Novel Adaptive Algorithm using Independent Component Analysis for Array Antenna System

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Abstract

In this paper, we propose a novel adaptive algorithm based on Independent Component Analysis (ICA) for multi-antenna systems. The proposed algorithm directly decomposes the observed signals at each antenna directly without any preamble signals or any array responses, when the observed signals are described as a linear combination of statistically independent source signals. The decomposed signals are almost same as the source signals without scale. The apaptive weight vectors are computed by the Minimum Mean Square Error method with the decomposed signals as a reference. The theory of ICA and the experimental results are demonstrated in this paper. The proposed algorithm is useful for the blind signal separation of wireless communication systems and future cognitive wireless systems.

1. Introduction

The problem of the interference between wireless systems becomes actural according to the recent rapidly development of consumer wireless systems. In order to avoid the interference, the adaptive antenna system is developed[1][2][3]. The adaptive antenna is able to decompose the wireless signal mixture. The conventional adaptive algorithm is not available to make a connection channel, because any information is not given as the preamble signals and an array response is known.

This paper presents a adaptive algorithm using Independent Component Analysis (ICA). ICA was proposed first by Herault & Jutten in 1986. A Fast-ICA, which is fast and robust ICA method, was proposed by Hyvarinen & Oja in 1997[4]. In the audio and the image processing, the ICA has been applied to many applications. However, there has been several report on the antenna signal processing to the best of our knowledge.[7][8] The proposed algorithm is expected to work well at the early connection phase, because the ICA uses the statistically independence as a key to decompose the mixture.

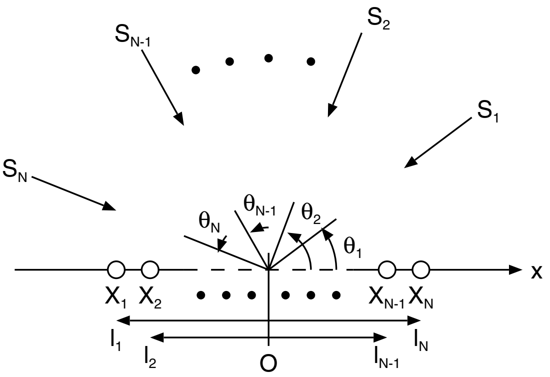


Fig. 1: Configuration of Adaptive Array Antenna

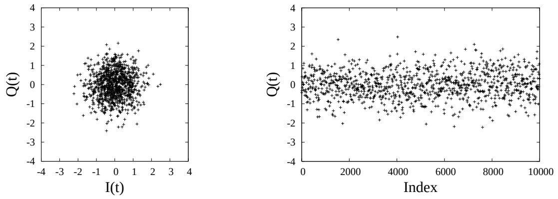
2. Theory

The configuration of the traditional adaptive array antenna is shown in Fig.1. The antenna elements are periodically arranged with the distance of tx_i. The source signals with angle of θ_j are arrived at the phase center of the array antenna. i indicates the antenna index and j indicates the source index. Every antenna element observes the mixture x_i of the source signals. The observed signals are described as eq.(1)

$$\mathbf{X} = \mathbf{AS} + \mathbf{N} \tag{1}$$

One of observed signals x_1 is shown in Fig.2. The total number of source signals is 10. The elements of the mixture matrix $\mathbf{A}$ are complex random numbers. The signal-to-noise ratio was set to 12dB. The signal was normalized with the variance of one and the expectation of zero. Fig.2(a) shows the consterattion diagram of the mixture where the x-axis indicates I-component of the signal and the y-axis indicates Q-component of the signal. Fig.2(b) shows the time variation of the mixed signals where the x-axis indicates the index of the sample. The other signals are the same as previous one. The observed signal looks like the gaussian noise.

ICA decomposes the mixture of source signals. The statically independence between the source signals plays an important role for decomposition. From the Center Limit Theorem, the probability density function (PDF) of the mixture



(a) Constellation (b) Constellation

Fig. 2: Mixtured Signal x_1 (One of 10 Signals)

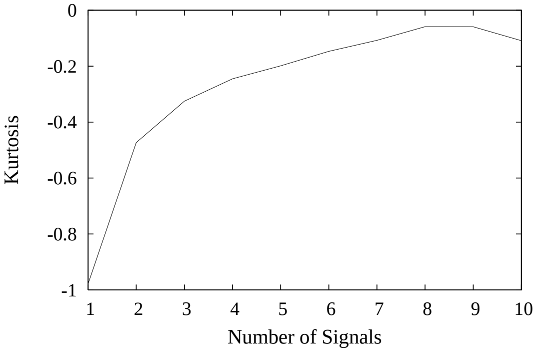


Fig. 3: Kurtosis of Mixture

consisting of infinite independent signals corresponds to the gauss function. Therefore, the distribution difference between the single independent signal and the gaussian noise is greater than between the mixturee signals and the gaussian noise.

The kurtosis is one of the popular criteria for the distribution difference between the signal and the gaussian noise. For the complex signal, the definition of the kurtosis is given by eq.2.

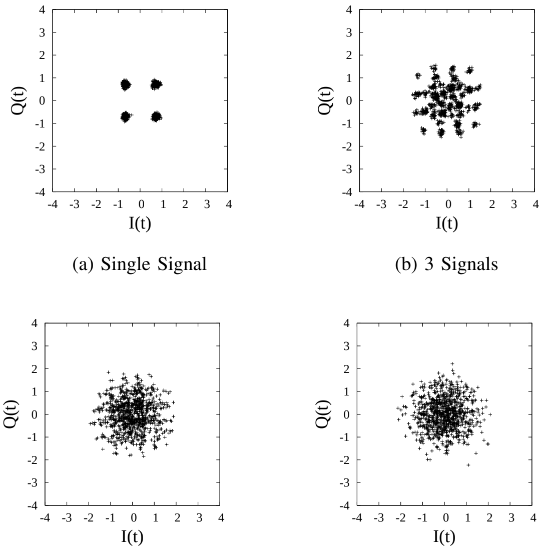
$$\mathrm{kurt} = \mathrm{E}\left\{|x|^4\right\} - 2 \tag{2}$$

The kurtosis is close to zero when the the signal corresponds to the gaussian noise. Figure 3 shows the kurtosis of the mixed signals which is indicated in Fig.4. Figure 4 shows the typical constellations for the mixtured signals; single, 3, 5 and 10 signals are shown. The mixture is close to the gauss noise when increasing the number of signals. Similarly, the kurtosis is close to zero when the number of signals increases.

Here, the decomposed signal $\mathbf{Y}$ is expressed by eq.3.

$$\mathbf{Y} = \mathbf{W}\mathbf{X} = \mathbf{W}\left(\mathbf{A}\mathbf{S} + \mathbf{N}\right) \tag{3}$$

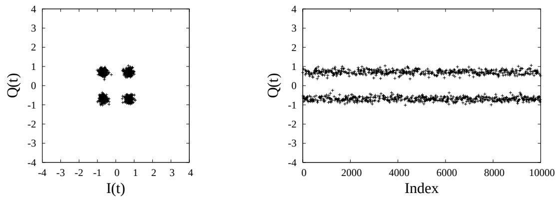
ICA estimates the decomposition matrix $\mathbf{W}$ to be the maximum kurtosis of $\mathbf{Y}$ as the cost function. When the kurtosis is maximized, the signal is expected to $\mathbf{Y}$ to the set of source signals except for the order and the scale. The kurtosis is



(a) Single Signal (b) 3 Signals

(c) 5 Signals (d) 10 Signals

Fig. 4: Constellation Diagram of Observed Signal



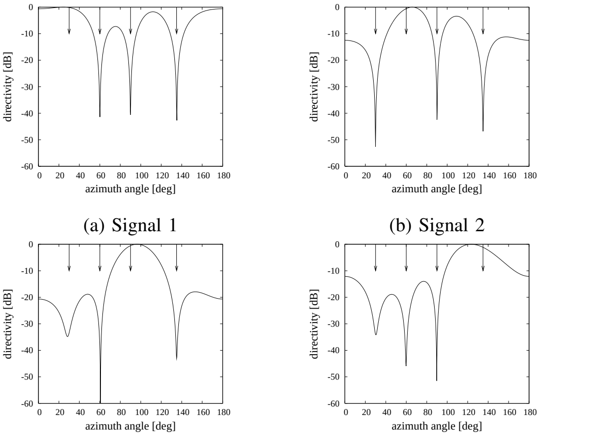
(a) Constellation (b) Time Variation

Fig. 5: Decomposed Signal from Mixtured Signals using ICA (One of 10 Signals)

a basic criterion to ICA, however much better criterion was proposed, e.g., negentropy. The fast-ICA is the most popular algorithm to maximize the criterion. The modified fast-ICA for complex values with negentropy[5] was used here.

Figure 5 shows the decomposed signals from the mixed signal (10 signals) by ICA. The QPSK constellation and the time variation of signal are recovered from the mixture. The SINR of the recovered signal was about 6dB in this simulation.

The weight vectors for the array antenna can be determined using the Minimum Mean Square Error for the recovered signal by the ICA as the reference. The synthesized far field pattern of the array antenna is shown in Fig.6 In order to simplify the pattern, 4 arrivals and 4-element antennas are used in this calculation. The undesired signals are supplessed by the antenna directivity. Therefore, the ICA with MMSE (ICA-MMSE) method is applicable to the adaptive array antenna control.



(a) Signal 1 (b) Signal 2

(c) Signal 3 (d) Signal 4

Fig. 6: Synthesized Far Field Pattern of Adaptive Array Antenna (Period : $\lambda_0/2$, 4 Antennas, 4 Signals, Omni Directional Element)

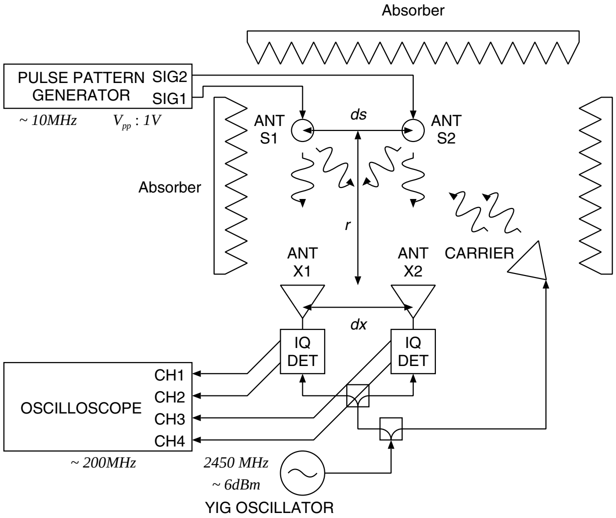


Fig. 7: Experimental Setup

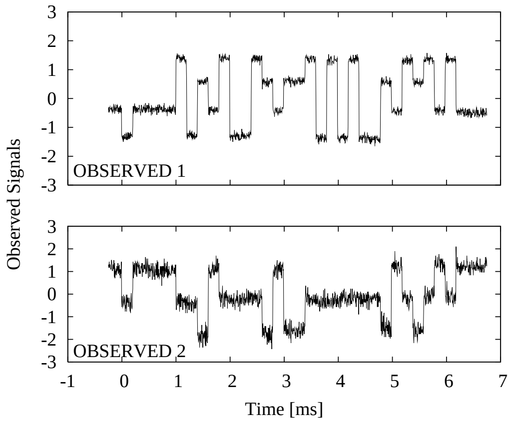


Fig. 8: Observed Signals

3. EXPERIMENT

The decomposition experiment was demonstrated for the RFID systems. In order to simplify the equipment, the ASK modulated source signal was used. 2 sources and 2-element antennas were used. Figure 7 shows the experimental setup. The antennas are located at same distance from the phase center. With the undesired signals supposed, a single signal can be detected. The carrier signal from YIG oscillator with the frequency of 2450MHz and the power of 6dBm was delivered through the coaxial cable. The carrier signal was radiated from the transmittance log-periodic antenna. The radiated carrier wave was scattered by the source antennas S_1 and S_2. The load of S_1 and S_2 vary according to the signal generated by the pulse pattern generator. The antennas X_1 and X_2 recieved the mixture of the scattered signal modulated with ASK. The recieved signals were recorded by the sampling oscilloscope. When the distance dx between antennas was 1.22 λ_0, r was 3.27 λ_0 and ds was 1.31 λ_0.

The program of the proposed algorithm was written in octave like MATLAB. For the BPSK or the ASK signals, the real valued ICA works well. Therefor, we use the only I-component of the recieved signals for the decomposition. The observed signals are shown in Fig.8. The x-axis indicates time in [mSec], the y-axis indicates the normalized I-component value. The mixture of the source signals was observed at each reciever antennas.

Figure 9 shows the decomposed signal from the observed signals. The properties are the same as before. The recovered signals are in good agreement with the source signals. It is the advantage of the proposed method that the only I(or Q) component of the observed signal is needed to decompose the mixture for the ASK and the BPSK signal. For the QPSK signal and more complicated modulation signal, the ICA-MMSE should be used to decompose the mixture, which leads to the synthesis of the far field pattern.

4. CONCLUSION

The novel adaptive algorithm based on Independent Component Analysis are proposed and demonstrated in this paper. The ICA decomposes the mixture of the source signals using the independence criteria, e.g. kurtosis, negentropy. The Center Limit Theorem plays an important role in the ICA decomposition. The ICA-MMSE algorithm synthesizes the weight vectors of the array antenna. The simulation results of the decomposition for the QPSK signals are shown. The proposed algorithm works well in the simulation. The experiment using the RFID system was demonstrated. The system works well in

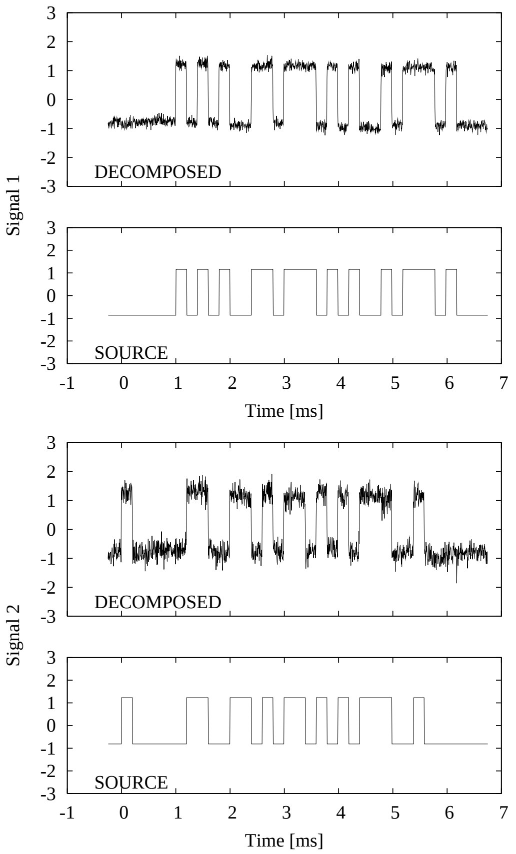


Fig. 9: Decomposed Signals

the experiment, too. The proposed algorithm is useful for the adaptive array to control, the MIMO communication systems and the future cognitive wireless systems.

Acknowledgements

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