ obtains the maximum, the nonlinear outputs need to be independent from each other, and at the same time the edge entropy $H(y_i)$ is required to obtain the maximum.

The selection of nonlinear function $g_i()$ is closely related to the value of edge entropy $H(y_i)$. In the Infomax algorithm, the nonlinear function always chooses *sigmoid* function.

$$y_i = g_i(u_i) = \frac{1}{1 + e^{-(au_i + b)}}$$

$$y_i' = g_i'(u_i) = \frac{a + e^{-(au_i + b)}}{(1 + e^{-(au_i + b)})^2}$$

According to the maximum entropy principle, when y_i is separated uniformly, $H(y)$ obtains maximum entropy.

Infomax algorithm uses the fixed nonlinear function form, and adjusts the separation matrix W via iterative feedback. So the observation signal is separated into independent signals.

T.W. Lee et al. use the two-probability model on the basis of Infomax algorithm, and change the probability models dynamically according to the statistical property changes of separation results in the process of blind signal separation algorithm iteration, making the best blind signal separation effect come true. According to Fig. 4, supposing that the input signal is x, the output is y. In the system corresponding to the output nonlinear variables, the independence judgment is the maximum information

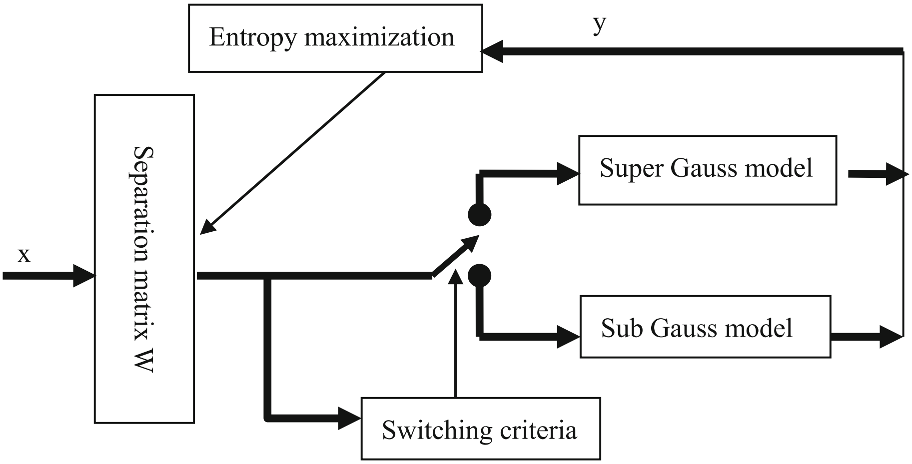

Fig. 4. Infomax extension algorithm model

transmission criterion. By adjusting the separation matrix W, the joint entropy $H(y)$ of nonlinear output y is maximized. Sub-Gaussian and Super-Gaussian probability density models are as followed:

$$p(u_i) = \frac{1}{2}\left(N\left(\mu, \sigma^2\right) + N\left(-\mu, \sigma^2\right)\right)$$

$$p(u_i) = p_G(u_i) \sec h^2(u_i)$$

Among them, $p_G(u_i) = N(0, 1)$ is the Gaussian density function with zero mean value and unit variance.

So the adjustment function of W is:

$$\Delta \mathrm{W} \propto \left[\mathrm{I - Ktanh(u)u}^T - uu^T\right]\mathrm{W}\begin{cases} k_{ii} = 1 : super - Gaussian \\ k_{ii} = -1 : sub - Gaussian \end{cases}$$

Among them, K is a N dimension diagonal matrix and a double probability model switching matrix. k_{ii} is the diagonal element.

3.2 Crosstalk Error

The ADS-B signal separation effect can be evaluated by crosstalk error, *PI*, which is defined as:

$$PI(C) = \frac{1}{M}\sum_{i=1}^{M}\left(\sum_{j=1}^{N}\frac{|c_{ij}|}{\max_j|c_{ij}|} - 1\right) + \frac{1}{N}\sum_{j=1}^{N}\left(\sum_{k=1}^{N}\frac{|c_{ij}|}{\max_j|c_{ij}|} - 1\right) - \frac{M-N}{N}$$

In the function: c_{ij} is the element of global transmission matrix C. $\max_j |c_{ij}|$ expresses the maximum value among the elements in row I of C. When PI is lower, C is more similar to diagonal matrix or its permutation matrix and the separation effect is much better. If the waveform of separated signal is totally the same as the source signal, then $PI = 0$.

4 Algorithm Simulation and Experiment

In order to check the feasibility of this algorithm in ADS-B signal separation, we select MATLAB as the simulation platform in this article, and check with two paths of ADS-B source signals originated randomly. In the simulation experiment, the ADS-B signal frequency sample is 10 MHz, and the number of sample data is 500. The signal that each ADS-B base station receives is the randomly overlapped signal of two paths of ADS-B source signals. As shown in Fig. 5, the ADS-B identification header exists in the front 80 us, which is used to ensure the identification power of ADS-B signals. The latter signal is the PPM coding signal, which uses the digital circuit coding.

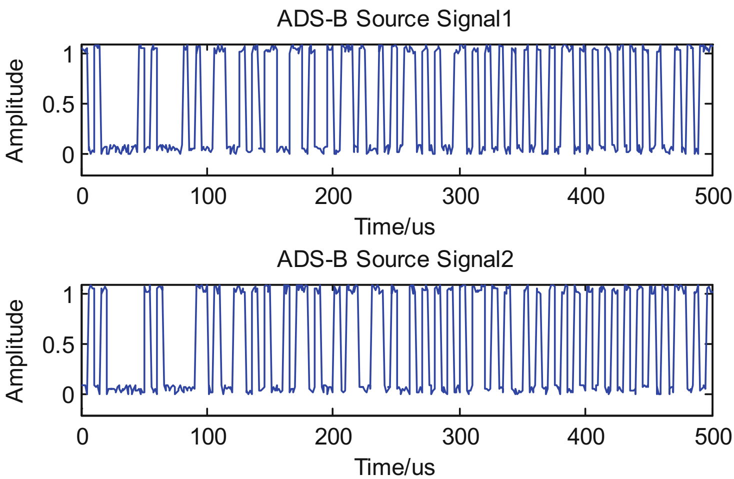

Fig. 5. ADS-B source signal

Using the digital matrix A originated randomly, we randomly mix and overlap the two paths of ADS-B source signals in Fig. 5 and we can obtain the mixed signals received in ADS-B base stations shown in Fig. 6. In the signals shown in Fig. 6, the identification of signal head couldn't be operated at all and it's hard to use normal ADS-B decoding algorithm to decode, causing the loss of two paths of ADS-B signals.

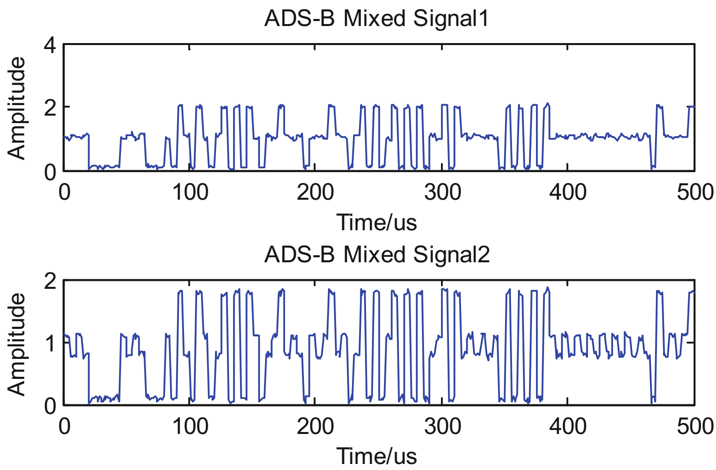

Fig. 6. Mixed ADS-B signals

We handle the signals via the Infomax extension algorithm, and separate the ADS-B mixed signals, gaining the separated ADS-B signals shown in Fig. 7. After comparing the ADS-B source signals shown in Fig. 5 and the separated ADS-B signals shown in Fig. 7, we can find that two paths of signals are substantially the same as each other, and the separated signals can be used to decode ADS-B signals. At the same time, in order to compare the error between source signals and separated signals, we output the signal crosstalk error in each iterative computation. As shown in Fig. 8, Infomax extension algorithm can separate ADS-B signals in a short time and has better astringency.

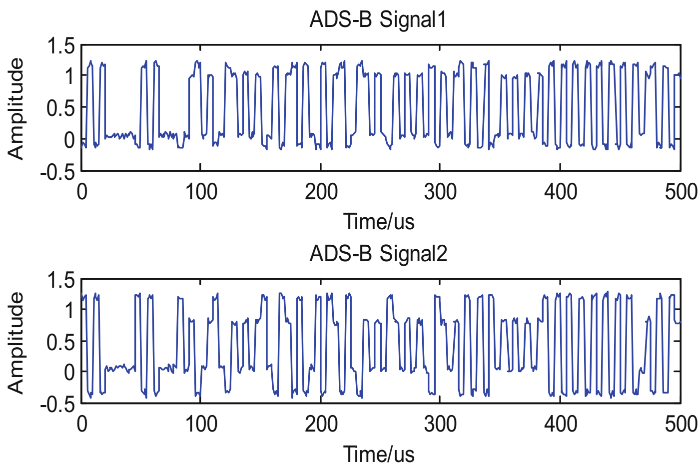

Fig. 7. ADS-B separated signals

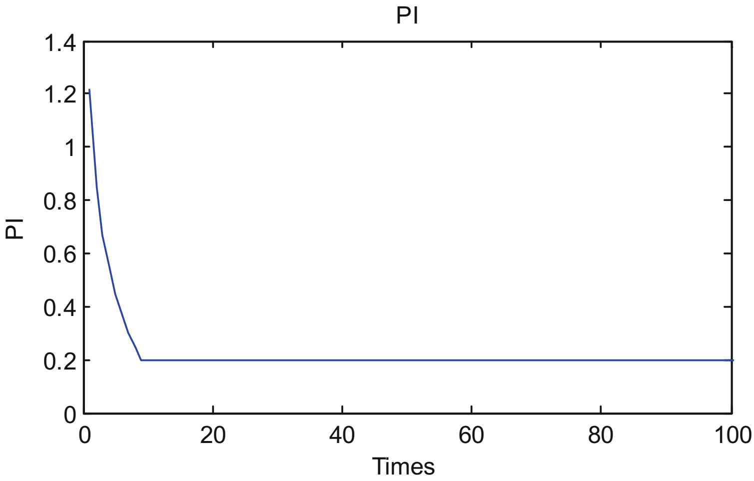

Fig. 8. Crosstalk error

5 Analysis of Simulation Results

Via the simulation analysis, it can be seen that the separated ADS-B signal waveform is substantially the same as the original signal, satisfying the ADS-B decoding algorithm's demands on ADS-B characteristic signals. From the PI curves, it can be seen that the error of separating noise signals via Infomax extension algorithm is little, which separates the ADS-B signals better. And ADS-B signal separation matrix can satisfy the demands of ADS-B separation more quickly. The value of PI in convergence is only 0.1957.

6 Conclusion

This article mainly discusses the ADS-B overlapped signal separation algorithm based on Infomax extension algorithm and the basic realization principle of Infomax extension algorithm. The effect of Infomax extension algorithm on ADS-B signal separation is checked with simulation experiment, and the feasibility of Infomax extension algorithm in ADS-B signal separation is verified.

References

1. Bell, A.J., Sejnowski, T.J.: An information maximization approach to blind separation and blind deconvolution. Neural Comput. **7**(6), 1129–1159 (1995)
2. Lee, T.W., Girolami, M., Sejnowski, T.J.: Independent component analysis using an extended infomax algorithm for mixed subgaussian and supergaussian sources. Neural Comput. **11**(2), 417 (1999)

3. Yan, H., Hua, H.: Noise removal in electroencephalogram signal via independent component analysis approach based on the extended information maximization. Chin. J. Tissue Eng. Res. (09) (2013)
4. Luo, Z., Zhou, W.: A modification to the blind source separation and its application on SEMG*. Chin. J. Sens. Actuators **22**(8) (2009)
5. Wu, X., Zhang, D.: The convergence property analysis of infomax algorithm. Comput. Eng. Appl. (7), 49–51, 59 (2003)
6. Guo, X., Wu, X., Zhang, D.: The application of Independent component analysis in the pattern extraction of mental EEG. Microcomput. Dev. (6), 36–39 (2002)