Detecting radar echoes from birds using phased-array radar technologies

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01 Introduction

Threats for aviation safety

Bird strike hazards

- Globally, from 1988 through 2019, 231320 strikes were reported, which killed more than 292 people and destroyed over 271 aircraft[1]

Hostility drones

- Drone black flights become increasing factor threating aviation safety[2]


10 Years Since the Miracle on the Hudson

Last Modified: Jun 8, 2020 Print

It's Been 10 Years Since the 'Miracle on the Hudson' – What's Changed in Aviation Safety?

Review on the Miracle on the Hudson in 2020[3]

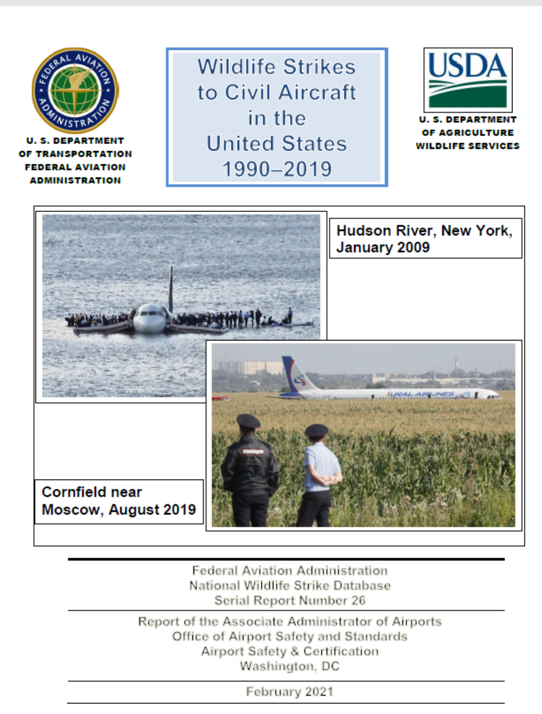
April 2017, drone black flight stop normal work at Shuangliu airport of Chengdu, China

1 A. R. Dolbeer, J. M. Begier, R. P. Miller, R. J. Weller, and L. A. Anderson, *Wildlife strikes to civil aircraft in the United States, 1990-2019*. 2021.
2 S. Park, H. T. Kim, S. Lee, H. Joo, and H. Kim, "Survey on Anti-Drone Systems: Components, Designs, and Challenges," *IEEE Access*, vol. 9, pp. 42635–42659, 2021, doi: 10.1109/ACCESS.2021.3065926.
3 https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/programs/nwrc/sa_spotlight/10+years+since+the+miracle+on+the+hudson

Duty of avian radar systems

Most of the reported bird strikes (>80%) occur on or near the airport surface(e.g., within 5 miles (~8km) of airports [1])

"Long-term goals include the integration of avian radar and bird migration forecasting into airspace management…"[1]


U. S. DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION
Wildlife Strikes to Civil Aircraft in the United States 1990–2019
USDA U. S. DEPARTMENT OF AGRICULTURE WILDLIFE SERVICES
Hudson River, New York, January 2009
Cornfield near Moscow, August 2019
Federal Aviation Administration
National Wildlife Strike Database
Serial Report Number 26
Report of the Associate Administrator of Airports
Office of Airport Safety and Standards
Airport Safety & Certification
Washington, DC
February 2021

Two different but related roles that avian radar systems can play:

(1) being sense-and-avoid systems: monitoring regional bird activities and providing alerts in real-time at airports.
- (1) Longer detection range
- (2) Shorter time delay
- (3) Better identification ability

(2) supporting wildlife management projects: mapping bird migration routes for predicting the bird hazard and planning flight
- (1) Long-time running
- (2) Data mining ability

1 A. R. Dolbeer, J. M. Begier, R. P. Miller, R. J. Weller, and L. A. Anderson, *Wildlife strikes to civil aircraft in the United States, 1990-2019.* 2021.

02 Theory & methods

Current state of avian radar systems

Most avian radar systems modified on marine navigation radars

- S-band (or X-band)
- Dual units: horizontal scan + vertical measuring height
- Array or parabolic dish antenna

Some typical commercial avian radar systems

Parameter	Content
Standard avian target (SAT)	0.5kg crow
	0.025 m^2
Detection range	>2km (1 SAT)
	>6km (2 SAT)
Detection height	>300m (1 SAT)
	>900m (1 SAT)
Track number	>1000
Location accuracy	50m (range)
	1.9km (cross-range)
Surveillance area	Radius >6km， height>900m
Coordinate precision	50m
Inspection frequency	<5s
Detection response time	<5s

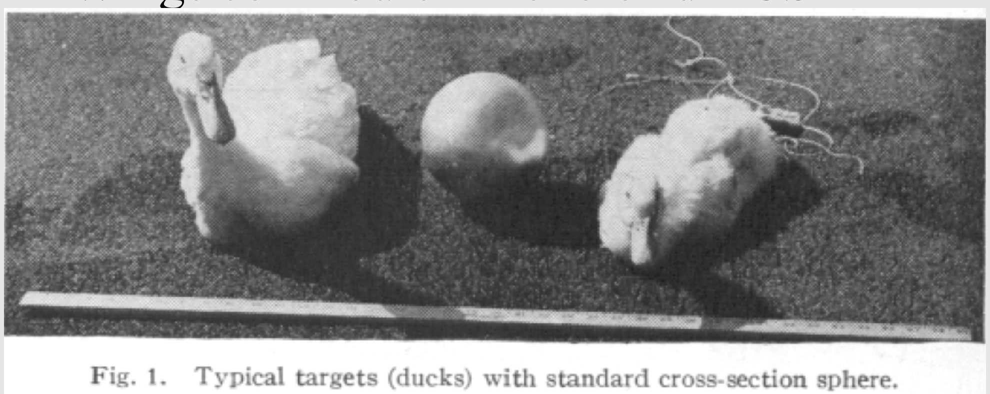
Required performance in Ac150/5220-25

Resonance effects within S-band for birds

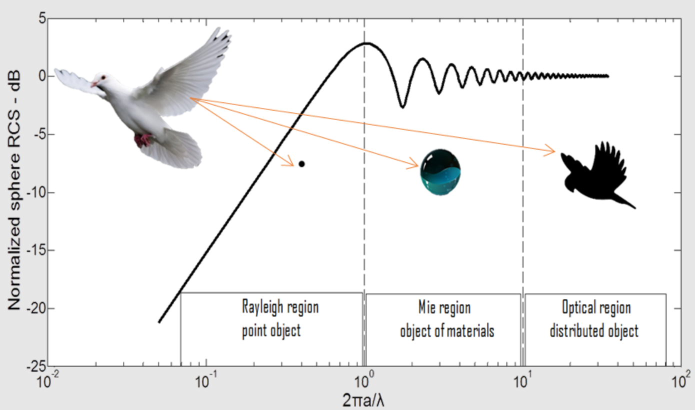
- Resonance effects mainly within S-band(marine radar band) in echoes from birds[1]
- RCS in the resonance region would be up to 5.4 dB larger than that in the optic region[2]

Water sphere model[2]

- Bird RCS is predominantly due to the 65% of its mass that is water[2]
- Wings contribute little to bird RCS[3]



History measurement[3]

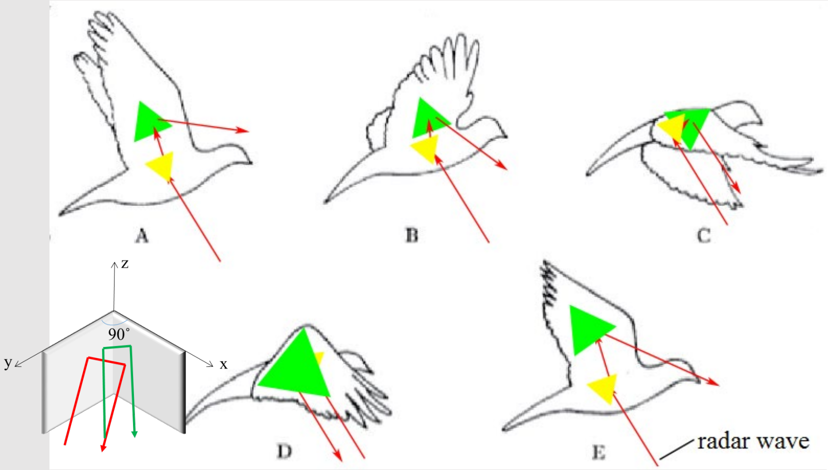


Scattering regions

1V. M. Melnikov, R. R. Lee, and N. J. Langlieb, "Resonance effects within S-band in echoes from birds," *IEEE Geosci. Remote Sens. Lett.*, vol. 9, no. 3, pp. 413–416, 2012
2 J. R. Moon, "Effects of birds on radar tracking systems," in *IEE Conference Publication*, 2002, vol. 490, pp. 300–304,
3 P. Blacksmith and R. B. Mack, "On Measuring the Radar Cross Sections of Ducks and Chickens," Proc. IEEE, vol. 53, no. 8, p. 1125, 1965

Wingbeat corner reflector effect

- Scattering centers theory in the optic region
- During certain flapping motions, the wings and body of birds in flight act as corner reflectors; thereby, when radar echoes fall upon either face will impinge onto the other face, and subsequently reflected towards the illuminator, thus contributing considerably to bird RCS, up to over 10 dB.



Wingbeat corner reflector(WCR) effect

a 1kg duck = 2 SATs RCS=0.05m² ??

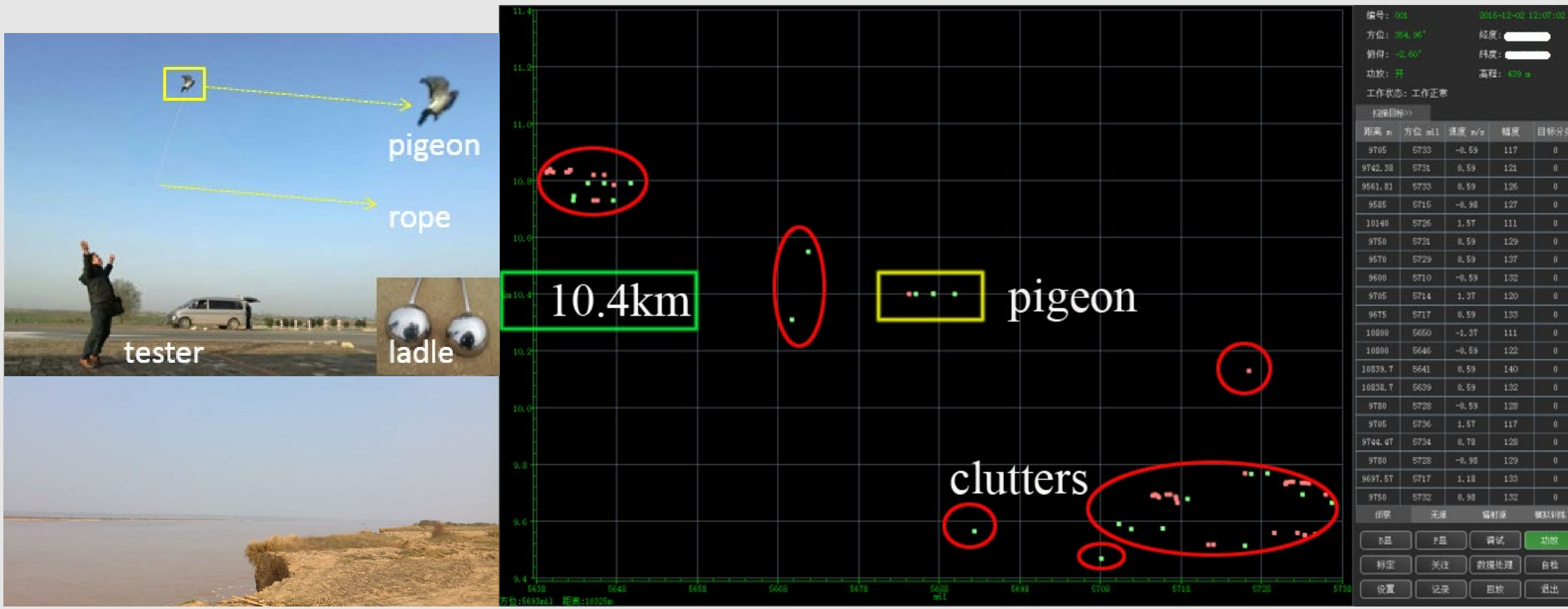
Water sphere model	Wingbeat corner reflector model
$\sigma = \pi \left(\frac{39m}{80\pi\rho}\right)^{\frac{2}{3}}$	$\sigma = \frac{8\pi a^2 b^2}{\lambda^2}$ (max)
m=1kg, ρ=1 g/cm³	a=b=5.4cm, λ=3cm
σ_{water}=0.0313 m²	σ_{WCR}=0.2375 m²

>>10

Our test measurements

Using a Ku-band radar measuring a cooperative 0.35kg pigeon

- Measured RCS of 0.25m^2
- Maximum detectable range of the pigeon is 12km with the detection probability at this range is above 95 %

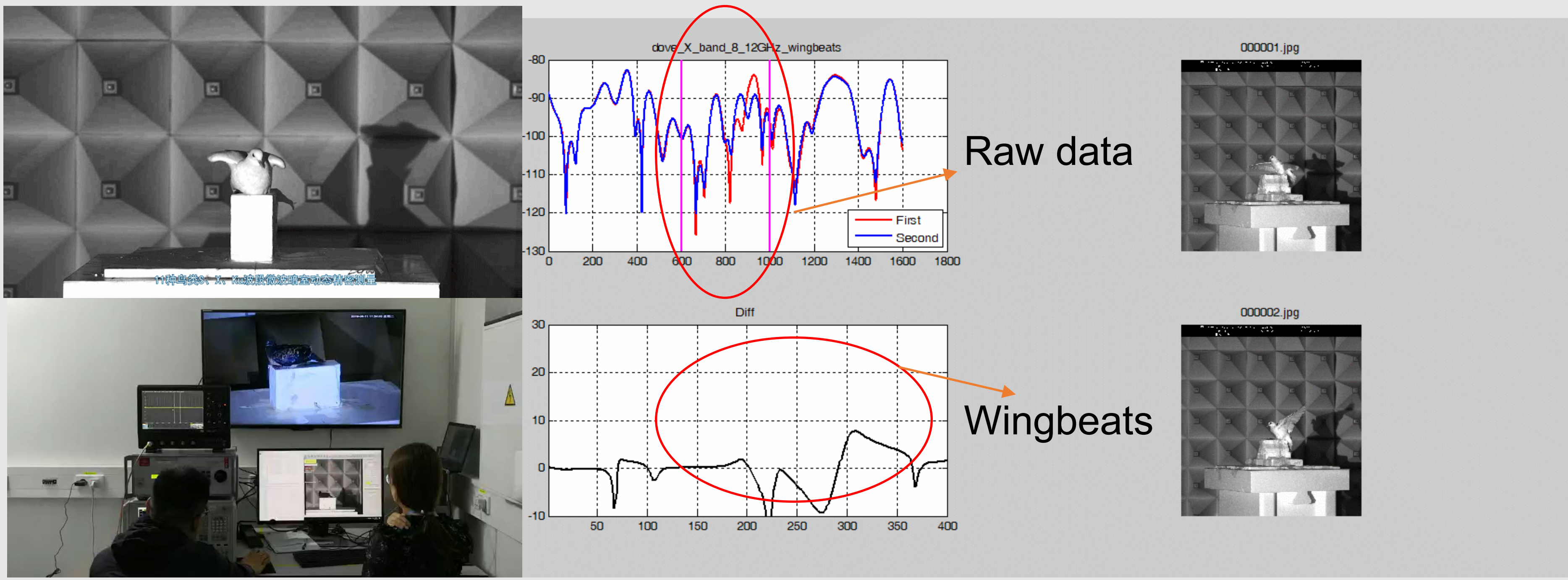


external field test at the Yellow River wetlands bird protection area in China

Our test measurements

Measurements in a microwave anechoic chamber

- Dynamic tacking echo data following wingbeat gaits
- Much over 10 dB within X-band, Ku-band, etc.
- Many bird species, including duck, pigeon, seagull, etc.



Microwave anechoic chamber measurement

Why not marine radar technologies

Insufficient wingbeat corner reflector signals

- Resonance region over the optic region: The higher frequency, the larger RCS of a corner reflector
- Short radar dwell time and low sampling frequency: The sampling frequency must be high enough to separate the consecutive wingbeats (e.g., <10Hz) and the dwell time must be long enough to capture the wingbeat corner reflector effect

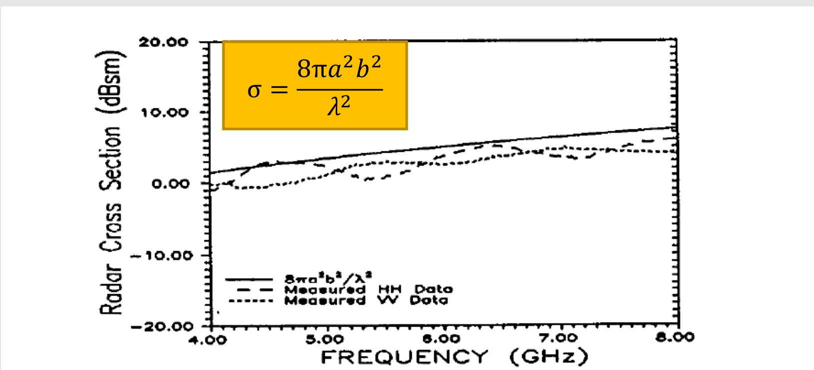
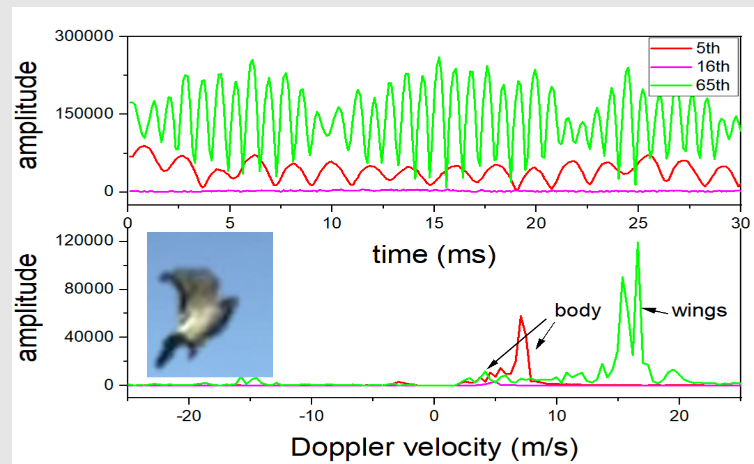


Figure 2. Measured RCS frequency response of 5.0" x 5.5" dihedral corner reflector oriented for maximum backscattered return.

A dihedral corner reflector' RCS[1]

Slower-speed scan may be better.



Doppler velocities of a pigeon's wings

1 K. W. Sorensen, "A dihedral corner reflector model for full polarization calibration of RCS measurements," in *Antennas and Propagation Society Symposium 1991 Digest*, 2002, pp. 748–751

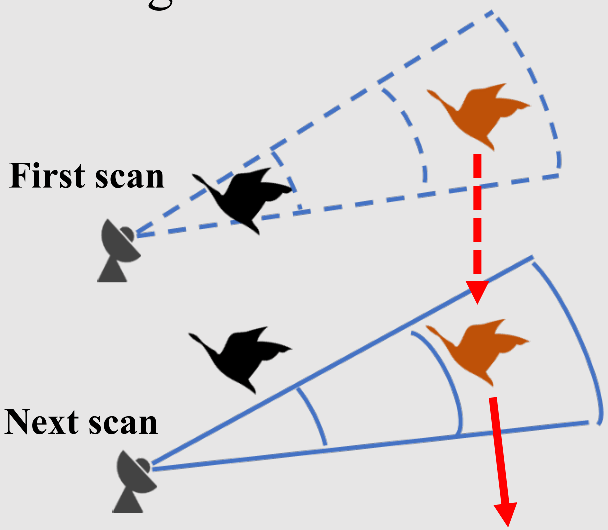
Why not marine radar technologies

Inadequate 3D position

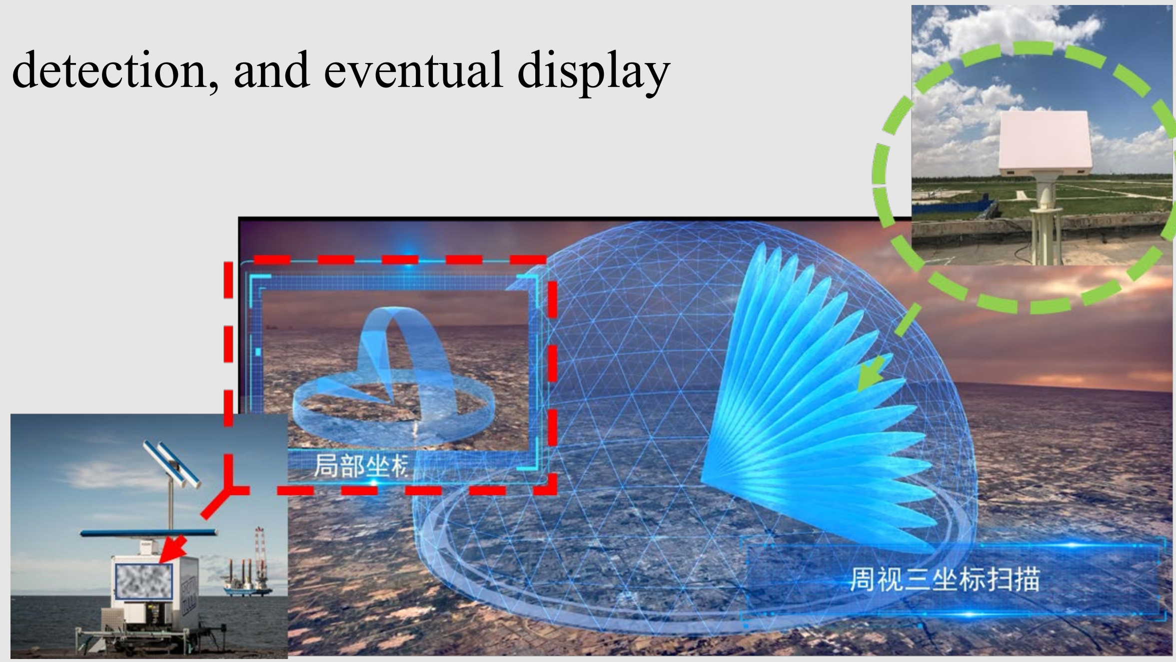
- Dual antennas need alignment of vertical and horizontal coverage

Time delay(~5 seconds)

- Detection after track method(~2.5 seconds) & 2D radar image processing algorithm(~3-4 seconds)
- Lags between an echo return, detection, and eventual display



Far bird not easily flying across the radar resolution



Coverage of the two type antennas [1]

1 The left coner picture of Robin radar refers to www.robinradar.com

03 Our avian radar solution

Our avian radar solution

Pulse-Doppler phased array radar

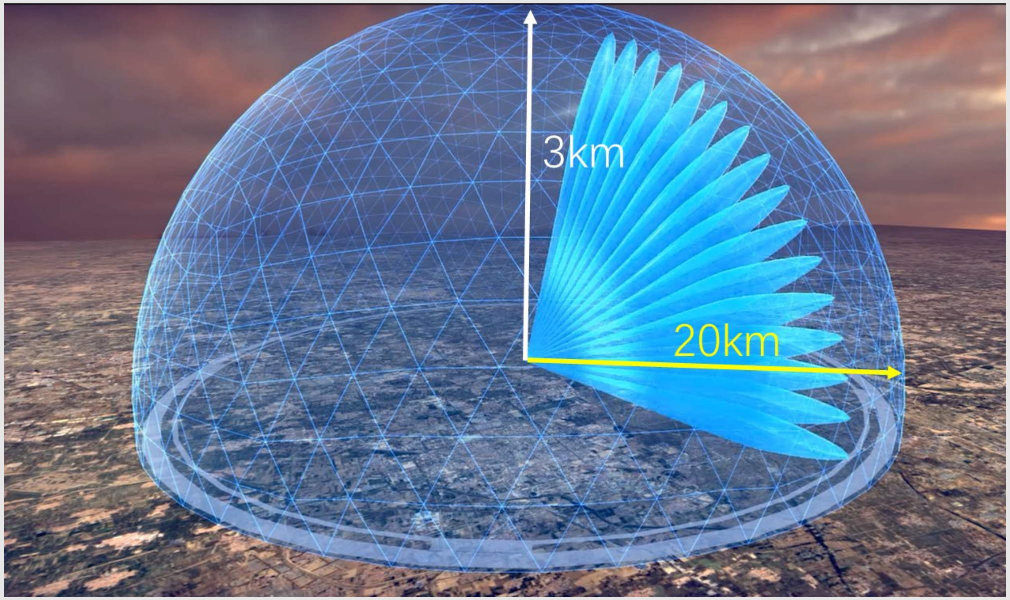
- Being a sense-and-avoid systems = (1)long detection range + (2)short detection response time + (3)reliable ATR ability

Radar type	Marine radar	Pulse-Doppler phased array radar
Scattering model	Water sphere	Wingbeat corner reflector
System model	Dual units	One unit
Bands	S & X	X
Antenna	Slotted array antenna	Active electronically scanned array antenna
	Parabolic dish antenna	
Detection range	~2 km (1 SAT)	>10 km (1 SAT)
	~6 km (SATs)	>20 km (SATs)
Identification method	Image processing	Signal processing
Detection response time (DRT)	~5 s	<30 ms
Inspection Frequency	<5 s	2~20 s (Adjustable)
Automatic target recognition (ATR)	Birds, clutters	large birds, small birds, drones, vehicles, ships, people, helicopters, etc.

Our avian radar solution

Far long detection range

- X-band, using the wingbeat corner reflector effect in the optic region for most birds to increase the radar range
- Detection range of 1 SAT & SATs >10 km & 20 km, respectively
- With DBF, surveillance area cover most cover airfield clearance zone(ACZ)



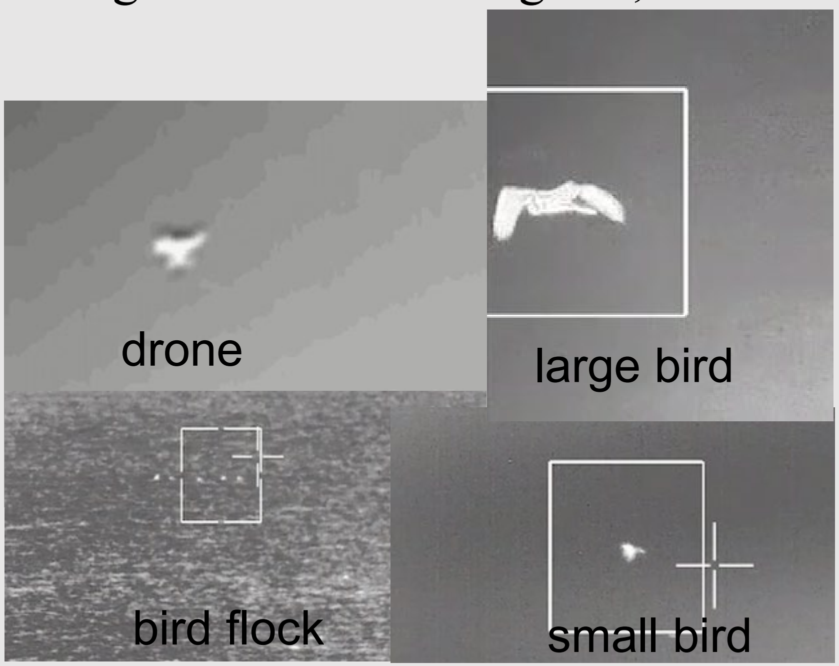
Surveillance area

Wuhan Tianhe Airport

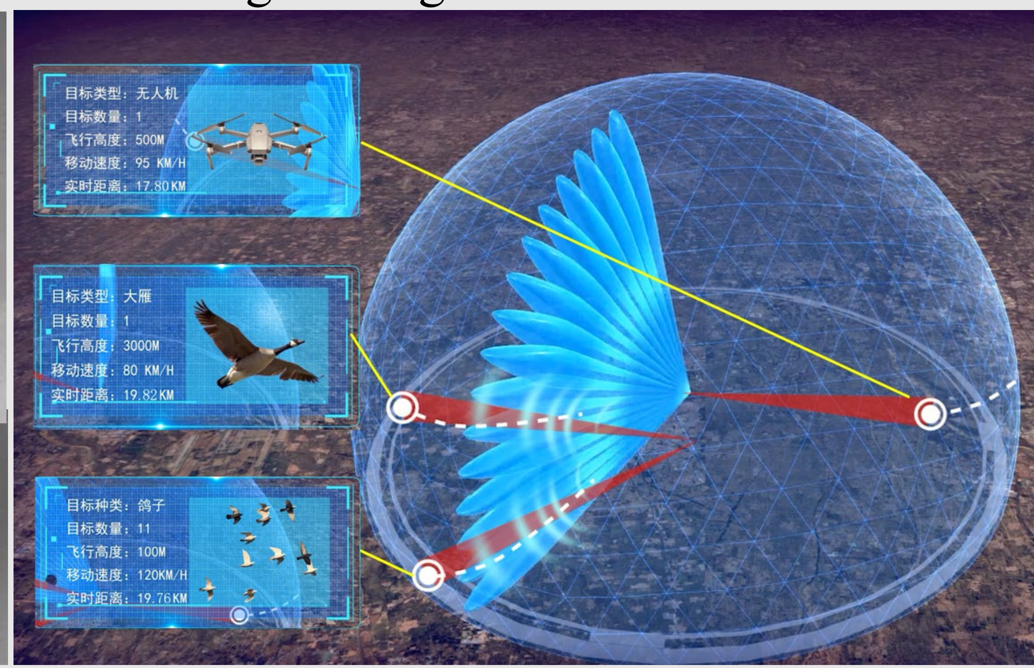
Our avian radar solution

Very short detection response time

- Detection response time < 30ms
- NO LAGs (e.g., 5 seconds) between an echo return, detection, and eventual display
- Using ATR to Detection & Identification radar echoes from birds via radar signatures in radar signals, and without tracking the target



Confirmed using optic& infrared sensors

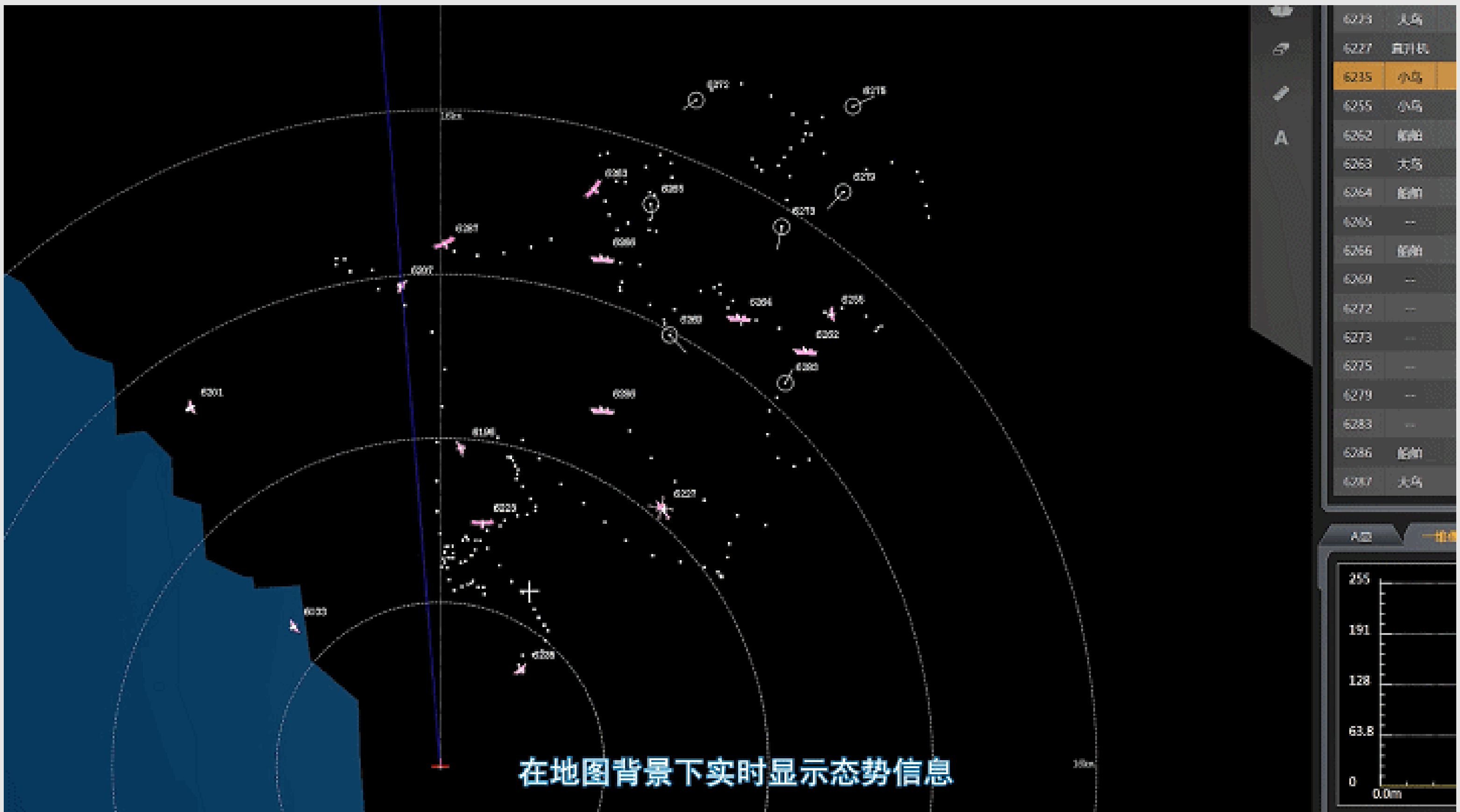


Identification without tracking a target

Our avian radar solution

Reliable automatic target recognition ability

- Classification while detection without tracking a target (DRT 30ms << 5 seconds)
- Identification probability of > 90% with high confidence level of >95%



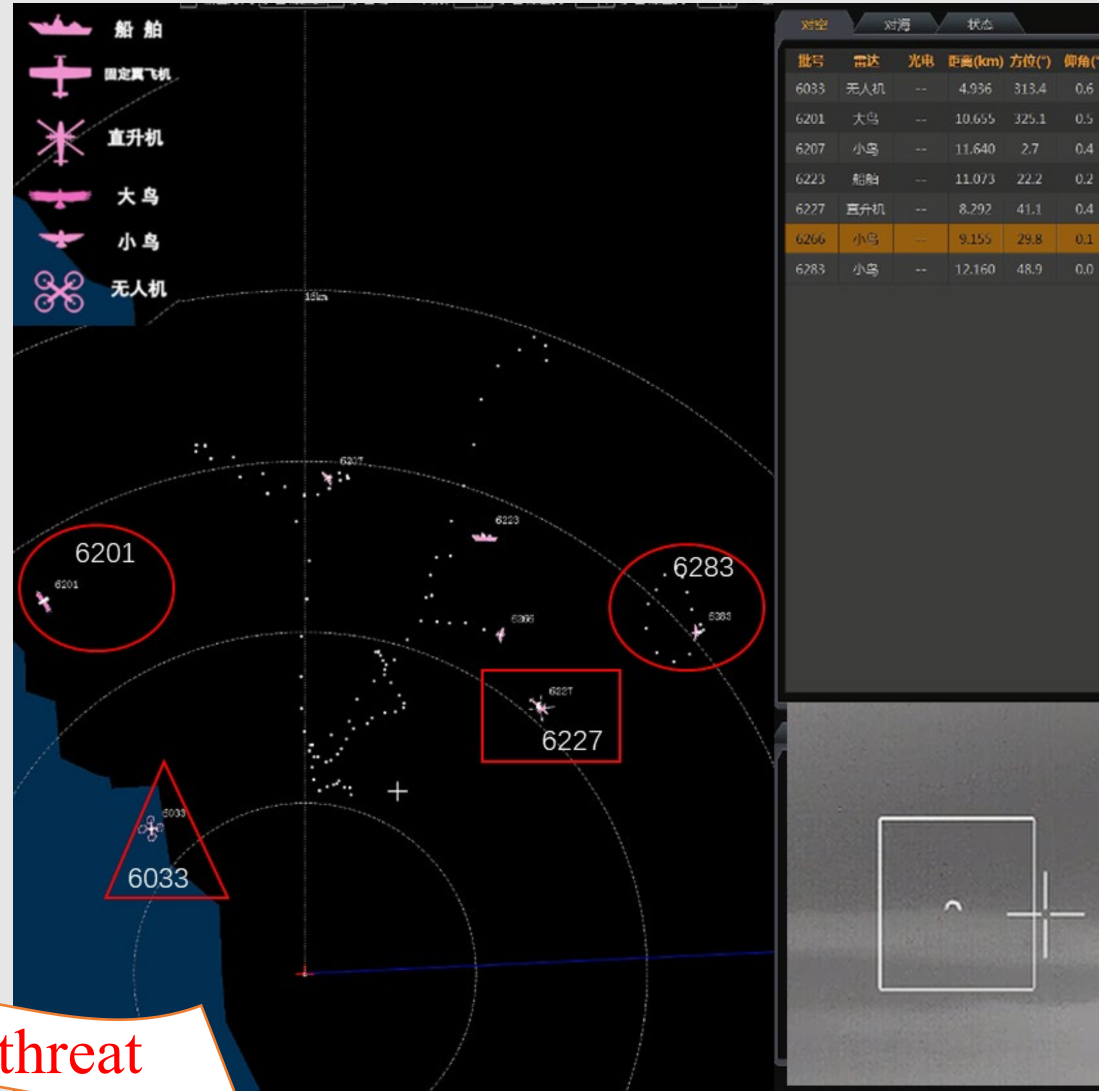
Our avian radar solution

4D situational awareness

- ■Classification while scan (CWS) technology
- ■4D (3D position + target attribution)
- ■Radar display presented whole scenario following the scan of the radar beam.

A small bird with No.6283 is about 12.1km, while that of a small bird with No.6201 is about 10.6km.

The bird of No. 6283 was flying near the helicopter of No. 6227.



No threat

04 About us

About US

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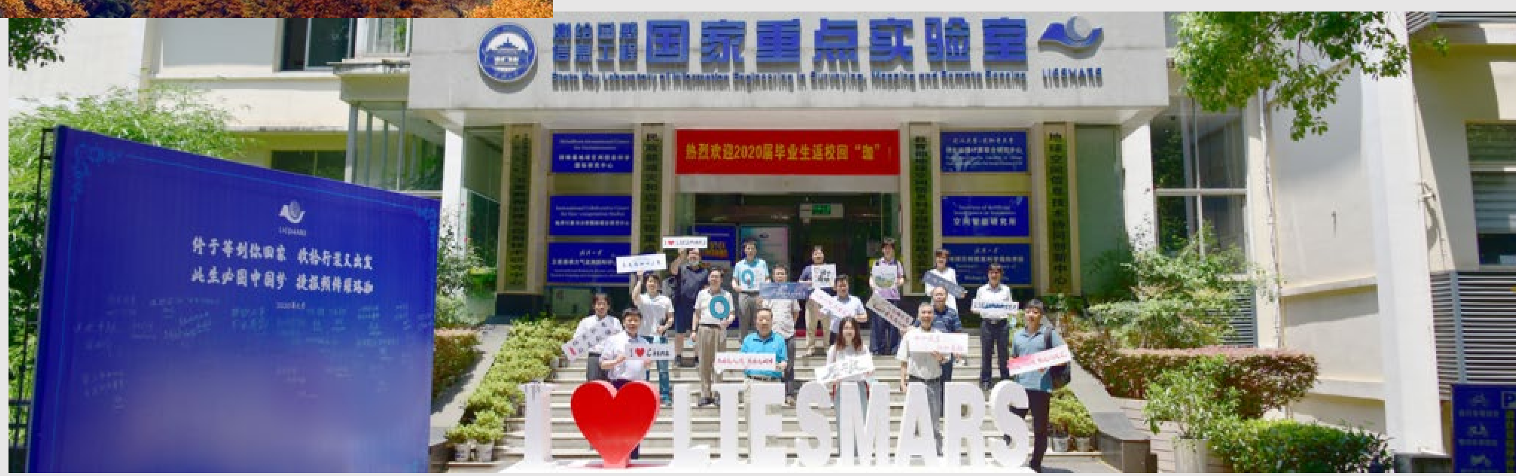

http://www.lmars.whu.edu.cn/en

Selected papers:

- **Jiangkun Gong**, Jun Yan, Deren Li, and Ruizhi Chen, “Comparison of micro-Doppler signatures registered using RBM of helicopters and WSM of vehicles,” in IET Radar, Sonar & Navigation, vol. 13, no. 11, pp. 1951-1955, 11 2019, *doi: 10.1049/iet-rsn.2019.0210.*
- **Jiangkun Gong**, Jun Yan, Deren Li, and Ruizhi Chen, "Using Radar Signatures to Classify Bird Flight Modes Between Flapping and Gliding," in IEEE Geoscience and Remote Sensing Letters, *doi: 10.1109/LGRS.2019.2949027.*
- **Jiangkun Gong**, Jun Yan, Deren Li, and Ruizhi Chen, "Using the wingbeat corner reflector effect to increase detection range of avian radar systems," in IET Radar, Sonar & Navigation, vol. 13, no. 10, pp. 1811-1815, 10 2019, doi: 10.1049/iet-rsn.2019.0002.
- **Jiangkun Gong**, Jun Yan, Deren Li, and Ruizhi Chen. “A Comparison of Radar Signatures Based on Flight Morphology for Large Birds and Small Birds.” IET Radar, Sonar & Navigation, 2020, doi: 10.1049/iet-rsn.2020.0064.
- **Jiangkun Gong,** Jun Yan, Deren Li, Deyong Kong, and Huiping Hu, "Interference of Radar Detection of Drones by Birds," Progress In Electromagnetics Research M, Vol. 81, 1-11, 2019. doi:10.2528/PIERM19020505

Patents:

- Jun Yan, **Jiangkun Gong,** Deyong Kong. A method for dynamically measuring RCS of birds， 201910880897.4.
- Jun Yan, **Jiangkun Gong,** Deyong Kong. A method for dynamically measuring RCS of small drones， 20191088045.7.

Thanks！