Improving Fidelity of Field Waveform Extraction in Independent Component Analysis

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***Abstract* — As wireless devices increasingly integrate communication modules and electronic components, mitigating self-generated electromagnetic noise interference is critical. Conventional antenna measurements capture an inseparable mixture of noise and communication signals. To isolate specific interference components, Independent Component Analysis (ICA) is a highly effective method. While our previous research demonstrated that increasing the number of receiving channels improves noise extraction fidelity, increasing the number of channels indefinitely is practically unfeasible. Therefore, this study investigates the optimal number of receiving channels relative to the number of target signals by executing ICA with varying channel counts, aiming to achieve both accurate and practical electromagnetic noise extraction.**

Keywords — independent component analysis (ICA), electromagnetic waveform, fidelity.

I. INTRODUCTION

In recent years, there has been a growing trend of electronic devices incorporating broadband wireless communication capabilities. In such devices, since wireless communication modules and the electromagnetic noise sources often reside within a single enclosure, it is becoming increasingly critical to mitigate interference caused by self-generated electromagnetic noise. However, when measuring electromagnetic noise using an antenna, it is impossible to isolate only the noise components that cause interference; all electromagnetic wave components, including the wireless communication signals, are measured as a mixture. Because these signals frequently overlap in both the time and frequency domains, traditional filtering techniques are often inadequate for isolating the noise without simultaneously degrading the intended communication signals. Therefore, in the rapidly expanding field of electromagnetic wave utilization, there is an urgent need for advanced source waveform estimation methods capable of blindly (no prior information) extracting the specific noise components from mixed observations.

Independent Component Analysis (ICA) is one of the principal methods for extracting specific components from mixed waveforms [1]. Previous research by our group demonstrated that ICA enables the extraction of electromagnetic noise, and that increasing the number of receiving channels enhances the reproduction fidelity of the extracted waveforms [2]. In practice, however, endlessly increasing the channel count is unfeasible. If an optimal number of channels exists relative to the number of target signals, selecting that specific count is highly desirable. To address this, this study evaluates the optimal number of receiving channels against the number of target signals by executing ICA with varying channel counts.

II. PRINCIPLE OF ICA

ICA is a statistical method of extraction based on the observation of a signal in which multiple statistically independent signals are mixed at several different measurement points.

In ICA, the M observed signals are represented by the vector $\boldsymbol{X} = (x_1, x_2, \dots x_M)^T$, and this observed vector $\boldsymbol{X}$ is assumed to be a mixture of N statistically independent unknown independent components forming the vector $\boldsymbol{S} = (s_1, s_2, \dots s_N)^T$ and an $M \times N$ mixing matrix $\boldsymbol{A}$, as shown in (1).

$$\boldsymbol{X} = \boldsymbol{AS} \tag{1}$$

Since the original signal $\boldsymbol{S}$ and the mixing matrix $\boldsymbol{A}$ are unknown values, the purpose of ICA is to separate the information of only the observation signal $\boldsymbol{X}$ into N independent signal components. If $M \geq N$, the problem can be solved as shown in (2), where an $M \times N$ real matrix $\boldsymbol{W}$ exists such that:

$$\boldsymbol{Y} = \boldsymbol{WX} \tag{2}$$

By solving this equation, a vector $\boldsymbol{Y}$ with mutually independent components can be constructed. Here, if the following (3), which is the identity matrix of $\boldsymbol{I}$ $(N \times N)$, holds, the vector $\boldsymbol{Y}$ matches the unknown independent component vector $\boldsymbol{S}$.

$$\boldsymbol{WA} = \boldsymbol{I} \tag{3}$$

The size of each component of the vector $\boldsymbol{Y}$ does not affect independence, and the independence is guaranteed even if the order of each component is changed.

It is usually derived by the following derivation procedure in ICA.

1) Centralize the observation data.
2) Make the data uncorrelated.
3) Orthogonalize each component in the direction of being independent of each other.

However, since the independent component $\boldsymbol{S}$ and the mixing matrix $\boldsymbol{A}$ have unknown values, there are usually innumerable solutions for ICA. Therefore, the following conditions is set to solve this problem.

- The components are independent of each other.
- The distribution of independent components follows a non-normal distribution.