Monostatic and Bistatic Radar Measurements of Birds and Micro-Drone

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Abstract — **This paper analyses the experimental results from recent monostatic and bistatic radar measurements of multiple birds as well as a quadcopter micro-drone. The radar system deployed for these measurements was the UCL developed NetRAD system. The aim of this work is to evaluate the key differences observed by a radar system between different birds and a micro-drone. Measurements are presented from simultaneous monostatic co/cross polarized data as well as co-polar bistatic data. The results obtained show comparable signature within the time domain and a marked difference in the Doppler domain, from the various birds in comparison to the micro-drone. The wing beat properties of the birds are shown for some cases which is a stark contrast to the rotor blade micro-Doppler signatures of the drone.**

Keywords— Bistatic radar; Radar; Birds; Micro-drone; Doppler signatures; classification.

I. INTRODUCTION

Recently the number of micro-drones available to the general public has significantly increased, due to the low price and ease of use. These platforms can be used for private leisure and filming, as well as for applications such as disaster response, search and rescue, and agricultural/environmental monitoring. However there are many potential misuses involving micro-drones, such as personal privacy violation, illegal filming of restricted areas, collision hazard with people, other UAVs, and larger aircraft, and even transport of illegal substances or explosive/toxic materials. The detection, tracking, and classification of small UAVs using traditional radar systems is a challenging task. These platforms have small radar cross section (RCS), fly at low altitude and low speed in comparison with conventional larger aircraft [1].

There is limited published prior research available on radar detection and classification of micro-drones. Previous work in [2, 3] investigated the change in RCS of a micro-drone and its blades through numerical simulations as well as experiments within a controlled environment. An important challenge to address, for effective radar detection of micro-drones, is the discrimination between drones and birds in order to avoid significant false alarm rates. After developing a radar sensitive enough for the detection of micro-drones the challenge of bird related false alarms is significant. In [4] features extracted at tracking levels were proposed for this purpose, whereas in [5-7] features extracted from the micro-Doppler signatures were investigated using experimental data from a monostatic X-band radar. Bird signatures have also previously been investigated within [8-9], although these do not compare the observed signatures directly to a comparable sized drone signature. Micro-Doppler signals have been successfully shown to contain significant information on target motion [10], these detailed signatures can be used to distinguish between types of vehicles, humans carrying items or not and potentially between birds and drones targets.

This paper presents the preliminary analysis of signatures for three different species of birds and a micro-drone (DJI Phantom Vision 2+ quadcopter). All datasets were collected using the same multistatic radar, in the same deployment configuration in order to allow direct comparisons between the various targets. The RCS and micro-Doppler signatures of the birds and micro-drone analyzed here provide practical information that will help the development of effective detection and classification methods. These experimental data include simultaneous monostatic and bistatic co-polarized data, as well as simultaneous cross-polarized monostatic data collected by two co-located radar nodes.

The rest of this paper is organized as follows. Section II describes the experimental setup and the radar system. Section III presents the data analysis with examples of range-time-intensity (RTI) plots and micro-Doppler signatures for 3 different species of birds and for a micro-drone. Section IV concludes the paper and discusses potential future analysis.

II. RADAR AND MEASUREMENT GEOMETRY

The radar system used for these measurements was the NetRAD system that has been developed at University College London (UCL) over the past 10 years [11]. NetRAD is an S-Band (2.4 GHz) coherent pulsed multistatic radar, with three separate but identical nodes. The system was configured to use a peak power of 0.2 W, bandwidth of 45 MHz, pulse length of 0.6 us and a PRF of 5 kHz. These configurations were successfully previously used to measure human micro-Doppler signatures [12] and was found to provide good quality information for the characterization of different micro-Doppler motions. The measurement methodology was to record 300,000 pulses of data over a period of 60 seconds in order to capture a number of movements per recording. The data was then broken down into key sections that showed the motion of either birds or the drone while in flight.

The geometry that was used was a straight baseline deployment of two of the radar nodes with an additional receive only node at the monostatic site. The baseline between the monostatic and bistatic node was limited to approximately 28 m due to the geometry of the site that was being used. In this configuration it was possible to measure simultaneous HH and HV polarized data at the monostatic site (Node 1 and Node 2), and bistatic HH (Node 3). The antennas used for the measurements were a H polarized transmit antenna with a 10° x 10° beamwidth and gain of 24 dBi at the monostatic node, and three receive antennas with 20° x 20° beamwidths at both the co-located monostatic (both HH and HV pol) and bistatic (HH pol) nodes. The polarimetry data was collected as the authors believe that this information may be used to discriminate between different target classes. The flapping motion of a wing beat should induce a pattern in the ratio of horizontal to vertical signatures, whereas a rotor blade is likely to not have the same pattern. The location of the experiments was in the South East of England in a flat field area that was approximately 100 m by 80 m in size, the deployment geometry used can be seen in Fig. 1.

The aim of the measurements was to observe supervised bird targets flying between two waypoints that were either individual bird trainers, or wooden perches for the bird to land/take-off from. These waypoints are labelled on Fig. 1 which shows the pairs A-B, C-D and E-F. The majority of experiments measured the birds flying between waypoints A-B, in flight paths both towards and away from the monostatic radar line of sight.

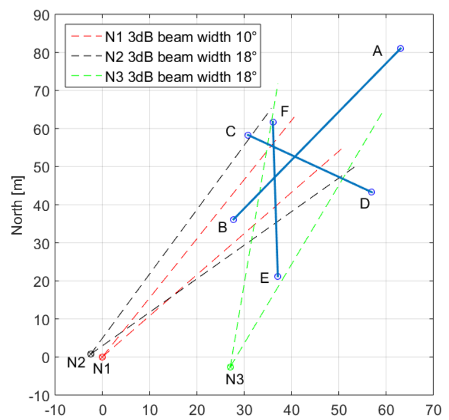

Fig. 1. Experimental setup and birds flight paths

As the birds flew from waypoint to waypoint the aspect angle with respect to each radar node changed and quantifying the effect of this on the recorded RCS and micro-Doppler signatures is of interest. Estimations for the orientation of the birds with respect to each radar node for a given flight path, shown in Fig. 1, are presented in Fig. 2. This shows that certain flight paths have a reasonable variation in aspect angles during the movement between waypoints. This potentially allows for the quantitative comparison of how the relative RCS and micro-Doppler signatures alter with angle.

During these measurements three different birds and one drone were observed. The birds used were a Hooded Vulture, Eurasian Eagle Owl and Barn Owl, images of the birds are shown within Fig. 3 (a) to (c). The animals were part of a falconry center based in the South East of England, they have been trained to fly to a handler when called and therefore more suitable to use for measurements than wild birds which require an element of luck and patience to be able to measure them in a controlled way over known geometries. The birds used are clearly very different in their size, shape, weight, feather types and even the way that they fly. The largest of the birds was the Hooded Vulture which weighed approximately 1.8 kg compared to Barn Owl which was the smallest at only 280 g. These physical characteristics will clearly produce very different RCS and micro-Doppler contributions from the different species.

The drone platform used during the measurements was a quadcopter style micro-drone. This device was flown over the same waypoints as the birds and a similar altitude, approximately 2 m above the ground. The drone used was a commercially available DJI Phantom Vision 2 which is approximately 0.35 x 0.35 x 0.19 m in size and weighs 1.2 kg. This is a widely used drone that is comparable to a large bird in size and weight, hence representing a challenging target to both detect and then classify for an operational radar, especially when presented with many other bird targets within the scene.

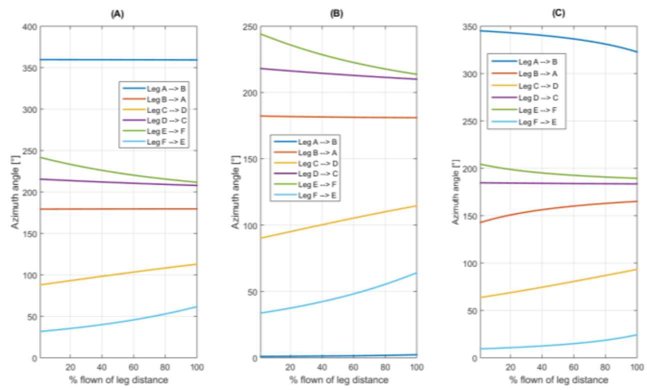

Fig. 2. Actual aspect angle of birds in flight dependent on flight path with respect to the radar nodes (a) Node 1 (b) Node 2 (c) Node 3

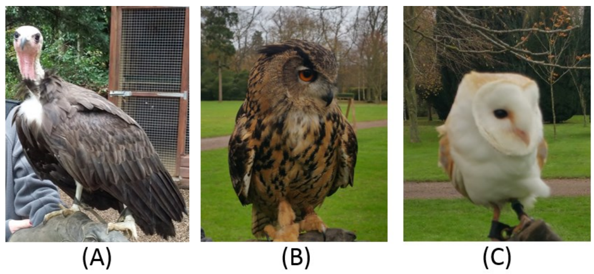

Fig. 3. Photo of (A) Hooded Vulture (B) Eurasian Eagle Owl (C) Barn Owl

III. DATA ANALYSIS

The analysis of the data produced was completed in both the time domain and the Doppler domain in order to compare the relative amplitudes of the signatures returned from the birds and drone. The Range Time Intensity (RTI) results shown are the match filtered values after normalizing to a peak of 0 dB within each measurement and displaying a dynamic range of 50 dB. Prior to plotting the data a high pass filter was applied in the Doppler domain with a cut off at 20 Hz in order to remove the high power D.C component within the data. The range bins of interest were selected and displayed for each case. The micro-Doppler analysis applied a Short Time Fourier Transform (STFT) to the range bins that the birds were present within. This STFT used a hamming window of length 0.3 seconds, an overlap of 95% between windows and a padding of a factor of 4 in the Doppler domain relative to the window length. The micro-Doppler signatures have also been normalized to a peak of 0dB within each measurement.

The RTI profiles of the Hooded Vulture from monostatic and bistatic HH pol are shown in Fig. 4 (a) and (b) respectively. The cross polarized data is not shown here as the target signature was too weak to be visible, this was seen in all RTI plots of all targets. For each RTI plot a subsection of the full 60 second recording is displayed, selected from when the target was actually in motion. During this time the Vulture was moving from waypoint A to waypoint B. The moving target can be clearly seen within both monostatic and bistatic RTI plots, although increased background clutter is present in the bistatic result. It was found that the target signature within cross polarized radar node data was significantly reduced, which was to be expected. Doppler processing was required to identify the targets within the cross polarized data. The micro-Doppler signatures from all radar nodes of the Hooded Vulture are shown in Fig. 5. The bird is more visible in the Doppler domain as the majority of background clutter is now separated from the moving target. Fig. 5 (b) and (c) from the bistatic and cross polarized monostatic nodes show horizontal lines, these are the result of unwanted Doppler images. The micro-Doppler signatures in the co and cross polarized monostatic data show a pattern of motion on top of the bulk velocity, particularly between 10 – 12 seconds and 14 – 16 seconds, it is believed that this was produced by the flapping of the wings. The reasoning for this is because the additional components appear at the beginning and end of the flight where the majority of the wing flapping occurred, compared to the gliding motion mid-flight. In general during each of the flights the birds were very close to the ground and depending of species only flapped their wings for a fraction of the full flight time. This may be different from the typical open air flight style of these birds and this should be considered when drawing conclusions from this observed data.

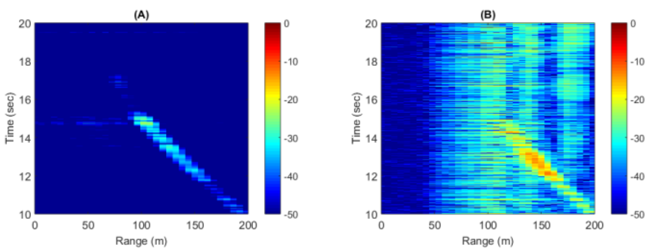

Fig. 4. RTI of Hooded Vulture moving from A to B (A) Monostatic HH (B) Bistatic HH

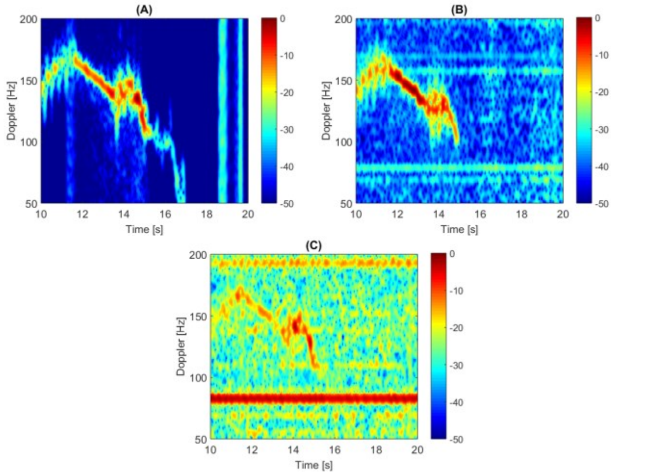

Fig. 5. Micro-Doppler of Hooded Vulture moving from A to B (A) Monostatic HH (B) Bistatic HH (C) Monostatic HV

The RTI profiles of the Eurasian Eagle Owl from monostatic and bistatic HH pol are shown in Fig. 6 (a) and (b) respectively. This large bird was also visible in the range domain, although the SNR was reduced in comparison the Vulture in the bistatic channel. The bird's signature is shown to reduce from approximately 140 m to 80 m two-way range during the flight, taking less than 4 seconds. Micro-Doppler analysis of the Eurasian Eagle Owl is shown in Fig. 7 for all three nodes. The target has a significant SNR (35-40 dB), similar to the Vulture, but moves at a slower velocity. The additional micro-Doppler wing flapping components are not as visible for this species. This demonstrates that classification based on wing flapping will be heavily dependent on bird species.

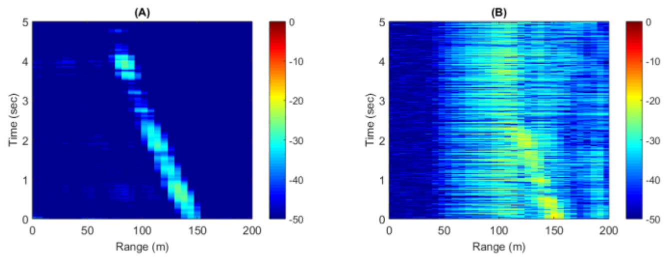

Fig. 6. RTI of Eurasian Eagle Owl moving from A to B (A) Monostatic HH (B) Bistatic HH

The RTI data from the barn owl has not been included as the signature in the time domain was very weak in comparison to the background clutter, due to its small size, hence reducing the usefulness of the direct RTI information. Only after micro-Doppler signal processing was applied was it possible to observe signatures of this bird, shown in Fig. 8. The monostatic H pol signature in Fig. 8(a) shows a great deal of modulation on top of the bulk velocity component. The flight style of this smaller species included a higher wing beat frequency and this has translated directly to the features observed in Doppler. The clear difference in wing beat frequency from Fig. 5(a) to Fig. 8(a) is clearly a useful classifier feature. The barn owl was also found to change velocity at a fast rate than the larger birds, which is likely linked to its more agile flight pattern.

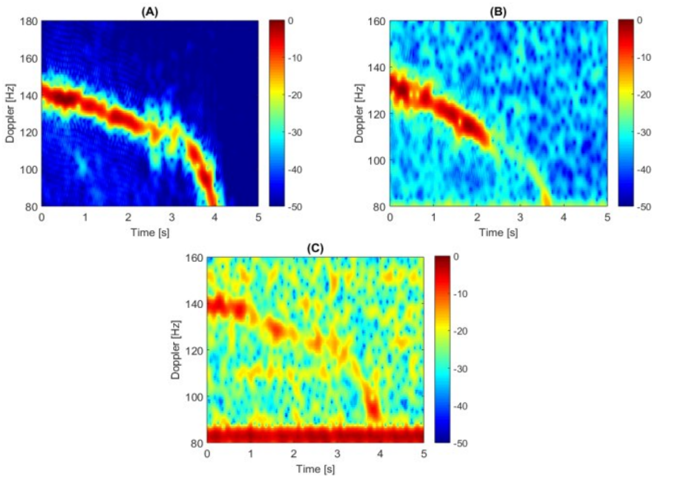

Fig. 7. Micro-Doppler signature of Eurasian Eagle Owl moving from A to B (A) Monostatic HH (B) Bistatic HH (C) Monostatic HV

The measurement of the bird signatures is now compared to the results from the DJI Phantom drone. This drone was flown over the same waypoints as the birds and the resulting data was processing in the same manner in order to directly compare the data. The RTI of the drone can be seen in Fig. 9. The quadcopter was also found to be clearly visible in the RTI plot for both the monostatic and bistatic radar nodes. Some interference was observed in the monostatic node, which was likely to be caused by unwanted WiFi signals.

The micro-Doppler signatures from the monostatic HH pol, HV cross pol and bistatic HH pol are shown in Fig. 10 (a), (b) and (c) respectively. This plot shows an expanded Doppler range due to the additional components observed at frequencies greater than 200 Hz that were not present within the bird measurements. These components are clearly seen in the monostatic H pol data and are thought to be caused by the rotor blades motion. This overall Doppler signature is clearly very different from that generated by the birds and could easily be used to differentiate between animal or rotor blade powered target. It was noted that the peak returns from the drone rotor blades were approximately 10 dB lower than the main body reflections.

IV. Conclusions

In conclusion the radar signatures in both the range and Doppler domain of co/cross polarized monostatic as well as co-polarized bistatic data have been shown for 3 different birds as well as a quadcopter drone. It was found that the micro-drone signature was comparable in RCS to the other bird targets, larger than the barn owl but smaller than the eagle owl and vulture. On the other hand the micro-Doppler signatures were found to be significantly different between the drone platform and the birds. Different wing beat patterns were observed between the 3 birds, as well as the high frequency rotational signal from the rotor blades of the drone. However, many small drones come with plastic rotors, virtually invisible to radar at some distance [2]. One potential way ahead to distinguish between the two classes would be to positively identify birds as birds. Bird wings are shown to have significant RCS compared to the bird body at certain aspect angles [13], and both micro-Doppler signatures and amplitude modulations [14] may contribute to the classification process. In the lower frequency bands, polarimetry is believed to give valuable information about birds and small drones. Future work will include analysis of polarimetric variables for differentiation between the classes.

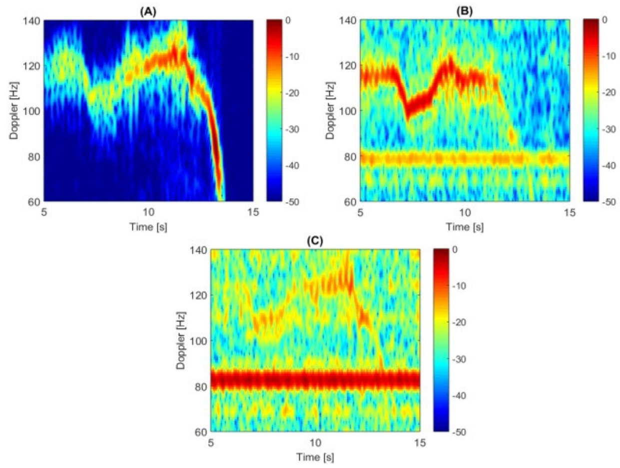

Fig. 8. Micro-Doppler signature of Barn Owl moving from A to B (A) Monostatic HH (B) Bistatic HH (C) Monostatic HV

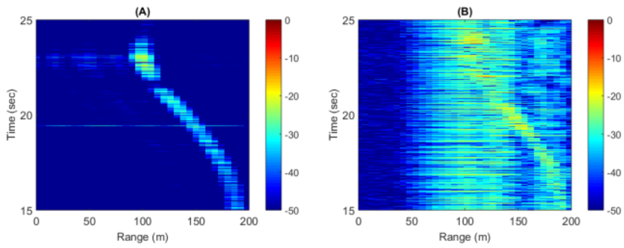

Fig. 9. RTI signatures of DJI Phantom quadcopter drone moving from A to B (A) Monostatic HH (B) Monostatic HV (C) Bistatic HH

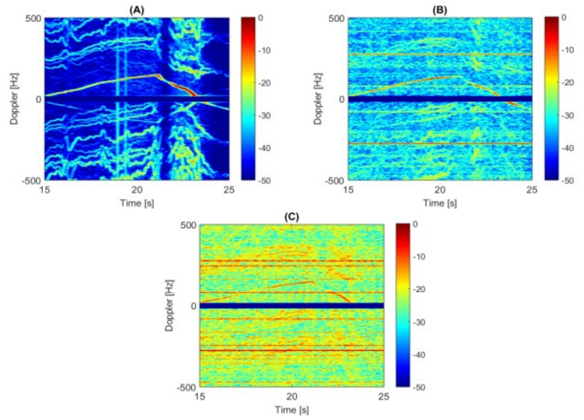

Fig. 10. Micro-Doppler signatures of DJI Phantom quadcopter drone moving from A to B (A) Monostatic HH (B) Monostatic HV (C) Bistatic HH

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