RCS Measurements of Various Drones at 24 GHz

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Abstract: Radar is one of the technologies that can detect drones. We have previously proposed to use an ultra-wideband (UWB) radar, which uses quasi-millimeter wave band (24/26 GHz) or millimeter wave band (60/79 GHz), for drone detection. The radar cross section (RCS) of a radar target is an important factor related with the radar performance such as detection, tracking, and classification. This paper experimentally investigates the RCS patterns of five types of drones with different shapes, sizes, and the number of rotor blades (Phantom 3, Bebop Drone, 3DR Solo, Mavic Pro, and Matrice 600). RCS measurements were conducted at 24 GHz for two polarizations, H-H and V-V. As a result, we have confirmed that the mean RCS values of the drones vary from $-8.1$ dBsm to $-19.1$ dBsm depending on body size, shape, and polarization.

Keywords: Radar cross section, drone, measurement, quasi-millimeter wave, polarization

Classification: Sensing

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1 Introduction

In recent years, the use of drones has become active in various fields including agriculture, surveying, disaster relief, and aerial shooting [1]. In addition, it is expected that the utilization of drones will continue to expand in the future. However, with the spread of drones, accidents and incidents are increasing year by year. For example, fall accidents into event sites or intrusions into airports have actually occurred [2]. Therefore, establishing a method to detect and monitor drones is an urgent issue.

Radar is one of the technologies that can detect drones [3–7]. The radar cross section (RCS) of a radar target is an important factor related with the radar performance such as detection, tracking, and classification. The RCS value of a target vary considerably with the size, material, viewing aspect and frequency. When dealing with radar system design, it is necessary to know the RCS of each target. There have been several studies on RCSs of drones [3–5]. In [3], the RCS patterns of two types of drones (SYMA, Air Vision) have been measured in the frequency of 8-12 GHz. In [4], the RCS values of flying drones (Phantom 3, Inspire, S900Hexa) have been measured in K-band (24 GHz) and W-band (94 GHz). In [5], the RCS values of rotor blades have been measured in three frequency bands (L-band: 1-2 GHz, S-band: 2-3 GHz, C-band: 5-6 GHz).

We have previously proposed to use an ultra-wideband (UWB) radar for drone detection and experimentally investigated its feasibility [6, 7]. For UWB radar systems, quasi-millimeter wave band (24/26 GHz) and millimeter wave band (60/79 GHz) are allocated in many countries including Japan. In [6] and [7], the RCS patterns of a drone were investigated in the quasi-millimeter and the millimeter wave bands. In these studies, we investigated the RCS of a quadrotor drone (Phantom 3), which is one of the most popular drones. However, there are various types of drones that differ in shapes, sizes, and the number of rotors. The RCS patterns of various drones in the frequency bands used by UWB radars have not been clarified so far. In [4], the RCS value at 24 GHz has reported, but it is the RCS value in flight, and the exact RCS pattern has not been investigated. Furthermore, the difference in the RCS due to polarization has not been clarified. It is important to investigate the RCS characteristics of various drones for designing radar systems that detect drones. Therefore, in this paper, we experimentally investigated the RCS patterns of five types of drones with different shapes, sizes, and the number of rotor blades. Measurements were performed at 24 GHz for two polarizations, H-H and V-V. Since 24 GHz is also allocated for ISM band radar systems [8], the results obtained by this research are considered to be useful for drone detection systems not only using UWB radars but also using ISM band radars.
2 Measurement procedure

In order to calculate RCS in actual environment, it is necessary to consider the losses due to measurement system. Therefore, in general, the RCS of a target $\sigma_t$ is calculated by Eq.1 using a standard reflector whose RCS is known [6].

$$\sigma_t = \left( \frac{P_t}{P_r} \right) \cdot \left( \frac{R_t}{R_r} \right) \cdot \sigma_r$$  \hspace{1cm} (1)

where $R_t$ and $P_t$ are the distance to the target and its received power, $R_r$ and $P_r$ are the distance to the standard reflector and its received power, respectively, and $\sigma_r$ is the RCS value of the standard reflector.

In this research, we measured RCS patterns of five types of drones with different shapes, sizes, and the number of rotors. Fig. 1(a) shows measured drones: Phantom3 (A), Bebop Drone (B), 3DR Solo (C), Mavic Pro (D), and Matrice 600 (E). The drones (C) and (E) have no cameras mounted. Each of the drones was mounted on a turntable in an anechoic chamber as shown in Figs. 1(b) and 1(c), and azimuth scan was done. The received power of the target was measured using a vector network analyzer (VNA: Keysight M9375A) while rotating the turntable by 360 degrees in increments of 0.6 degrees. Standard gain horn antennas (20 dBi) were used for transmit (Tx) and receive (Rx) antennas. Measurements were carried out with H-H polarization and V-V polarization. Data were collected at a center frequency of 24 GHz. The bandwidth was set to 0.5 GHz and gave a full width at half maximum (FWHM) equal to 1.18 m (larger than the size of all the drones). A metal sphere with a diameter of 0.21 m ($\sigma_r = -15$ dBsm) was used as a standard reflector.
3 Measurement results

Fig. 2 shows the measured RCS patterns for each polarization, where the front of each of the drones is defined as 0 degrees (lower side in Fig. 1(a)). The mean RCS values of H-H polarization of the drones (A), (B), (C), (D), and (E) are $-12.6 \, \text{dBsm}$, $-17.5 \, \text{dBsm}$, $-16.7 \, \text{dBsm}$, $-18.5 \, \text{dBsm}$, and $-8.1 \, \text{dBsm}$, respectively. Also, for V-V polarization, the mean RCS values of the drones (A), (B), (C), (D), and (E) are $-11.7 \, \text{dBsm}$, $-19.1 \, \text{dBsm}$, $-17.2 \, \text{dBsm}$, $-17.0 \, \text{dBsm}$, and $-9.0 \, \text{dBsm}$, respectively. According to the results, the mean RCS tends to increase with the size of the body. Although the diagonal length of the drone (A) is smaller than that of the drone (C), the mean RCS value of the drone (A) is larger than that of the drone (C). This is because the height of the drone (A) is larger than that of the drone (C), and a camera is mounted on the drone (A). From the RCS patterns, we can see that the RCS increases at some angles. This is because each drone has a wide reflective surface.
at those angles. For example, in Fig. 2(a), the RCS is increased at 180 degrees because the reflection from the battery part, which has a large plane perpendicular to the angle of incidence of the radio wave, is large. In addition, it can be seen that the variation of the RCS with aspect angle is relatively large, and the difference between the maximum and minimum values of each drone is approximately 25 dB to 35 dB.

Fig. 3 shows the probability distributions and the cumulative distribution functions (CDFs) of the RCS patterns for two polarizations. Regarding the difference in the RCS due to polarization, the difference is not clearly visible in the probability distributions, but is clearly visible in the CDFs of the drones except for the drone (C). For the drones (A) and (D), the RCSs of H-H polarization are smaller than that of V-V polarization, and for the drones (B) and (E), the RCSs of H-H polarization are larger than that of V-V polarization. For example, when CDF is 0.75, for the drone (A), the RCS of H-H polarization is 1.6 dB smaller than that of V-V polar-
ization, and for the drone (B), the RCS of H-H polarization is 2.3 dB larger than that of V-V polarization. This is because the parts that make up the drones (A) and (D) have large surfaces which have long vertical lengths, while the parts that make up the drones (B) and (E) have large surfaces which have long horizontal lengths. Therefore, since the tendency of RCS due to polarization depends on the shape of each drone, it is not possible to determine which polarization is better for drone detection. However, such characteristics in the RCSs of drones due to polarization should be noted when designing radar systems.

4 Conclusion

In this paper, we have experimentally investigated the RCS patterns of five types of drones with different shapes, sizes, and the number of rotor blades. The RCS measurements were conducted at 24 GHz for two polarizations, H-H and V-V. It was found from the results that the mean RCS values of the drones vary from −8.1 dBsm to −19.1 dBsm depending on body size, shape, and polarization. It was also found that there is a difference in RCS between H-H and V-V polarizations depending on types of drones.

In future research, we will investigate a technique to distinguish a drone from other flying objects.

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