Drone Detection and Speed Estimation Algorithm through Singular Vector in LFM Chirp Pulse Radar

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Abstract

Due to the development of unmanned mobile technology and cost reduction, unmanned mobile vehicles are increasingly commercialized, and unmanned mobile vehicles are being operated in various fields. At the same time, the damage caused by unmanned mobile vehicles is rapidly increasing, but it is difficult to detect in an urban environment as unmanned mobile vehicles are miniaturized and high-performance due to technological development. It is difficult to detect and estimate the speed of drones moving at low speeds. In this paper, we present a signal processing algorithm capable of distinguishing between clutter signals and low-speed target drones and detecting and estimating the speed of low-speed target drones even in clutter environments.

1 Introduction

Recently, the drone industry is growing significantly due to the development of drone technology and the reduction of development costs, and drones that were previously used only for special purposes are also widely used for civilian purposes. As the accessibility of drones increases, there are many advantages, but on the other hand, malicious terrorism using them is increasing. In particular, terrorism against major national facilities (airports, substations) and military facilities causes many dysfunctional factors.

Conventionally, as a method of detecting a moving drone, a technique of distinguishing a stationary clutter signal and a drone signal through a spectrogram using an MTD (Moving Target Detection) algorithm is used[1]. However, existing studies have limitations that are very difficult to apply to low-speed drones. In this study, by overcoming the limitations of the conventional technology, we distinguish between clutter signals and low-speed target drones. In addition, we present a signal processing algorithm capable of detecting and estimating the speed of a target drone moving at low speed even in a clutter environment.

2 Overview of Target Detection and Velocity Estimation SVD Algorithm

The pulse signal reflected by the drone after being transmitted by the TX system is received through the RX system. And this signal goes through the pulse compression process through the digital signal processing stage. The pulse compressed signal is:

$$\begin{aligned} S(t) &= A\left\{\alpha rect\left(\frac{t-t_{rx}}{\tau}\right)\exp\left(j\left(\phi_L^{RX}(t)+\pi\alpha\left(t-t_{rx}\right)^2\right)\right)\right. \\ &\quad +\beta rect\left(\frac{t-t_{rx}-\tau_{\text{target}}}{\tau}\right) \\ &\quad \left.\exp\left(j\left(\phi_{\text{Target}}^{RX}(t)+\pi\alpha\left(t-t_{rx}-\tau_{\text{Target}}\right)^2\right)\right)\right\} \end{aligned} \tag{1}$$

where $\phi_L^{RX}(t)$ and $\phi_{Target}^{RX}(t)$, are phase noise of leakage and target signal. And A, α, β means the changed signal amplitude for leakage, target and total, respectively.

To apply the singular value decomposition algorithm, the received I/Q data is rearranged into a matrix. At this time, the row is the sample array corresponding to one PRI, and the column corresponds to the number of pulses. The signal separated using SVD (Singular Value Decomposition) is:

$$\mathbf{Y} = \underbrace{\sum_{i=1}^{m_1}\sigma_i\mathbf{u}_i\mathbf{v}_i}_{\text{Leakage of RX}} + \underbrace{\sum_{i=m_1+1}^{m_2}\sigma_i\mathbf{u}_i\mathbf{v}_i}_{\text{Target of RX}} + \underbrace{\sum_{i=m_2+1}^{m_3}\sigma_i\mathbf{u}_i\mathbf{v}_i}_{\text{Noise of RX}} \tag{2}$$

When the singular value decomposition algorithm is applied to the rearranged matrix, it is divided into a diagonal matrix composed of singular values and two orthogonal matrices. At this time, the column vector of the orthogonal matrix on the left is called the left singular vector, and the column vector of the orthogonal matrix to be multiplied on the right is called the right singular vector. The left singular value vector means data composed of samples corresponding to the sample time in one pulse, and the right singular value vector means data as many as the number of pulses rearranged in the pulse period. The singular value, which means the amount of information of the decomposed matrix, reflects the intensity information of the reflected target[2].

By utilizing these characteristics, a stationary clutter signal and a low-speed drone signal are distinguished. In addition, the Doppler information of the drone signal moving at a low speed of the received signal is loaded on the phase change information according to the pulse period. At this time, the Doppler information is loaded on the right singular value vector. Therefore, if FFT is applied to the right singular value vector, the speed of the target drone can be extracted.

3 Pulse Doppler radar structure and experimental setup

Pulse Doppler radar is largely composed of a transmitter, a receiver, a digital signal generator, and a digital signal processing stage. The LFM signal has a chirp rate of 15 MHz, a chirp duration of 4 usec, and a PRI of 60 usec. This signal is converted into a 9.405~9.420GHz signal through an upconverter and transmitted through a 19.2dbi antenna at 200W intensity. In the above signal, the leakage signal and the target signal are received through the same antenna. The received signal is converted into a digital signal with a sampling rate of 50 MHz through USRP X310, and the signal is processed through MATLAB in a computer. This experiment was conducted on the roof of Munji-dong, KAIST, Daejeon, and DJI Inspire 2 was used as the drone.

Figure 1. Pulse Doppler radar structure and experimental setup

4 Experimental results and discussion

The algorithm was applied using real I/Q data using a pulse doppler radar and a low-speed moving drone. To use the algorithm, 1000 pulse signals were accumulated. The result of pulse integration for the accumulated signals is shown in Fig. 2. The phase of the signal changes randomly due to the channel environment between the radar and the target and the moving characteristics of the target, and as a result of pulse integration, the signal strength to the target decreases.

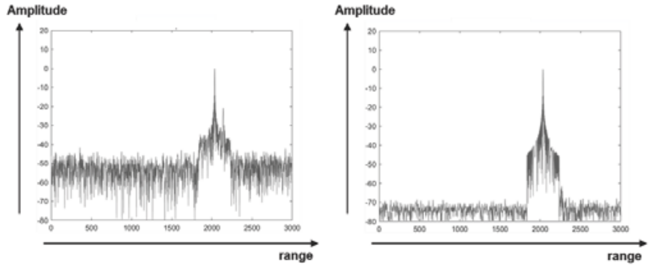
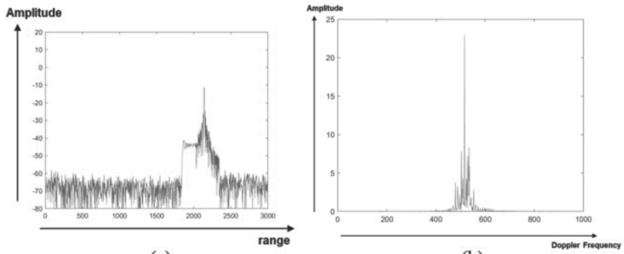


Figure 2. Pulse compression and Pulse integration result of Received signal reflected from the target

The phase change of the target signal reduces the SNR in pulse integration, which simply adds the result of pulse compression. However, in the SVD algorithm, it plays a role in separating the target and other signals. In addition, the velocity information can be extracted by separating the phase information as it is into the singular vector. This result can be seen in Fig. 3.



(a) (b)

Figure 3. Target information extracted by applying SVD (a) Pulse compression (b) Speed estimation

In Fig. 3(a), the target signal is effectively separated through SVD. And the result of FFT on the right singular vector is shown in Fig. 3(b). When the right singular vector is decomposed, the vector becomes Hermitian, so the FFT result appears as a complex conjugate. In the FFT result, the speed information of the slow-moving drone signal is included.

5 Conclusion

The right singular vector contains information of a signal that changes with a PRI period. In the case of a target moving at low speed, the amount of information that changes according to speed is included as a Doppler component, and this information is displayed in the form of a phase. Since this phase information has a specific Doppler frequency value when FFT is performed, the velocity information is expressed as a corresponding frequency component. By FFT of the right singular vector and extracting the frequency component, the velocity information of the slow-moving target can be obtained. Through this process, it is possible to detect and extract speed even for low-speed drones that are difficult to extract by conventional methods.

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