Characteristics of ultra-wideband radar echoes from a drone

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Abstract: This letter proposes to use an ultra-wideband (UWB) radar for drone detection and experimentally investigates feasibility of the proposal. First, the radar cross section (RCS) of a typical quadrotor drone is clarified. Next, radar range profiles of a flying drone are discussed. As a result, we have confirmed that an UWB radar with high range resolution can detect a drone and observed a unique feature of the echoes reflected from the drone’s rotor blades. The feature will enable us to distinguish a drone from other flying objects.

Keywords: ultra-wideband, radar, drone, RCS, measurement

Classification: Sensing

References

1 Introduction

In recent years, small drones which have multiple rotor blades are widely used for various usages. Those usages include package delivery and observations of disaster-stricken areas [1]. The increase in drone is causing social problems. The case of a drone that fell to the Japanese Prime Minister’s official residence is still fresh in our mind. Since a drone has payload of several hundred grams to several kilograms even in small size, it has a danger of being used for terrorism. Therefore, it is an urgent issue to realize a system that detects malicious drones and captures them quickly.

Radar is one of the technologies that can remotely detect drones. Unlike camera images or sound concentrating microphones, radar is available in all weather conditions, because it is rarely hindered by rain or fog. In [2] and [3], for the drone detection, the uses of a continuous wave (CW) radar and a narrowband pulse radar have reported, respectively. These studies tried to detect and distinguish a drone from other flying objects such as birds and insects, by analyzing the Doppler signatures of the drone.

Ultra-wideband (UWB) radar is a technology that offers high precision ranging and high range resolution by transmitting and receiving ultrashort pulses with a bandwidth of 0.5 GHz or more [4]. In [5], a method for identifying a type of a car by using an UWB radar has been proposed. The method detects the echoes reflected from each part of the car with high accuracy. We thought that UWB radar could capture unique features of a drone such as the echoes from the rotor blades. In this letter, we propose to use an UWB radar for drone detection and experimentally investigate feasibility of the proposal. First, the radar cross section (RCS) of a typical quadrotor drone is clarified. Next, radar range profiles of a flying drone are discussed. In general, the higher the frequency, the easier for the radar to observe the target’s characteristics. Therefore, we used the submillimeter wave band (@ 24/26 GHz), which is relatively high frequency and is also employed for automotive radars.

2 RCS measurements of a typical quadrotor drone

RCS is the measure of a target’s ability to reflect echo signals toward the radar. The RCS value, which vary considerably with the target’s size, material, viewing aspect and frequency of radar radio wave, affects the radar performance. Therefore, it is important to measure the RCS of a target for radar system design. The RCS of a rotor blade of a drone has been reported so far [6]. In this report, the RCSs of the rotor blade of two kinds of materials (metal, carbon) were measured in three frequency bands (L-band: 1–2 GHz, S-band: 2–3 GHz, C-band: 5–6 GHz). However, the RCS of a drone including the entire body has not been clarified. In order to calculate RCS in the actual environment, it is necessary to consider losses due to
measurement system. To take the losses into consideration, in general, the RCS of a target $\sigma$ is calculated by

$$\sigma = \left( \frac{P}{P_{ref}} \right) \cdot \left( \frac{R}{R_{ref}} \right) \cdot \sigma_{ref}$$

(1)

using a standard reflector whose RCS is known [7]. Where $\sigma_{ref}$ represents the RCS value of the standard reflector. $R$ and $R_{ref}$ are the distance to the target and that to the standard reflector, respectively. $P$ and $P_{ref}$ are the received power from the target and that from the standard reflector, respectively.

A quadrotor drone (DJI Phantom 3 with plastic rotor blades) was mounted on a turntable in an anechoic chamber as shown in Fig. 1(a). Three axes ($x$, $y$, and $z$ axes) fixed to the drone’s body are defined as shown in the Fig. 1(b). Measurements were carried out with H-H polarization in two cases. In the first case, we placed the drone on the turntable so that the drone’s $z$ axis was vertical, as shown in the Fig. 1(b). Then we rotated the drone $\theta$ degrees around the $z$ axis. In the second case, the drone was placed on the turntable so that its $y$ axis was vertical, and we rotated the drone $\phi$ degrees around the $y$ axis. The received signal power from the target was measured using a vector network analyzer (VNA) while rotating the turntable by 360 degrees in increments of 0.6 degrees. The center frequency $f_c$ was set to 24 GHz. For comparison, measurements, where $f_c$ was set to 2.4 GHz, were also carried out. The bandwidth $BW$ was set to 0.5 GHz. Besides, a metal sphere with a diameter of 0.24 m ($\sigma_{ref} = -13 \text{ dBsm}$) was used as the standard reflector.

Figs. 1(c) and 1(d) show the measured values of the RCS patterns in the two cases. The average value of RCS at $f_c = 24 \text{ GHz}$ is $-13 \text{ dBsm}$ in both cases. We can see that the RCS pattern of $f_c = 24 \text{ GHz}$ changes more sharply depending on
the angle than that of $f_c = 2.4$ GHz. This is because the wavelength is shorter than the size of the drone when $f_c = 24$ GHz, thus reflections from each part of the drone’s frame are obtained. Furthermore, in the case of $f_c = 24$ GHz in Fig. 1(c), there is a peak at 90 degrees. The reason is probably because there is a large reflective surface on the side of the drone mounted camera.

### 3 UWB radar measurements for a flying drone

We also measured radar range profiles, which indicate intensity of echo signals as a function of distance. Using a VNA’s time-domain function, the range profile measurements were carried out for 30 seconds while we let the drone fly. We conducted this experiment in a laboratory in order to avoid the influence of wind on the drone’s flight. Fig. 2 shows the measurement system, where $f_c = 24$ GHz, $BW = 3, 1, 0.5$ GHz. Standard gain horn antennas (25 dBi) with H-H polarization were used and the height was set 1.2 m above the floor. In this experiment, we set two measurement scenarios; the case of hovering at a distance of 3 m and the case of flying round-trip at a distance of 3 m to 7 m. In both cases the altitude was set at 1.2 m above the floor.

Fig. 3(a) shows the measured range profile at $BW = 3$ GHz when the drone is hovering. We can see an intense echo at 3 m distance and also unsteady fluctuation in distance due to hovering. Furthermore, there are two echoes that similarly fluctuate in the distances just before and after the intense echo. This is because the echoes, which are reflected from the drone body and the rotor blades, can be separated with the high range resolution capability. These echoes from the rotor blades are mainly reflected signals from all of the motor parts (rotors) that rotate the blades. Because rotors are always installed in a drone, it is expected that such feature is observed even with other types of drones. This is a unique feature of a drone with rotor blades and it will be useful for distinguishing a drone from the other flying objects. For example, it can be expected to extract the feature of the range profile using Hough transform as in [8]. Fig. 3(b) shows the measured range profile at $BW = 3$ GHz when the drone is flying round-trip. We can see that the change in the distance due to the drone moves is detected accurately. Since the operator was fine-tuning the drone’s direction of flying, there are variations in the distance. The measured range profiles at $BW = 1$ GHz and 0.5 GHz are shown in
Figs. 3(c) and 3(d), respectively, when the drone is hovering. In contrast to the case in Fig. 3(a), the echoes reflected from the rotor blades cannot be separated with these bandwidths. This is due to degradation of range resolution. From the above measurement results, although it depends on the size of drones, the bandwidth (range resolution) of 3 GHz or more is probably necessary in order to obtain the unique feature of a drone.

4 Conclusion

In this letter, we have proposed the use of an UWB radar for drone detection and investigated its feasibility experimentally. Firstly, a typical quadrotor drone’s radar cross section (RCS) that is an important value for radar system design was measured. As a result, we found that the average value of the RCS was $-13$ dBsm ($@24$ GHz). Secondly, range profile measurements for a flying drone were conducted. As a result of the experiment, we confirmed that the UWB radar with high range resolution could detect a flying drone and observe its unique feature that was produced by rotor blades. This feature must be useful for distinguishing a drone from other flying objects such as birds and insects.

In future research, we will investigate a technique to distinguish between a drone and the other flying objects, and the detection performance when millimeter wave band ($@79$ GHz) is used. We will also investigate whether the unique feature can be observed for other types of drones, as well as the drone used in this experiment.