Suppression of Impulsive Noise in Power Line Communication using Weighted FastICA

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Abstract. In this paper, a weighted blind source separation (BSS) method is developed to eliminate $\alpha$-stable distribution impulsive noise in the power line communication (PLC). In this work, a weighted independent component analysis (ICA) is conceived to construct the determined ICA model from a single channel observation. This operation can achieve the advantages of low complexity blind separation work and exempting channel parameter estimation. The system noise model is described by the transmission characteristic of power line. Simulation experiments show that the proposed ICA algorithm can effectively achieve noise elimination, and guarantee the practical communication requirements.

1. Introduction

Power line communication refers to communication technology and system applications relying on power lines and transmission and distribution networks as transmission media[1]. It is a kind of communication technology which does not need to be re-wired and uses existing power line resources to transmit data, voice, video, etc. Compared with wireless communication, PLC provides users with high-speed Internet access services and voice services, thus increasing new options for users to access the Internet and make phone calls, which is conducive to other telecommunications service providers to improve their services and reduce prices[2-4].

Existing power lines are mainly used for power transmission, on which there are variations in line impedance, frequency selective fading and various noises, so power lines are not suitable for signal transmission. Noise interference is one of the most important factors affecting PLC performance[5]. Especially, impulse noise has the greatest influence on signal transmission. As the impulse noise is so unpredictable in its pattern and of great energy level to swallow the signal we need, traditional signal processing methods exhibit no much use in dealing with this problem without prior information about the mixing process or the generation of the signals[6-7]. But the ICA based blind source separation (BSS) method can solve it effectively. ICA can separate or extract unobserved sources from the mixed signals with little prior information[8]. In such case, blind method guarantees a high communication accuracy by separating the source signals and noise.

In order to suppress impulse noise, various methods for suppressing impulse noise have been proposed in different literature. The simple and universal method is blanking and clipping to the received signal in time domain[9-10]. These methods are easy to implement and have low complexity, but the impulse noise on the power line is time-varying. In practical applications, it is very difficult to obtain the optimal amplitude blanking and clipping threshold. Andreadou et al. use error correction coding to suppress power line impulse noise[11-12]. This technique reduces the occurrence of error...
bits in transmission process by increasing redundant bits of transmitted data. In [13], Zhidkov proposed a method to reduce impulse noise without noise characteristic parameters. The OFDM demodulated signal is compensated in frequency domain for impulse noise. When the amplitude of impulse noise increases or the OFDM signal is modulated by high-order modulation, the effect of noise suppression will be greatly reduced. In [14], Naffouri uses compressed sensing to estimate impulse noise roughly, then uses a matrix based on prior information to estimate the position of impulse noise accurately. Finally, the MMSE method is used to recover the signal. This method needs to know the probability density function of impulse noise in advance. However, in practical power line communication, the probability density of impulse noise is often difficult to predict. Mehboob and Ren proposed an adaptive impulse noise suppression method to reconstruct impulse noise[15-16]. But this method needs to know the characteristic parameters of impulse noise in advance, such as variance, etc. Once the parameter estimation is not accurate, the effect of noise suppression will be difficult to meet the actual needs. From previous literature, note that traditional noise suppression methods have certain limitations, and most of them depend on the characteristic parameters of noise. However, if the channel state information and noise features are unknown, the existing methods are not applicable. The annoying channel and noise parameters must be estimated before noise suppression assignment. For this problem, the blind separation mechanism is very promising and attractive for achieving adaptive interference cancellation.

In this paper, a key idea that weighted FastICA (Fast Independent Component Analysis) algorithm without prior knowledge is conceived to filtering out the impacts of the impulsive noise in the power line communication. Through weighted transformation, the multivariate blind separation model is constructed, and then FastICA algorithm can effectively separate source signal from noise. In Section II, the signal model is given. The principle of the algorithm is shown in Section III. The experimental results are presented in Section IV. Finally, the conclusions are drawn in Section V.

2. Signal Model and Problem Formulation

2.1. $\alpha$-stable distribution.

Except for Gaussian distribution($\alpha = 2$), Cauchy distribution($\alpha = 1, \beta = 0$) and Pearson distribution($\alpha = 0.5, \beta = -1$), the probability density function of $\alpha$-stable distribution has no uniform expression, and is generally described by its characteristic function. In [17], it can be expressed in (1).

$$\phi(u) = \exp \left\{ j a \mu - \gamma \mu^\beta \left[ 1 + j \beta \text{sgn}(\mu) \omega(\mu, \alpha) \right] \right\}$$

(1)

Where parameter $\alpha \in (0, 2]$ is characteristic index, which determines the degree of pulse characteristics of the distribution. The smaller the $\alpha$ value, the thicker the tail of the corresponding distribution, so the more significant the pulse characteristics. When $\alpha = 2$, the eigenfunction (1) becomes $\phi(\mu) = \exp \left\{ j a \mu - \gamma \mu^2 \right\}$, which is the same as the Gaussian distribution with the mean $a$ and the variance $2\sigma^2$, that is, the Gaussian distribution is a special case of the stable distribution of $\alpha$. The parameter $\beta \in [-1, 1]$ is called a symmetry parameter and is used to determine the slope of the distribution. $\beta = 0$ corresponds to a symmetric distribution, abbreviated as $S\alpha S$. The parameter $\gamma$ is called the dispersion coefficient, also known as the scale coefficient, which is a measure of the degree of dispersion of the sample relative to the mean, similar to the variance in the Gaussian distribution. However, in Gaussian case, the dispersion coefficient is twice the variance. The parameter $a$ is called a position parameter. For $S\alpha S$ distribution, if $\alpha \in (0, 1]$, then $a$ means the mean, otherwise, $a$ means the median.

2.2. Signal model and problem formulation
In this paper, assuming that both impulse noise and Gaussian noise coexist in the process of signal transmission. Therefore, the signal noise model can be written in (2).

\[ x(t) = as(t) + bn_s(t) + n(t) \]  

(2)

Where \( s(t) \) is OFDM source signal, \( n(t) \) is Gaussian noise, \( n_s(t) \) is impulse noise subject to \( \alpha \)-stable distribution, this article will use these three sources. \( a, b \) is equivalent to channel influence factor. Due to the advantages of blind separation [8], it will be considered to achieve noise cancellation in this paper. We don’t need to estimate the channel influence factor by help of blind separation.

It is noteworthy that Independent component analysis (ICA) can be described by \( X = AS \), where \( X \) is the \( M \) dimensional observation signal, \( A \) is \( M \times N \) the dimensional mixed matrix, and \( S \) is the \( N \) dimensional signal source. In general, ICA is multivariate data-driven method and fit for blind separation of determined model \( (M = N) \) and overdetermined model \( (M > N) \). Especially, it is difficult to complete source extraction and separation at the condition of \( M = 1 \). This is a well-known single blind separation problem, which has attracted tremendous attention from academic community.

Note that the equation (2) is single observed model, so the weighted method will be conceived to constructed a determined blind separation model and implement blind noise cancellation.

3. Weighted FastICA Algorithm Principle

Consider the received model (3), the two random weighted factor \( w_1, w_2 \) is injected to build a ICA processing model, namely,

\[ x'_1(t) = a_{11}s(t) + a_{12}n_s(t) \]
\[ x'_2(t) = a_{21}s(t) + a_{22}n_s(t) \]  

(3)

In equation (3), the Gaussian noise is not considered but used in simulations. Because of whiten processing, this assumption is reasonable. In equation (3), \( a_{ij} = w_i a, a_{22} = w_j b \). The dimension of the mixture matrix \( A \) is \( 2 \times 2 \), so that the observed signal is 2 channels, and both signals contain source signals, and impulse noise, as shown in equation (4).

\[ X = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} s(t) \\ n_s(t) \end{bmatrix} = AS \]  

(4)

Independent Component Analysis (ICA) aims to separate independent signals from unknown observed mixed signal, and to reproduce each of the independent source signals separately. This process also could be modeled as that in the flow chart that follows in Figure 1.

![Figure 1. ICA block diagram](image)

Basically, current ICA algorithm researches can be classified into two categories, one is iteration estimation methods based on information theories and principles, and the other is algebraic approaches based on statistics. In this article, FastICA algorithm of negative entropy maximization estimation method based on information theories is mainly discussed.

Non-Gaussian is a commonly used criterion for ICA. Compared with Gaussian noise and useful signals, \( \alpha \)-stable distribution noise is the strongest non-Gaussian, so according to non-Gaussian, using FastICA algorithm based on negative entropy, \( \alpha \)-stable distribution impulse noise can be extracted first.

For independent component analysis, a few pre-processing steps and a loop calculating process need to take places to apply the FastICA algorithm to the observed signals. A specific flow chart is
presented in Figure 2.

![Flow Chart of The FastICA Algorithm](image)

Figure 2. The Flow Chart of The FastICA Algorithm

4. Simulation and Analysis

The signal model uses the introduced in section 2.2, the OFDM modulated signal is the source signal, the carrier frequency is 1000, its sampling frequency is 32000, and the number of sampling points is 10000. The parameter $\alpha$ of the $\alpha$-stable distribution noise takes different values in the specific simulation, $\alpha = 0.8, \beta = 0, \gamma = 1, \alpha = 0$. Mixed matrix $A$ is a $2 \times 2$-dimensional random matrix. The base signals are depicted in Figure 3.

However, according to what had been discussed before, the number of the observation signals has to be bigger than the number of the source signals. So here as two source signals, namely the OFDM signal and the impulsive noise signal, are both treated as the inputs to the communication system, at
least two mixed observation signals are needed to truly recover the inputs.

To generate the two random mixed observation signals, one by another, the two random number couples used as mixing weighing assignment vectors are multiplied respectively with the OFDM signal and the impulsive noise signal, then the results are added up together to generate the vector of one mixed observation signal. The signal waveform is showed in Figure 4.

In Figure 5, according to the non-Gaussian property, the first signal separated by the FastICA algorithm is impulse noise, which is very close to the original alpha stable distribution noise. Through calculation, its correlation function reaches 0.99.

However, when we change the Gaussian white noise variance, the separation effect is not ideal, which means that the algorithm has high requirements for the non-Gaussian of the input independent components. In Figure 6, the waveforms with increased variance and reduced separation effect are given. Therefore, it is meaningful to achieve robust blind separation in future work.

In addition, this paper simulates the decrease of the coefficient $\alpha$ and the trend of the correlation function, as shown in Table 1. $\alpha \in (0, 2]$, when $\alpha$ decreases, the non-Gaussian property is stronger, and the separation result of the algorithm is better, so the smaller is $\alpha$ correlation coefficient, the
larger is $\gamma$.

| $\alpha$ | 1.8 | 1.6 | 1.4 | 1.2 | 0.8 | 0.6 |
|---------|-----|-----|-----|-----|-----|-----|
| $\gamma$ | 0.7068 | 0.9042 | 0.9242 | 0.9728 | 0.9998 | 1.0000 |

5. Conclusions
In this paper, we developed a weighted FastICA algorithm for impulsive noise cancellation in specific power line communication scenarios. For strong impulse noise of power line communication and real-time changing channel environment, the FastICA algorithm can separate the useful signal and noise without any characteristic parameters. If non-Gaussian impulse noise is stronger, the better separation effect will be obtained. Of course, this algorithm also has certain limitations in the application of power lines, such as separation efficiency and Gaussian noise effect. It is strongly recommended to be investigated in the future work.

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