Radar Signatures of Small Consumer Drones

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The proliferation of small consumer drones has raised much recent interest in their regulation and monitoring.

One potential way to detect and identify these drones is using a ground-based radar.

**Objective:** To investigate the radar signatures of these small drones.
Approach

• Carry out laboratory measurement of small consumer drones.
• Examine their radar signatures in the form of inverse synthetic aperture radar (ISAR) images.
• ISAR imaging provides not only radar cross section (RCS), but also maps the dominant scattering in 2-D.

Scientific Questions:

1. Will the small size and low reflectivity of the drone body result in a very low RCS?
2. Will the spinning propeller blades result in significant Doppler artifacts [1]?

Laboratory Measurement Setup

• Vector network analyzer (VNA) $S_{11}$ measurement.
• Drone mounted and rotated on a turntable.
• Start with baseline scenario and then deviate.
• Calibrated results in terms of absolute RCS using a calibration sphere.
• Horn mismatch and room clutter are reduced by subtracting the moving average.
• 3 GHz of bandwidth.
  – 5 cm of down-range resolution.
ISAR Image Formation

- 2-D image generated using 2-D inverse Fourier transform of frequency/angle data.

\[
\text{Image}(r, cr) = \frac{1}{K_x K_y} \int \int E^s(f, \phi) e^{ik_x r} e^{ik_y cr} \, dk_x dk_y
\]

where

\[
\begin{align*}
    k_x &= \frac{4\pi f}{c} \cos \phi \\
    k_y &= \frac{4\pi f}{c} \sin \phi
\end{align*}
\]

- Angular swath chosen for equal down-range / cross-range resolution of 5 cm.
- Slide swath along angle to generate an ISAR movie.
Baseline Scenario

• DJI Phantom 2 (35 cm diagonal).
• Azimuth scan at zero-elevation angle: results in a top-view of the drone.
• 12-15 GHz, blades stationary, VV-pol, no camera.

ISAR movie available at: http://users.ece.utexas.edu/~ling/DroneISARMovie.gif
ISAR Snapshots

- ISAR image snapshots at different look angles with an outline of drone overlaid.
- Maximum RCS in each snapshot is listed.
Deviations From Baseline

Baseline Scenario

- Blades Spinning
- Frequency Change
- Polarization Change
- Mounted Camera
- Elevation Scan
- Larger Drones
Deviation From Baseline

- No significant differences between blades rotating and stationary.

- On average, RCS at 3-6 GHz about ~12 dB lower than 12-15 GHz.
• HH-Pol: weaker battery return, stronger motor return.

• Camera can only be seen at specific look angles.
Elevation scan instead of azimuth scan.
Captures the shape of the drone in another imaging plane.
Instead of top-view of the drone, captured the side-view.
In practice, collected by flipping drone on its side and rotating.

Deviations From Baseline

Max = -9.0 dBsm
EL = -90°, AZ = 0°

Max = -9.3 dBsm
EL = 0°, AZ = 90°
• Drone shape and size captured.
• Maximum RCS smaller than Phantom 2 due to body shape.
• Similar trends as Phantom 2.
Larger Drones: DJI Inspire 1

- Drone shape and size captured.
- Additional feature from the horizontal frame.
- Highest maximum RCS of the three drones.
- Similar trends as Phantom 2 and 3DR Solo.

DJI Inspire 1 (56 cm diagonal)

12-15 GHz

- EL = 0°, AZ = 270°
- Max = -3.0 dBsm

3-6 GHz

- EL = 0°, AZ = 270°
- Max = -13.7 dBsm
Recap

• Overall RCS level is low, but the drone size and shape can be captured in the ISAR imagery.
• Non-plastic portions dominate their radar signatures (such as motors, battery pack, and carbon-fiber frame).
• Drone propellers did not contribute a significant return relative to the drone body (static or spinning).
• Data collection was under idealized conditions, but it should be feasible to collect such data from an actual drone in flight.

• **Next**: Carry out in-flight measurement of the small drone.
• **Scientific Question**: Can focused ISAR images be generated from these small drones in flight?
In-Situ Measurement Using a UWB Radar

• PulsON 440 (P440) ultra-wideband (UWB) radar by Time Domain Corporation.
• Emits short pulses at a pulse repetition frequency of 10 MHz.
• Equivalent frequency bandwidth from 3.1 to 5.3 GHz centered at 4.3 GHz.
In-Flight Measurement Setup

- Measurement setup on the ground includes P440 radar, circulator, and single horn antenna.
- Phantom 3 Adv. is used since it has extractable GPS flight data.
- Collect range profiles (at 100 Hz) as the drone flies by in a straight line.
Motion Compensation

- Motion compensation is necessary to remove translational motion and retain only the rotational motion.
- Images generated through blind motion compensation (alignment of the RCS centroid).
- Baseline images also generated with aid from “ground truth,” GPS flight data.
- Angle estimate based on $\phi = \cos^{-1}(R/R_{min})$. Images formed using same $k$-space imaging as before.
Phantom 3 Adv. Results

- Images obtained from blind motion compensation are on-par with images obtained from GPS-assisted motion compensation.
- Images are focused but narrower bandwidth of radar and limited number of scatterers on the drone make it challenging to discern the shape.
Larger Drone: DJI Inspire 1

ISAR movie available at: http://users.ece.utexas.edu/~ling/DroneISARMovie_Inspire.gif
Images after blind motion compensation are comparable to those obtained in laboratory measurement.
Compared to Phantom 3

Size difference, from Phantom 3, is observed.
Conclusion

- ISAR images can capture the drone shape and size despite its small size and low reflectivity.
- Spinning propellers do not contribute significant Doppler clutter.
- Focused images can be generated from in-flight measurement.
- Radar is a potential candidate for tracking and classification of small consumer drones.
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