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High-resolution, multi-frequency and full-polarization radar database of small and group targets in clutter environment

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Detection of small low-altitude targets such as drone swarms, migrating insects and birds is crucial for both military and civilian applications [1]. There exist two main challenges which significantly affect the radar detection and tracking performance. Firstly, weak echo signals of small targets will be buried in strong ground clutter and rain clutter [2]. Meanwhile, the mutual interference among multiple targets will cause missed detections and incorrect track associations [3]. Despite various research efforts in recent years aimed at addressing these two problems, accurate detecting and tracking of weak and dense targets still remains an ongoing challenge for current radar systems.

In order to develop detection and tracking techniques, it is essential to analyze the characteristics of target echoes and clutter, wherein real radar data is significant. This data-sharing project aims to provide real data collected by current high-resolution, multi-frequency, and fully-polarized radar systems to support the research and performance assessment of detection and tracking algorithms. Radar clutter and low-altitude targets, including small and group targets, are available in this database. Since scattering characteristics of targets and clutter vary with the polarization and frequency bands, the data collected under multiple frequency bands and four different polarizations provides more information of targets and clutter. Thus, this database can significantly aid the analysis of target and clutter characteristics.

A series of low-altitude targets and radar clutter measurement trials were conducted in 2023 at Dongying, Shandong, China. Two distinct radar systems, a high-resolution phased array radar and a multi-frequency fully-polarized radar, were employed to collect data [4]. The available data include radar clutter, migrating insects and birds, as well as drones and drone swarms. This database serves as a fundamental resource for the analysis of algorithms concerning weak target detection and tracking within clutter background and in multiple target scenarios.

Brief introduction of radar systems. The high-resolution phased array radar is a Ku-band stepped frequency radar with a synthetic bandwidth of 1 GHz. Its range resolution is around 0.2 m with hamming window and its detection range spans from 300 to 2000 m. It can operate at staring mode and scanning mode with mechanical scanning at the azimuth domain and phased scanning at the elevation domain. The high-resolution range profiles (HRRPs) are obtained by synthesizing stepped-frequency chirp pulses. Measured data of the phased array radar consists of four channels, the sum beam, the azimuth difference beam, the elevation difference beam, and the sidelobe cancellation beam.

The multi-frequency fully-polarized radar is designed to operate at the X, Ku, and Ka bands simultaneously with full polarization for each band. Both the X and Ku bands have two sub-frequency points which are operated in a time-sharing manner. It is a mechanical scanning tracking radar system adopting the stepped frequency waveform with a synthetic bandwidth of 1 GHz which is the same as the phased-array radar. Its detection range spans from 255 to 1650 m. The multi-frequency fully-polarized radar has the ability to measure the angle in both the azimuth and elevation domain at the Ka-band based on the amplitude-caparison monopulse technique.

Overview of measurement trails. The clutter and aerial targets observation trails are introduced below.

(1) Radar clutter measurement trials. The ground clutter and rain clutter data have been collected by high-resolution phased array radar operated at staring mode. The ground clutter mainly includes three types of strong clutter: power tower, reservoir, and building. The elevation angle is fixed to be 2.24°. The rain clutter data were collected when the elevation angle was fixed to be 4.71°, 12.23°, and 80.71°, respectively. The weather conditions were also recorded at the same time.

(2) Migrating insects and birds observations. The radar systems are located on one of the migratory routes in east China where they could observe a huge number of migratory insects and birds [5]. The radar echoes of these non-cooperative targets collected by two kinds of radar systems are provided. The migrating insects and birds observation

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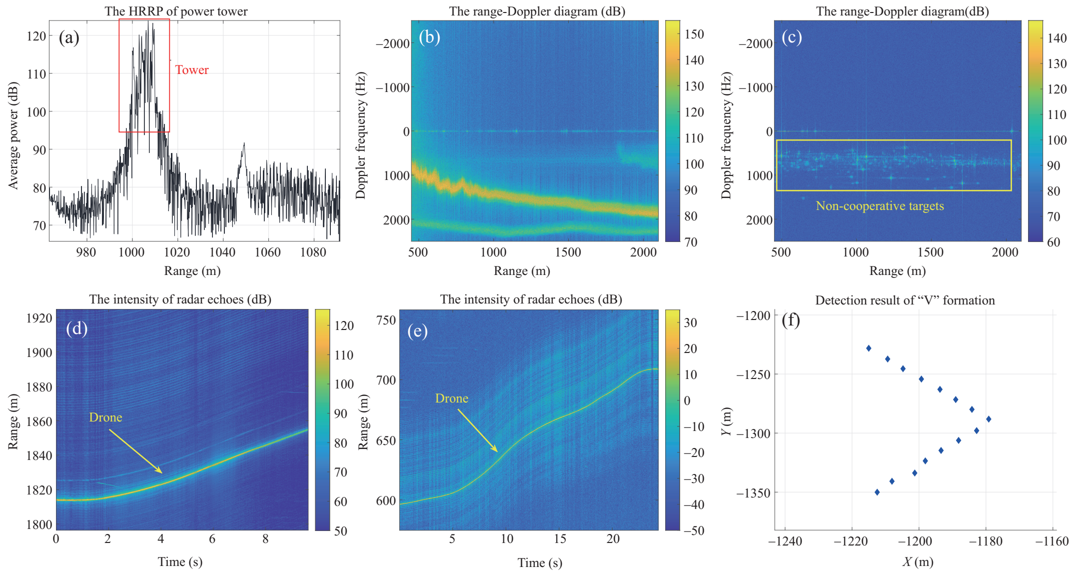

Figure 1 (Color online) Illustration of typical data. (a) The HRRP of ground clutter; (b) rain clutter; (c) migrating insects and birds; (d) single drone with uniform acceleration motion; (e) single drone with rapid maneuvering flying; (f) detection result of drone swarm with "V" formation.

trails were conducted in the evening and the radars first worked in scanning mode to determine the azimuth where there are large quantities of non-cooperating targets. After determining the azimuth angle, the radar was switched to staring mode to collect data. Auxiliary environment data are also collected.

(3) Drone observations. The radar of a single drone with uniform motion and uniform acceleration motion was collected by high-resolution phased array radar. The drone used in these experiments is DJI M300. It moved horizontally at three different altitudes. The phased array radar operated at staring mode. The drone moved radially along the radar line-of-sight and its velocity range is 0–5 m/s. The azimuth angle was fixed and the elevation angle changed with the altitude of the drone. The real-time kinematic (RTK) measurements of the drone are provided to help users determine the real trace of the drone.

The radar echoes of the DJI Phantom 4 drone with six different modes of motion were collected by multi-frequency fully-polarized radar operated at tracking mode. These motion modes include hovering, circling, climbing, radial flying, tangential flying, and rapid maneuvering flying.

(4) Drone swarm observations. The radar echoes of drone swarms with "I" formation and "V" formation have been collected by high-resolution phased array radar [6]. The phased array radar operated at fast scanning mode with a rotation rate of 20 r/min. In the elevation domain, the radar electronically scans over eight different elevation angles ranging from 5.31° to 9.41°. The drone swarm consists of fifteen drones spaced 10 m apart. The motion of the drone swarm included the following stages: taking off, flying in formation around a circle, lateral flying in formation, lasting a total of 8.5 min.

Illustration of typical data are given in Figure 1.

Usage. This database is aimed to support the research concerning the detection and tracking of aerial targets, which includes the clutter suppression methods, weak target detection methods, as well as the detection and tracking methods of group targets.

The data are provided in '.dat' format consisting of the data head, the frame head, and the HRRP data. The data head specifies the type of radar systems, channel, and waveform parameters. The frame head includes the exact time and beam direction of each pulse. Detailed data storage protocol is available along with the data files. A data loading program is provided for the convenience of use.

Access methods. The database and detailed introduction are available on the website[1)].

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