Performance of Digital Drone Signage System Based on DUET

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Abstract

In this letter, we study a scenario based on degenerate unmixing estimation technique (DUET) that separates original signals from mixture of FHSS signals with two antennas. We have shown that the assumptions for separating mixed signals in DUET can be applied to drone based digital signage recognition signals and proposed the DUET-based separation scheme (DBSS) to classify the mixed recognition drone signals by extracting the delay and attenuation components of the mixture signal through the likelihood function and the short-term Fourier transform (STFT). In addition, we propose an iterative algorithm for signal separation with the conventional DUET scheme. Numerical results showed that the proposed algorithm is more separation-efficient compared to baseline schemes. DBSS can separate all

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signals within about 0.56 seconds when there are fewer than nine signage signals.

Keywords: Degenerate unmixing estimation technique (DUET), digital signage, DUET-based separation scheme (DBSS), drones.

1 Introduction

As the market for commercial drones grows, unauthorized drones in certain areas can cause security problems. Techniques for isolating RF signals for detecting unlicensed drones are becoming increasingly important. The blind signal separation (BSS) technique is used to distinguish a signal source when an unknown signal is received. To distinguish signals, antennas are needed as many as the number of signal sources, which has many disadvantages in terms of complexity [1–5]. At the same time, due to spread of commercial drone using frequency hopping spread spectrum (FHSS) on industrial scientific medical (ISM) band, related BSS methods have been variously studied [6–9]. The degenerate unmixing estimation technique (DUET), as one of the BSS methods, was proposed to distinguish voice signals with only two microphones regardless of the number of signal sources [10–13]. In these previous studies, even though the DUET is studied in a RF-domain with MIMO systems, these studies require equal number of signal sources and antennas, which is not appropriate in environments with multiple drones using FHSS signals. In recent, a digital signage system has been proposed to provide customized information for drones [14–17].

In this paper, we demonstrate that the DUET method, which is previously used only for voice signals, can be used for FHSS as well, using the assumptions used in DUET. It also provides a way to effectively classify the FHSS signals transmitted and received through the ISM band in multiple drone's environment. The proposed algorithm, DUET-based separation scheme (DBSS), adds an iteration process to the DUET so that it can be demodulated even in environments with many sources. In addition, only two receive antennas are used regardless of the number of signage signal sources, preventing performance degradation caused by the complexity of receivers. We also simulated how the performance changes depending on the parameters that determine the iteration and the number of signal sources.

The remainder of this letter is as follows. In Section 2, we formulate whether the DUET method can be applied to digital signage signal. In

Section 3, we give a solution for the problem. The simulation results and conclusions are presented in Sections 4 and 5, respectively.

2 Applicability of DUET to Digital Signage Drone Signals

Figure 1 illustrates the proposed digital signage system based on digital drones. The two digital drones use the DUET algorithm to identify the user's signals and pass them on to the display. Digital drones can perform physical relays and signal recognition processes of RF signals. Digital drone is used in next-generation signage system because it can control wireless signals flexibly regardless of physical constraints. Through this, the display can transmit suitable signage for each user. In order to distinguish current FHSS signals, the same number of antennas should be used. This is not appropriate in environments where multiple drones are operated.

DUET scheme is a system model used to separate the mixed audio signals by frequency, but it can also be applied in a mixed environment of FHSS signals. In DUET, the following four assumptions should be applied [10]. The DUET method is implemented under four assumptions: Anechoic Mixing, W-Dispoint Orthogonality, Local Stationary, and Microphone Closed Together [18 , 19].

Anechoic Mixing assumes that the environment where the signal source exists is Line of Sight. The condition is satiated with the drone operated only in the outer field. W-Dispoint Orthogonality is an assumption that the

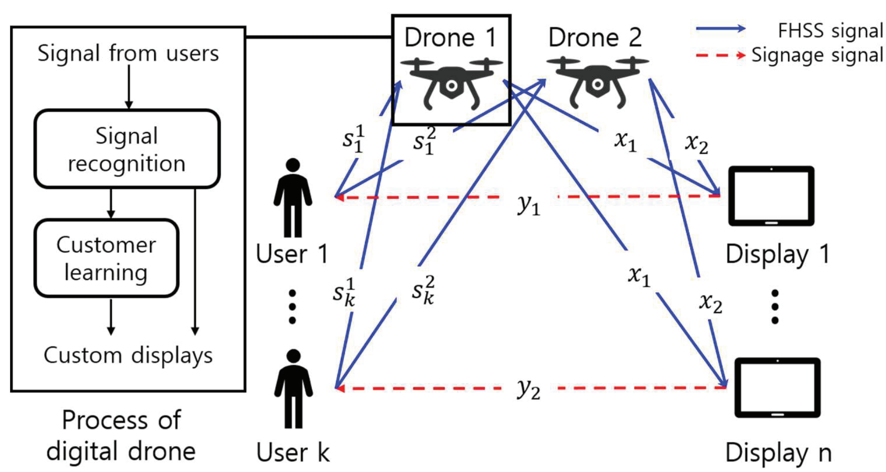

Figure 1 A system model of digital signage display based on two digital drones.

source of the signal is independent. This acceptance is accepted for the drones because the FHSS signal generated by the drones has different factors. Local Stationary is the assumption that the signal source does not affect other signal information All the drones performance with their communication with their response transmits, then FHSS signal from the drones satisfying the charges. Microphone Closed Together assumed that the distance between the antennas should be less than a certain level. In this paper, the DUET simulation limits the distance between the antennas to less than 5 cm.

We agreed that the four options in the DUET can be applied to the FHSS signal used by the Drone.

3 Feasibility of DUET to FHSS Signals

Figure 2 illustrates the identification of FHSS signals in the DUET scheme. The original signal s is represented by the mixture signal a caused by multipath channel. DUET method uses two antennas that demodulated the mixture signal a estimate the number of digital signage signals. Figure 3 illustrates the proposed algorithm for separate FHSS signals on field. First, it receives the mixer signals x_1 (t) and x_2 (t) for two antennas as shown in

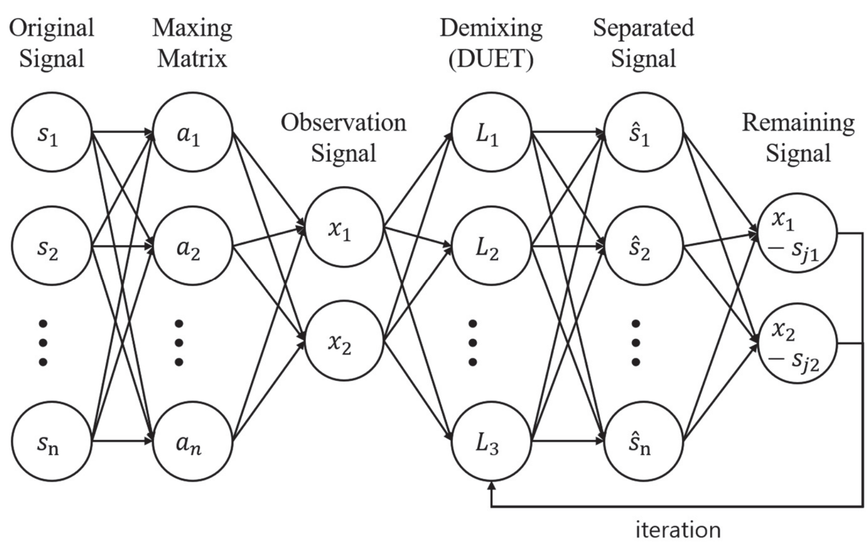

Figure 2 System model of proposed DBSS algorithm.

Equation (1). A short-term Fourier transform of the time-domain signals of Equation (1) yields a signal expressed as a time-frequency value $S_j(\tau,\omega)$. Also, by applying the W-Disjoint Orthogonal (W-DO) assumption of the Fourier transform pair $s_j(t-\delta) \leftrightarrow e^{-i\omega\delta}S_j(\omega)$ and the signal of drones, the following equation can be obtained:

$$\begin{bmatrix} \frac{X_1(\tau,\omega)}{X_2(\tau,\omega)} \end{bmatrix} = \begin{bmatrix} 1 \\ \alpha_j e^{-i\omega\delta_j} \end{bmatrix} S_j(\tau,\omega). \tag{1}$$

Then, solving the above simultaneous equations, we can estimate the parameters representing the relative attenuation between channels $\alpha_j(t)$ and the delay $\delta_j(t)$ as follows:

$$(\alpha_j,\delta_j) = \left(\left| \frac{X_2(\tau,\omega)}{X_1(\tau,\omega)} \right|, -\mathrm{Im}\left(\ln \frac{X_2(\tau,\omega)}{X_1(\tau,\omega)} \right) \Big/ \omega \right). \tag{2}$$

We can estimate the energy histogram for all α_j and δ_j and find the position of the peak component in the obtained histogram. Given a using the following equation:

$$\begin{aligned} L_j(\tau,\omega) &= p(X_1(\tau,\omega), X_2(\tau,\omega|\alpha_j,\delta_j)) \\ &= \frac{1}{2\pi\sigma^2} e^{-\left(\frac{1}{2\sigma^2}\right)\left|\alpha_j e^{-i\delta\omega} X_1(\tau,\omega) - X_2(\tau,\omega)\right|^2 / (1+\alpha_j^2)}. \end{aligned} \tag{3}$$

(3) is the separated signal from STFT form of the received signal $\mathrm{S_j}(\tau,\omega)$. Through this subtraction, the sum of the non-separated signals can be obtained. In this algorithm, this process is repeated until the average power of the unseparated signal is less than iteration threshold λ_i. The lambda is set to the ratio of received power of the mixture signal $x(t)$.

The algorithm pseudocode for DBSS is described as follows.

Algorithm 1 The proposed algorithm of iteration DUET

1: **Input**: mixture signal $x(t)$, threshold λ_i
2: **Construct** STFT for input $S_\mathrm{j}(\tau,\omega)$
3: **While** $S_j(\tau,\omega) > \lambda_i$
4: **Initialize** simultaneous Equation (7), $L_j(\tau,\omega)$
5: **Update** $S_\mathrm{j}(\tau,\omega) = S_j(\tau,\omega) - L_j(\tau,\omega)$
6: **Construct** Inverse-STFT of separated signal
7: **Output:** separated signal S_j, separation accuracy

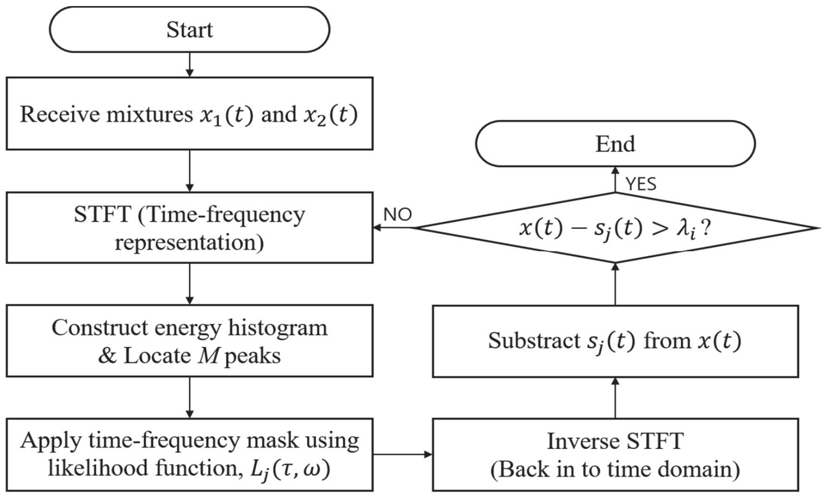

Figure 3 The proposed algorithm of iteration DUET for digital signage signals.

4 Simulation Results

In this section, we provide simulation results to show the effectiveness of DBSS. The system is set up as follows:

Table 1 Simulation parameters

Parameter	Value
Center frequency	2.45 GHz
Distance between drones	>5 meters
Distance between drone and receiver	120 meters
Hopping channel	24 channels
Frame rate (iteration time)	22ms
Receiver	NI USRP-2920
Modulation	BPSK
Sampling times	10^4

Figure 4 shows a simulation of full separation probability according to the number of signal sources. In Figure 4(a), when the number of signal sources is 8 or less, the DBSS can separate the received FHSS signal within 0.56 seconds (STFT calculation and 12 iteration). Commercial drones are usually operated at 250 meters and at a flight speed of 40 km/h, so the FHSS operation speed is enough to control the unlicensed drones. Figure 4(b) shows a performance simulation based on the value of the iteration threshold λ_i for

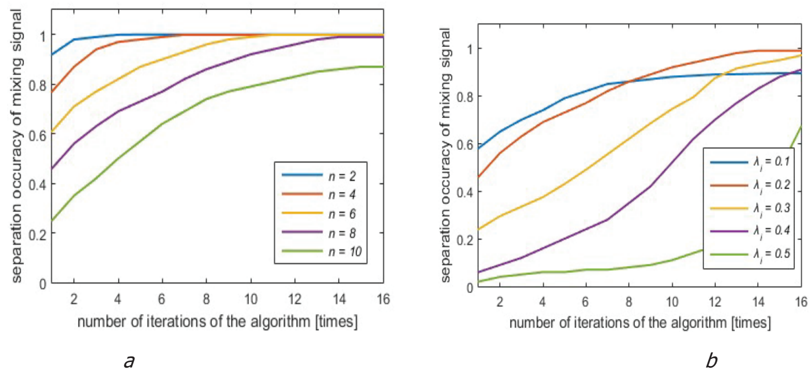

Figure 4 Signal separation accuracy versus iteration of proposed algorithm (a) when $\lambda_i = 2$ and (b) when $n = 8$.

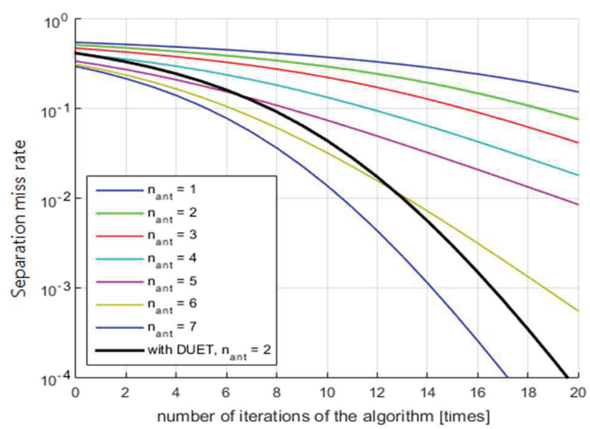

Figure 5 Signal separation accurate curve with and without DBSS method.

the same number of signal sources (n = 8). If the lambda is too high ($\lambda_i = 0.5$ in Figure 4), it will not be able to isolate the signal and will only iterate the algorithm with the same input. Therefore, we need to set proper λ_i depending on the number of sources.

Figure 5 shows the accuracy of separation of FHSS signals with and without the DBSS method. The number of signal sources is seven, and $\mathrm{n_{ant}}$ is the number of antennas. When DBSS is not used, the performance difference clearly varies according to the number of antennas. Using the DBSS method, you can achieve performance like using 6 antennas while using only 2 antennas.

5 Conclusion

In this letter, we have proposed an iterative DBSS algorithm based on DUET system to separate the digital signage signals from drones. Using the proposed algorithm, we can optimally separate multiple FHSS signals using only two antennas. Simulation results demonstrated the signal can be separated effectively through proper adjustment of the parameters.

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Biographies

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