Machine Learning Techniques for Radar Automatic Target Recognition (ATR)

Chapter 5: Radio Frequency Data for ML Research

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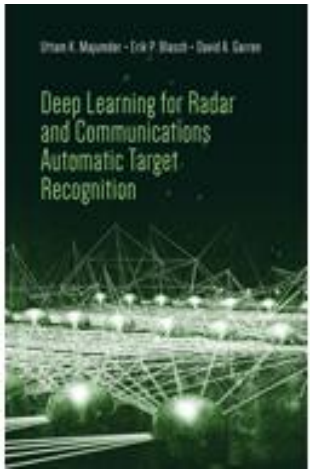
Deep Learning for Radio Frequency Automatic Target Recognition (ATR)

Lecture Outline



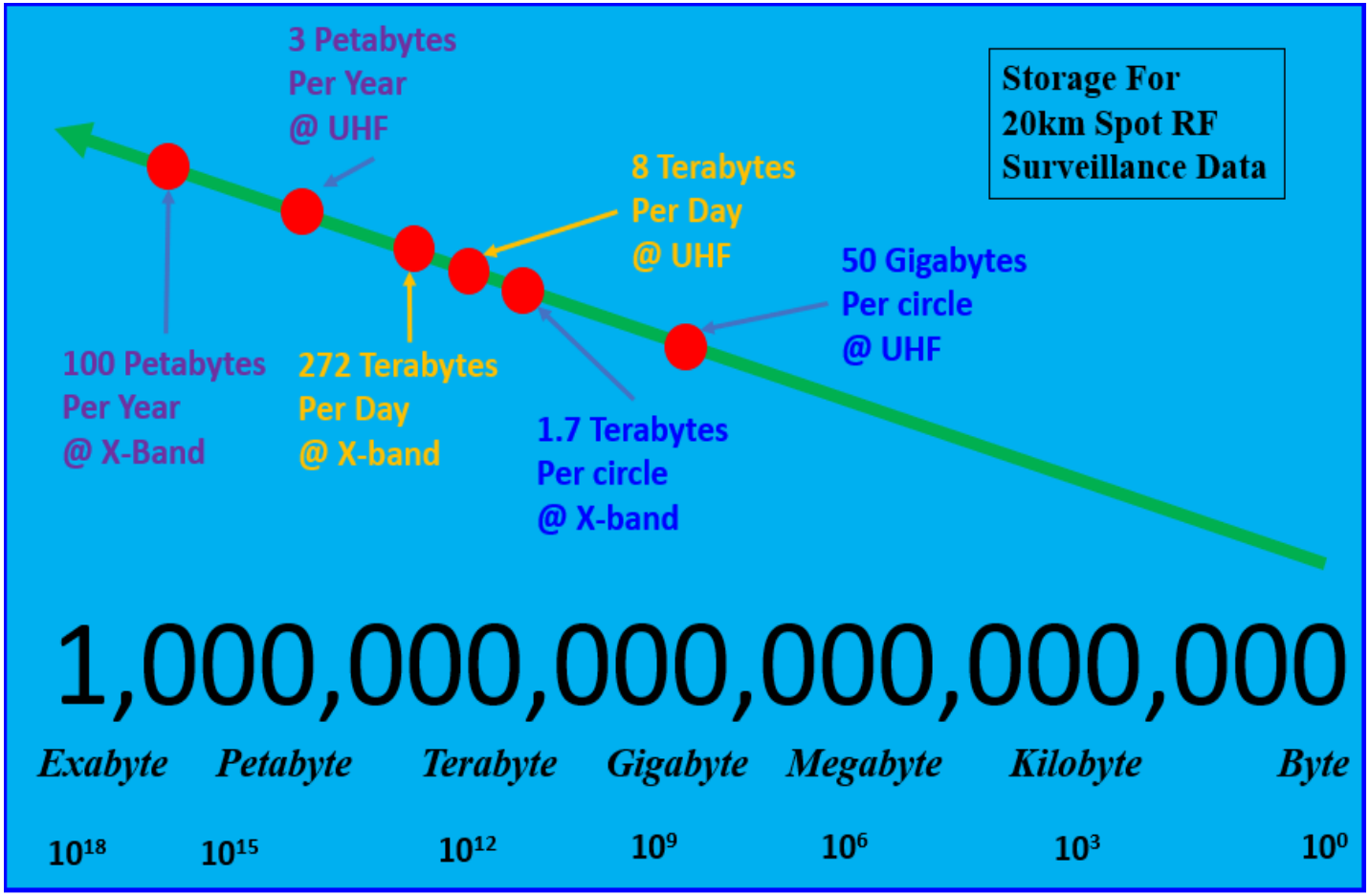
1. **Radio Frequency ATR: Past, Present, and Future:** **20 min**
2. **Mathematics for Machine Learning / Deep Learning:** **20 min**
3. Review of ML Algorithms: 25 min
4. **Deep Learning Algorithms: 30 min**
5. **RF Data for ML Research: 15 min**
6. **DL for Single Target Classification: 25 min**
7. **DL for Many Targets Classification: 25 min**
8. **RF Signals Classification: 20 min**
9. **RF ATR Performance Evaluation: 25 min**
10. **Emerging ML Algorithms for RF ATR: 35 min**

1.3 Radio Frequency (RF) Data

- Unlike video imagery, RF data are difficult to collect
- Measured RF data collection involves
  - *Radar sensors (X-band, UHF/VHF) integration and data collection by a certified aircraft*
  - *A detailed experiments design (collection scenarios)*
  - *Ground truthing*

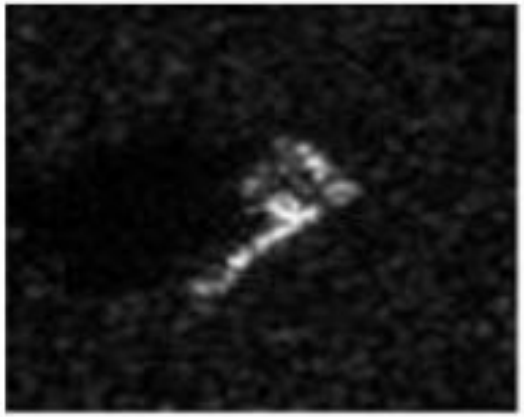
Hence, obtaining measured RF data are expensive

Radio Frequency Data



1.3 Measured RF Signature

- Synthetic Aperture Radar (SAR) technology is used imaging
  - 1D SAR: range profile
  - 2D SAR: Image of a Scene/Target/Object
  - In general, 1 foot resolution SAR image is common
    - In X-band, ~0.5GHz BW
- Detecting and identifying object from radar images could be hard for a human operator



1.3 Synthetic RF Data

- **It is possible to generate radar data by simulation**
- **Electro-magnetic prediction code is used**
  - Computationally very expensive and requires High Performance Computing (HPC) systems
- **Even with an HPC system, it requires days to generate synthetic RF signature of a vehicle/object**
- **Compute time depends on:**
  - Fidelity/Accuracy of the signature prediction
  - Number of objects/targets in the scene
  - Background (with or w/o clutter and other objects) of the scene

1.3 RF Data Sources for AI/ML Research

1. **Public Release MSTAR Dataset**
   - https://www.sdms.afrl.af.mil/index.php?collection=mstar
2. **SAMPLE Dataset**
   - https://spie.org/Publications/Proceedings/Paper/10.1117/12.2523460?SSO=1
3. **PEMS Dataset**
4. **Civilian Vehicles Dataset**
   - https://www.sdms.afrl.af.mil/index.php?collection=cv_dome
5. **Ship Detection Dataset**
   - https://github.com/CAESAR-Radi/SAR-Ship-Dataset
6. **RF Signals Dataset**
   - http://www.genesys-lab.org/oracle **(RF Fingerprinting)**

1.3 MSTAR Data

Moving and Stationary Target Acquisition Recognition (MSTAR)

Table 1. The number of images of each object at different depression angles.

Targets	BMP2	BTR70	T72	BTR60	2S1	BRDM2	D7	T62	ZIL131	ZSU234
17°	233	233	232	256	299	298	299	299	299	299
15°	587	196	582	195	274	274	274	273	274	274

1.3 SAMPLE Dataset

Synthetic And Measured Pair Labelled Experiment (SAMPLE) Data

- Elevation: 14-17 degrees
- Azimuth: 10-80 degrees
- Resolution: 0.3m x 0.3m
- Bandwidth: 591 GHz
- Center Frequency: 9.6 GHz
- Polarization: HH
- Image Size: 128x128
- Pixel Spacing: 0.2m x 0.2m
- Extent: 25.8m x 25.8m
- Taylor Weighting: -35 dB

Class	Measured	Synthetic	Total
2S1	177	177	354
BMP2	108	108	216
BTR70	96	96	192
M1	131	131	262
M2	129	129	258
M35	131	131	262
M548	129	129	258
M60	178	178	356
T72	110	110	220
ZSU23	177	177	354
Total	1366	1366	2732

Benjamin Lewis; Theresa Scarnati; Elizabeth Sudkamp; John Nehrbass; Stephen Rosencrantz; Edmund Zelnio, "A SAR dataset for ATR development: the Synthetic and Measured Paired Labeled Experiment (SAMPLE)". Proc. SPIE 10987, Algorithms for Synthetic Aperture Radar Imagery XXVI, 109870H (14 May 2019); doi: 10.1117/12.2523460

1.3 PEMS ATR Dataset

Performance Estimation for Multi-Sensor (PEMS) ATR Data

- **10Targets with 4 variants**
  - BMP2 No Mount Assembly
  - M2NA No Missile Launcher Assembly
  - T72 No Barrel
  - ZSU234 No Radar
- Elevation: 11-20 degrees
- Azimuth: 0:2:358 degrees
- Resolution: 12in x 12in
- Bandwidth: 500 MHz
- Center Frequency: 9.6 GHz
- Polarization: HH
- Articulation States: -90:5:90

Table 1: Data Generated for Challenge Problem

Class Num	Target	Articulation 1 (deg)	Articulation 2 (deg)	Total Images
1	2S1	Gun [0]	Turret [-90:5:90]	66,600
2	BMP2	Gun [0]	Turret [-175:5:180]	66,600
3	BMP2NM	Gun [0]	Turret [-90:5:90]	66,600
4	BTR70	Gun [0]	Turret [-90:5:90]	66,600
5	M1A1	Gun [0]	Turret [-90:5:90]	66,600
6	M2NA	Gun [0]	Turret [0:5:90 270:5:355]	66,600
7	M2NANL	Gun [0]	Turret [0:5:90 270:5:355]	66,600
8	M35	Rail [0:90:90]	Left Door [0:5:70]	54,000
9	M548	Rail [0:90:90]	Left Door [0:5:70]	54,000
10	M60	Gun [0]	Turret [-90:5:90]	66,600
11	T72	Gun [0]	Turret [-90:5:90]	66,600
12	T72NB	Gun [0]	Turret [-90:5:90]	66,600
13	ZSU234	Radar [0]	Turret [-90:5:90]	66,600
14	ZSU234NR	Gun [11,45,60]	Turret [-90:5:90]	199,800

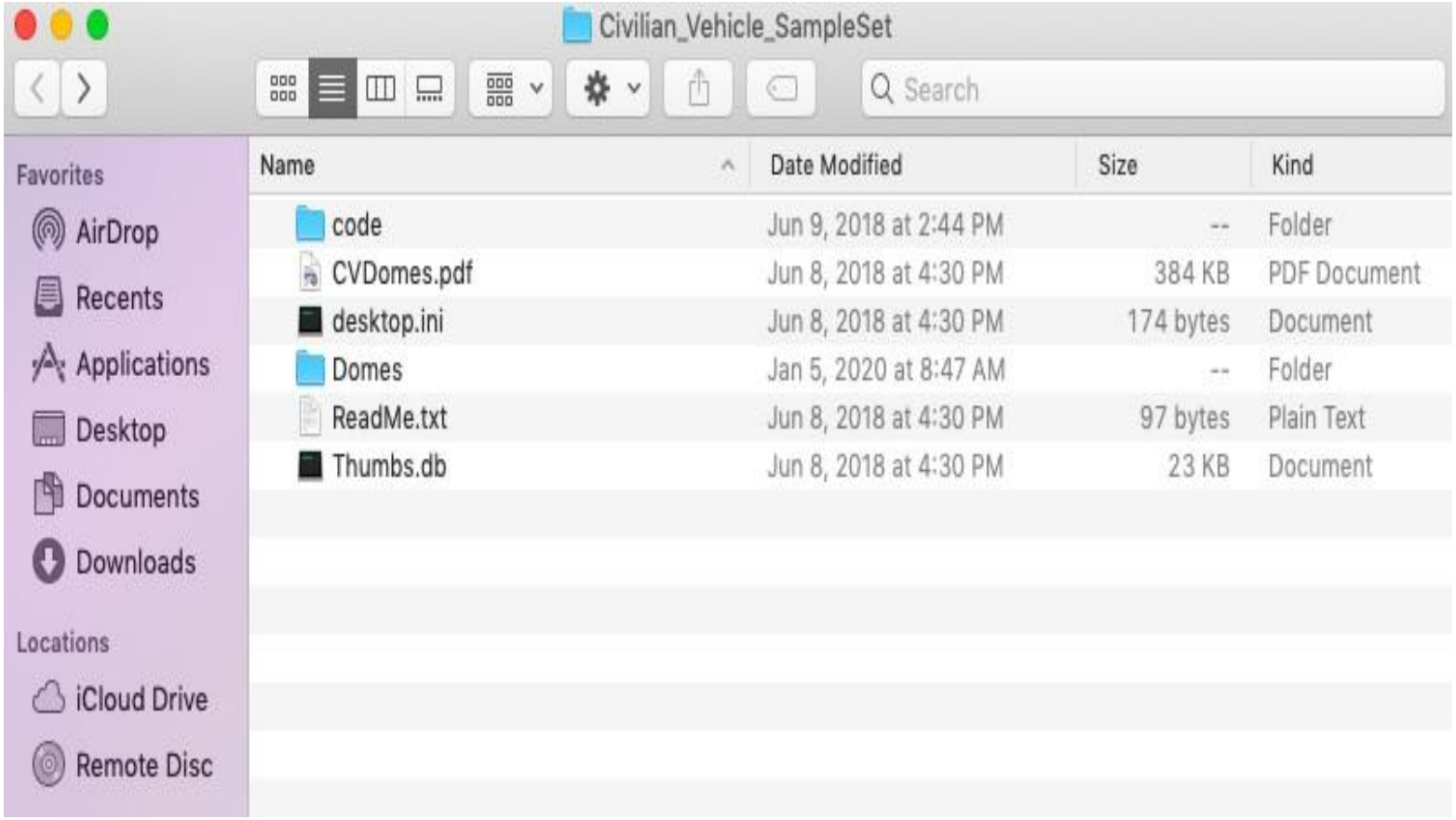
C. Paulson, L. Westerkamp, E. Zelnio., "Challenge problems consideration for the 7 habits of highly effective ATRs", (Conference Presentation)", Proc. SPIE 11393, Algorithms for Synthetic Aperture Radar Imagery XXVII, 113930V (27 April 2020); https://doi.org/10.1117/12.2561780

1.3 Civilian Vehicle Datasets (CVDome)

				
Toyota Camry	**Honda Civic 4Dr**	**Jeep 1993**	**Jeep 1999**	**Nissan Maxima**
				
Mazda MPV	**Mitsubishi**	**Nissan Sentra**	**Toyota Avalon**	**Toyota Tacoma**

Parameter	Value
Radar center frequency	9.6 GHz
Unambiguous range	≈ 15 m
Extrapolation extent	$\leq 0.25°$
Azimuth extent	360°
Elevation extent	30° to 60°
speed of light	299792458 m/s

CVDome Data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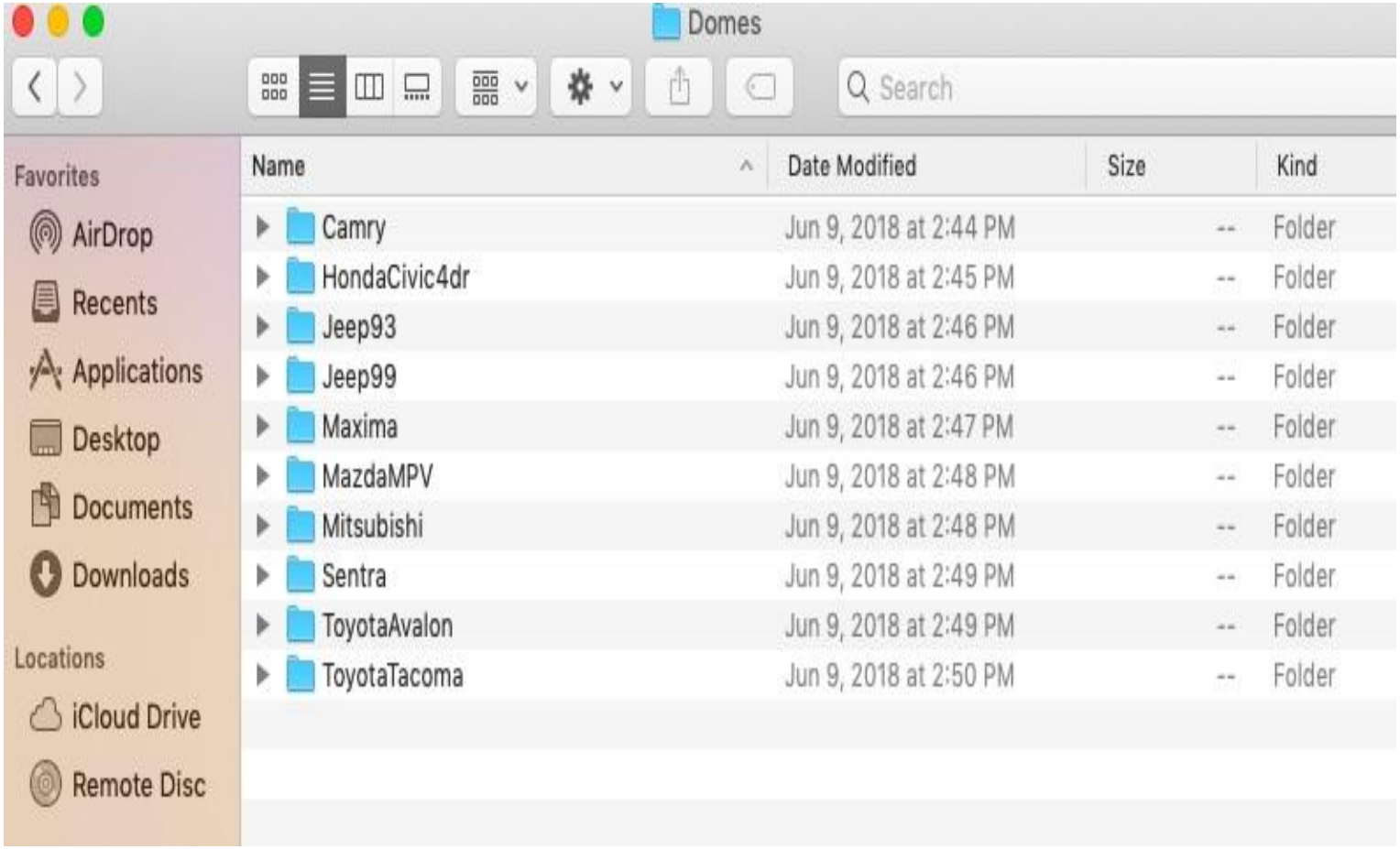
CVDome Data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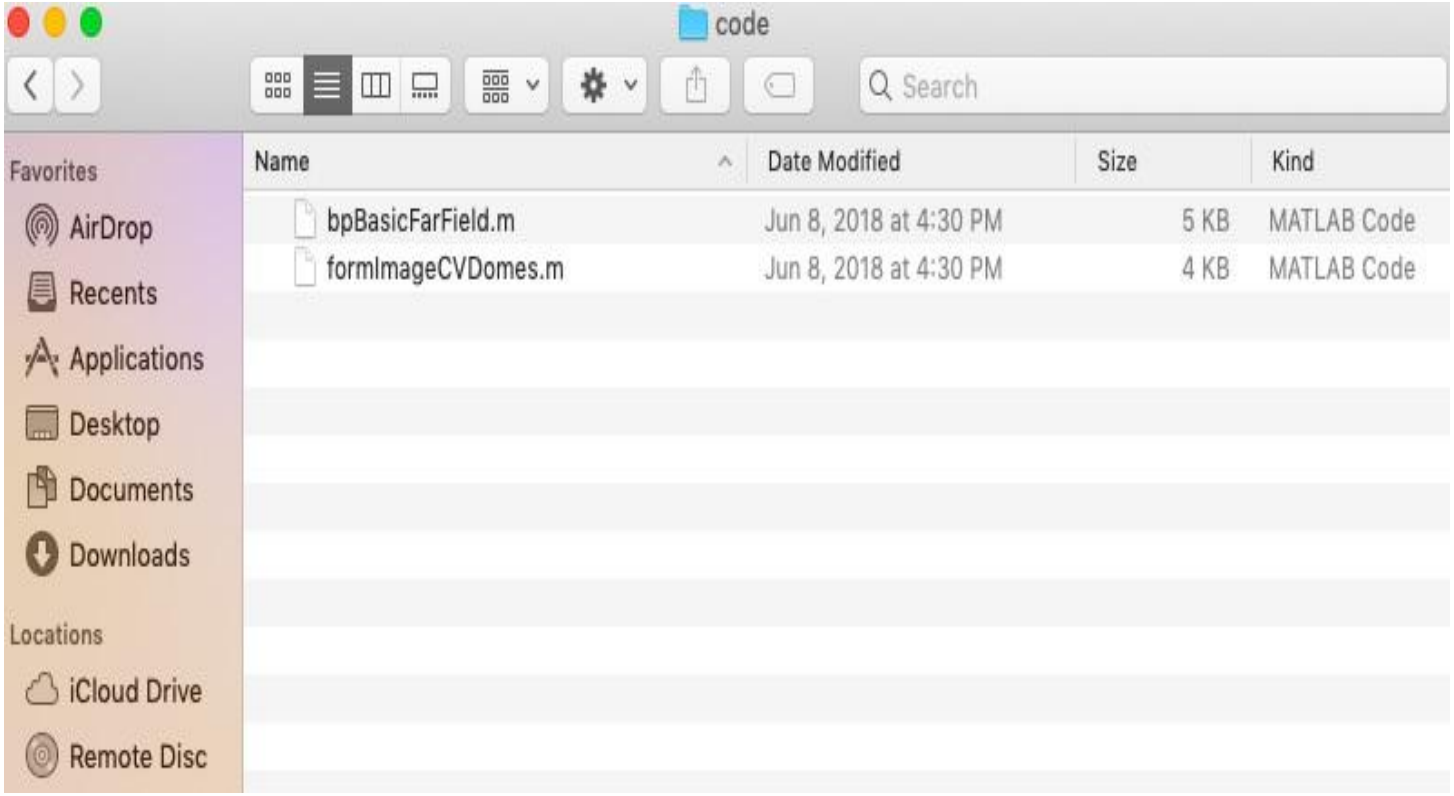
CVDome Data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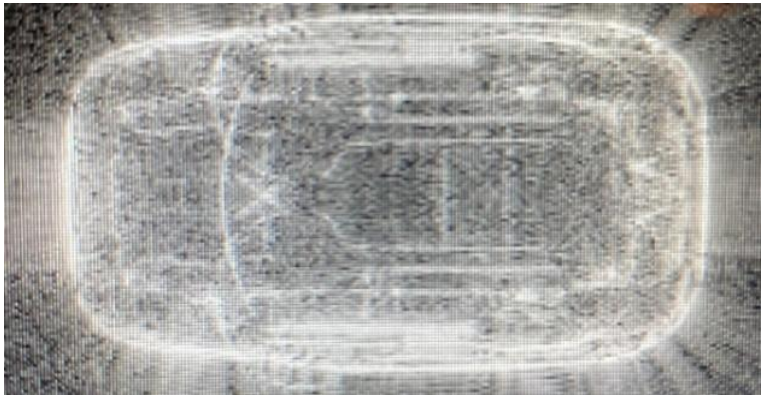
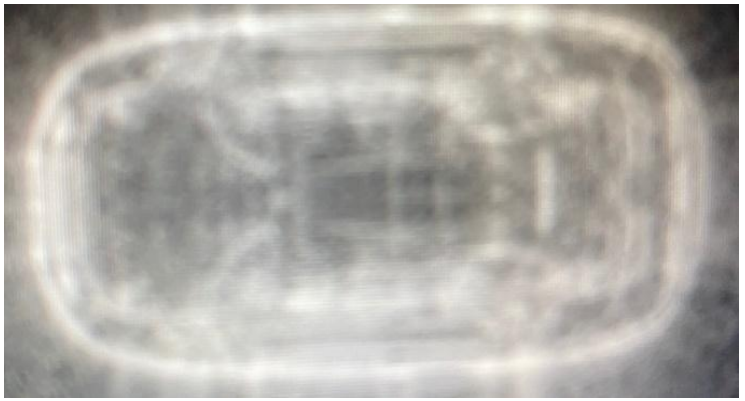
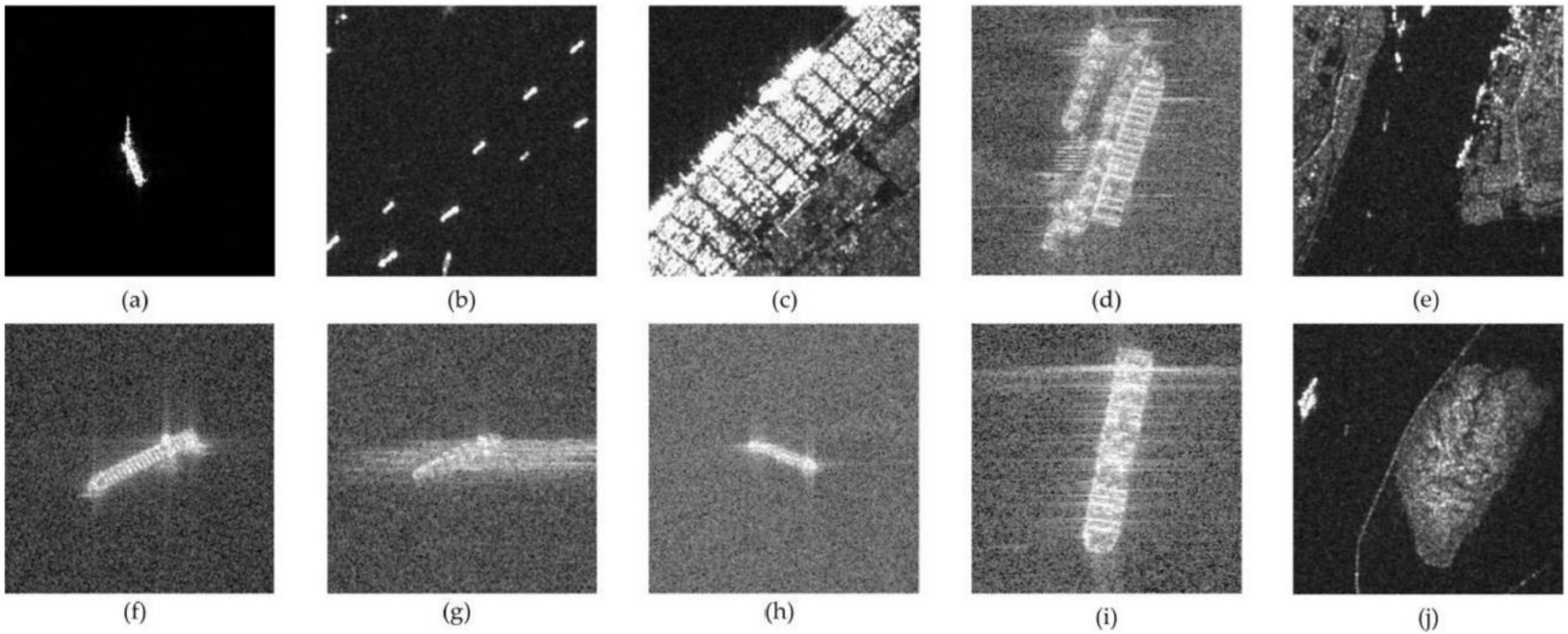
SAR Image from CVDome





1.3 RF Ship Detection Dataset



A SAR Dataset of Ship Detection for Deep Learning under Complex Backgrounds." Remote Sensing 11 (7). doi: 10.3390/rs11070765

https://github.com/CAESAR-Radi/SAR-Ship-Dataset

Summary of RF Data

- We Presented Available RF Data for ML research
- Discussed how these data can be obtained
- Discussed Why RF data are expensive