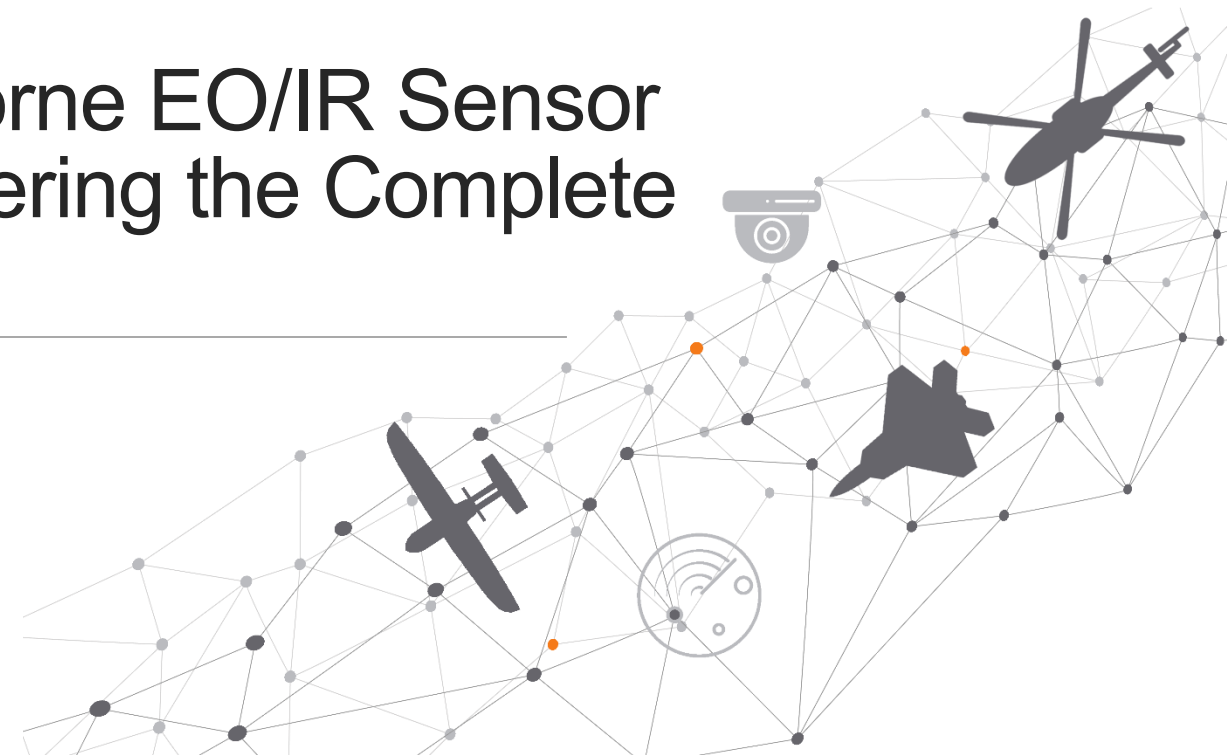


Performance Models for Airborne EO/IR Sensor Deployment Planning Considering the Complete Image Chain

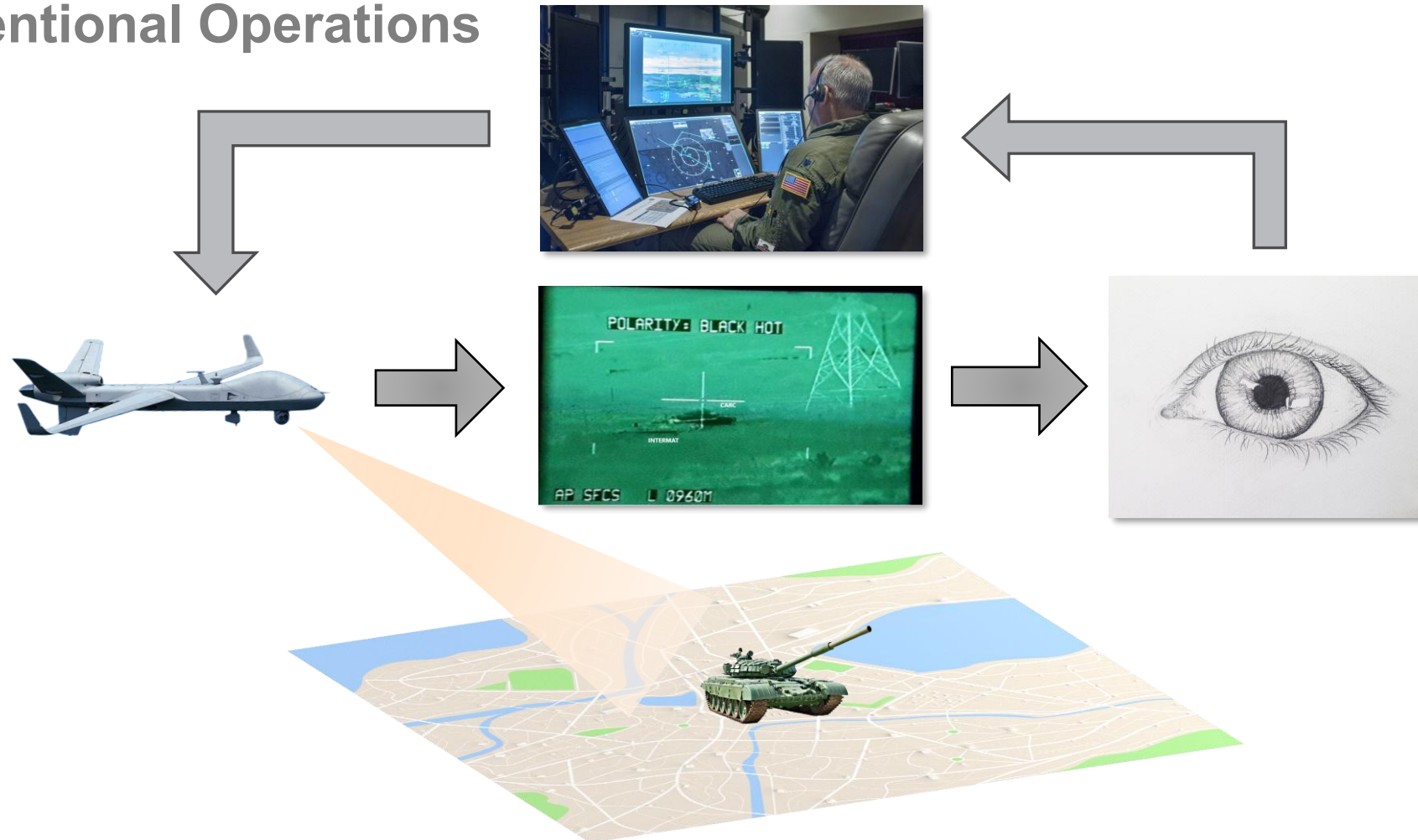
ADRIAN ALBERT

PROF. DR.-ING PETER STÜTZ



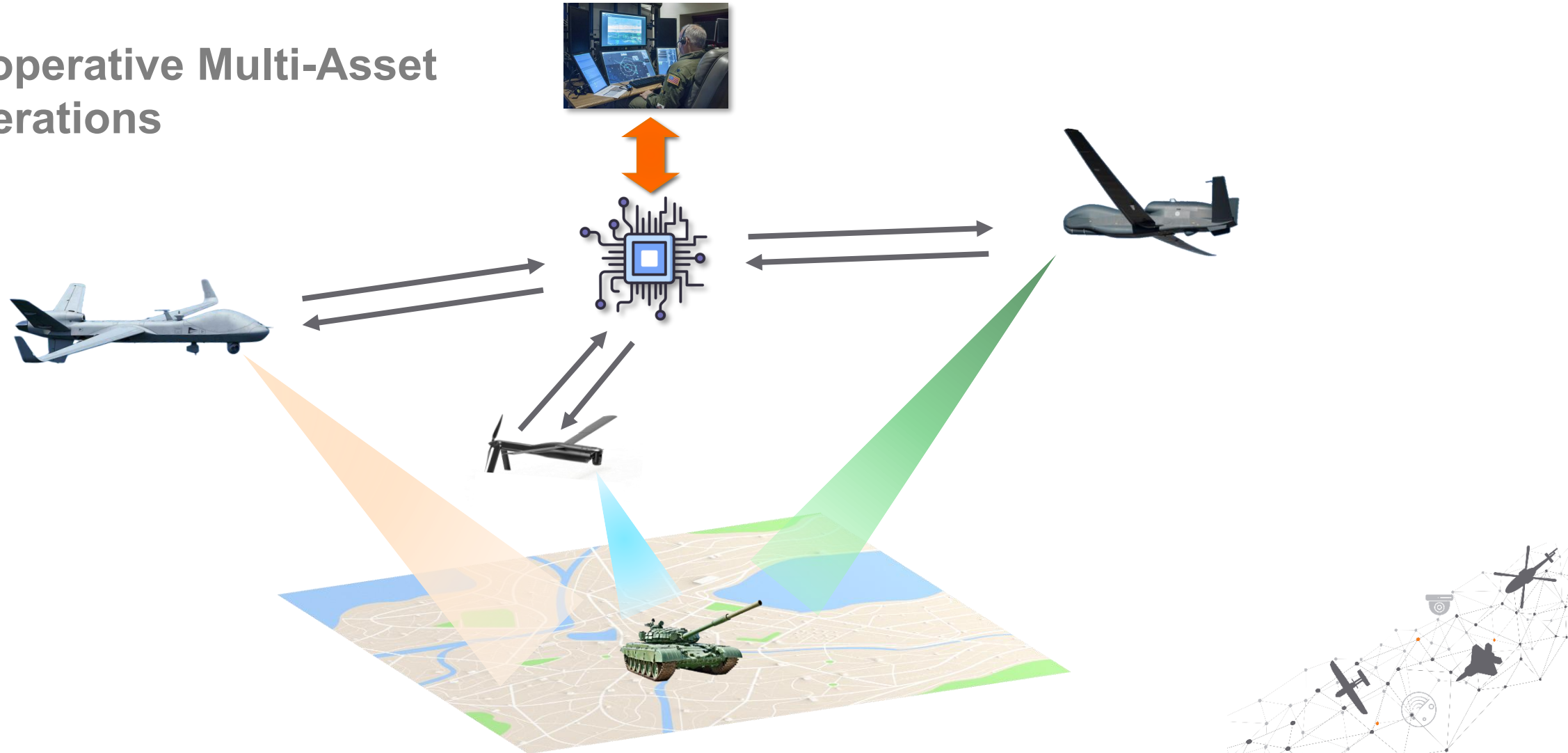
Motivation

Conventional Operations

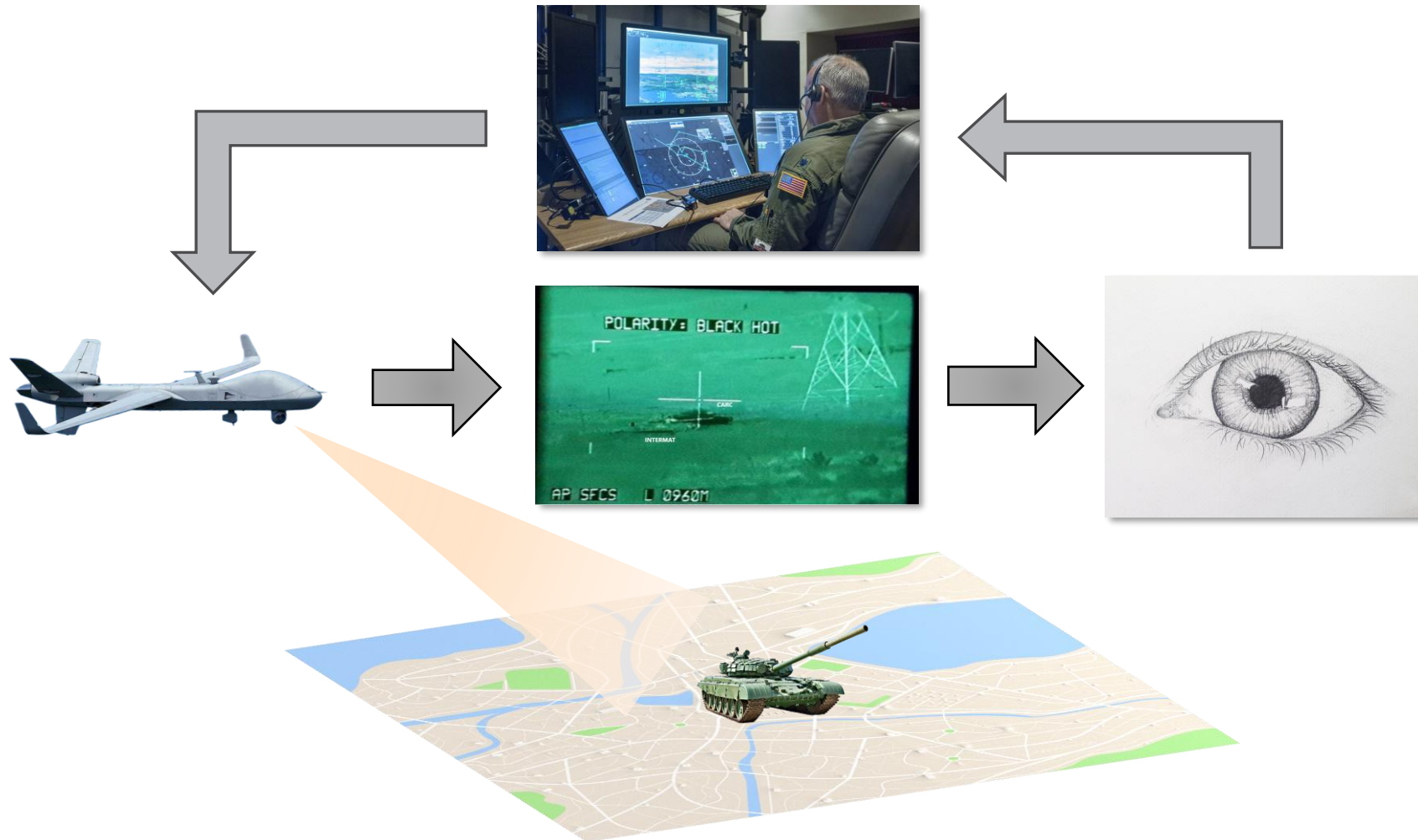


Motivation

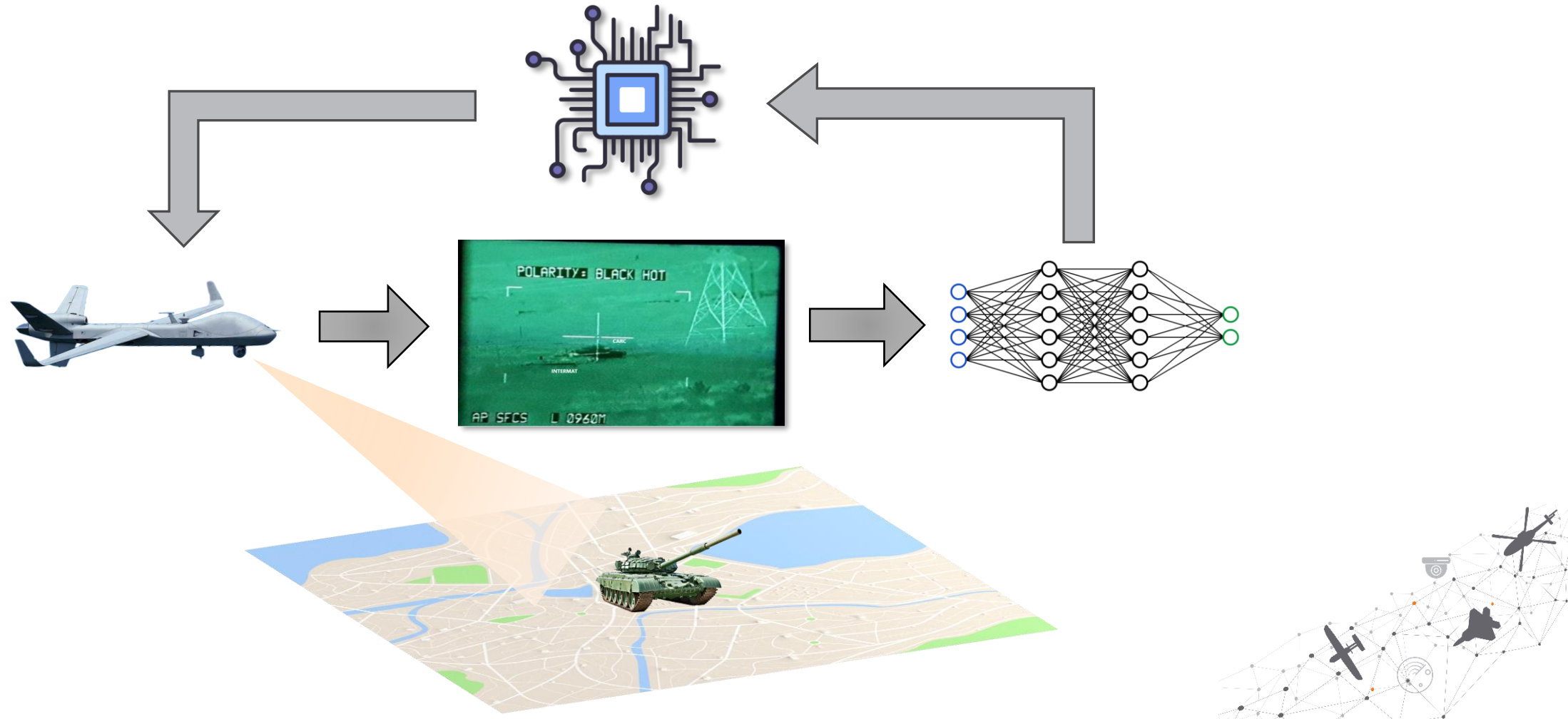
Cooperative Multi-Asset Operations



Motivation



Motivation

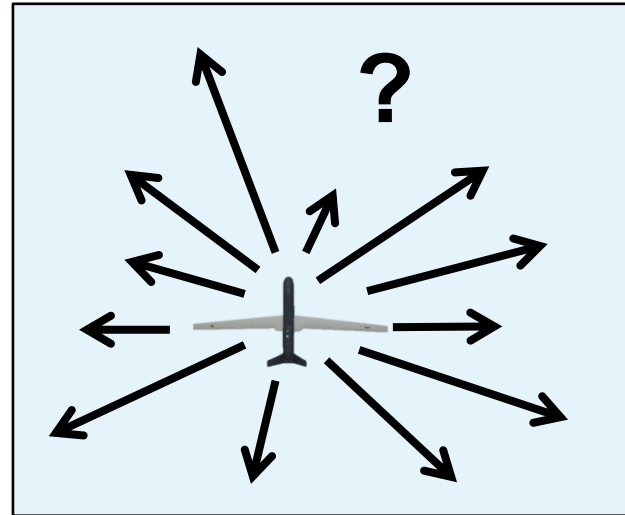


Motivation

Target Area



Operational Area



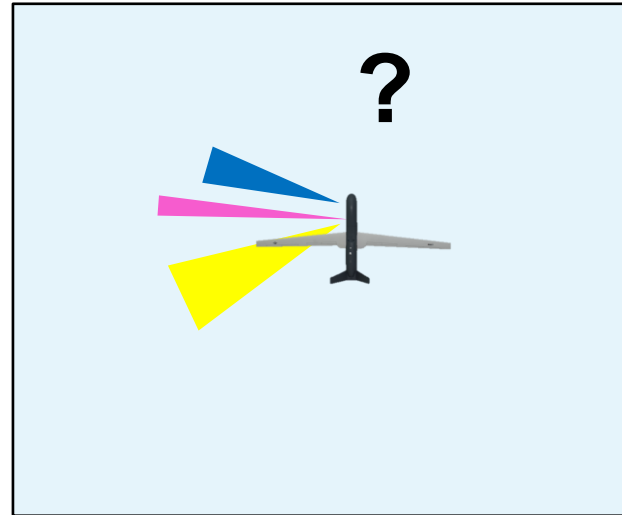
- **Where to place the airborne asset?**
- Where to direct the sensor?
- Which Zoom level shall be used?

Motivation

Target Area



Operational Area



- Where to place the airborne asset?
- **Where to direct the sensor?**
- Which Zoom level shall be used?

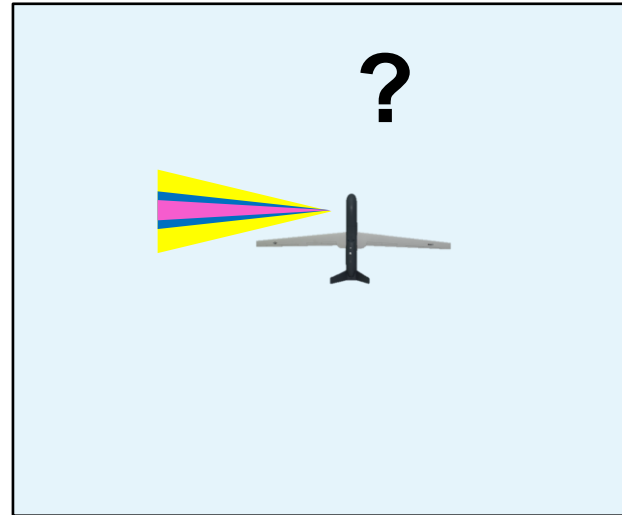


Motivation

Target Area



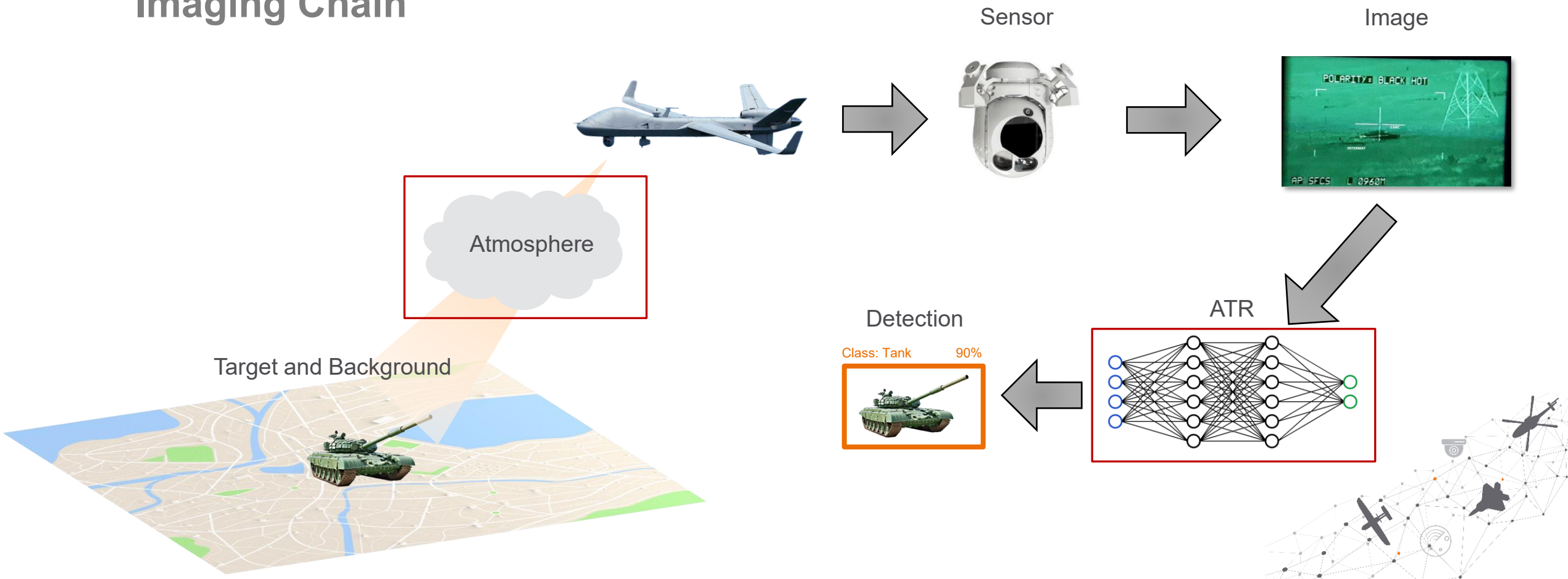
Operational Area



- Where to place the airborne asset?
- Where to direct the sensor?
- **Which Zoom level shall be used?**

Motivation

Imaging Chain



Automatic Target Recognition

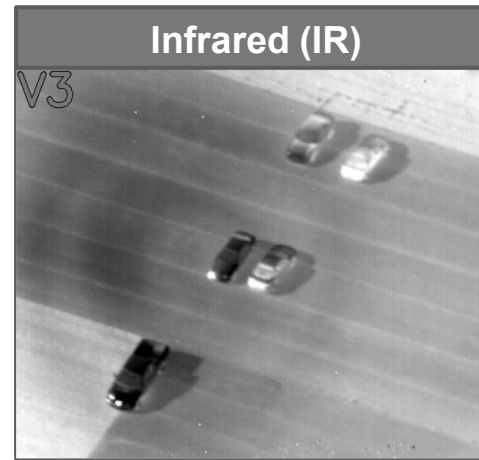
Why Performance Models for ATR?

- **Existing** imaging-system performance models are **primarily** designed for **human observers**
- Identify the **image characteristics** that determine **successful target detection and classification**
- Determine the **required image quality** and **contrast** for **successful target detection and classification** and, consequently, the appropriate sensor settings
- Use this knowledge to **enable** performance-based **EO/IR sensor deployment planning**



Automatic Target Recognition - Dataset

Air Force Research Laboratory – SDMS – Video Sample Set #1



Dataset Overview

- **Simultaneous acquisition by three sensors** covering the same scene
- **Various air-to-ground scenarios**
- **Total of 30 video clips**

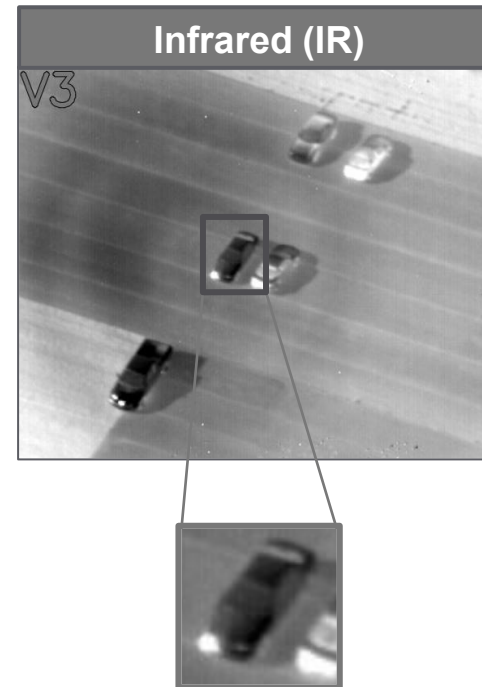
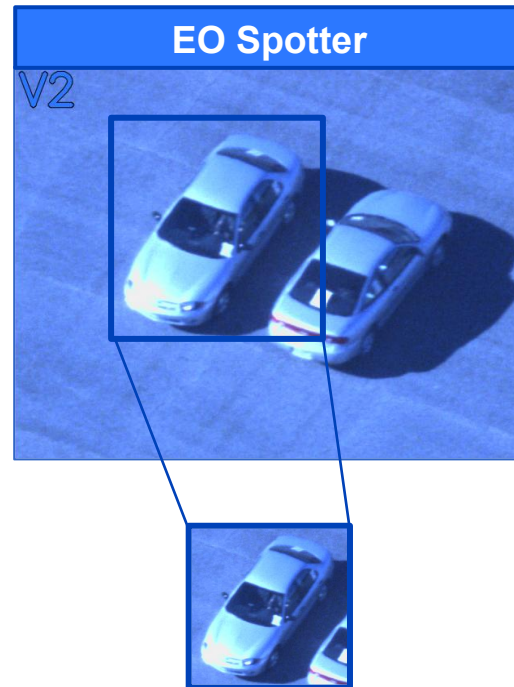
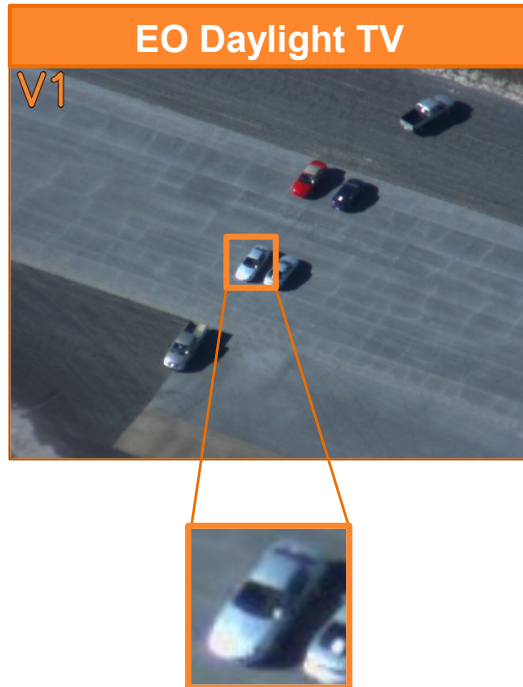
Key Dataset Advantage

Variation in target contrast and spatial resolution enables analysis of their influence on ATR performance

	V1	V2	V3
Type	EO	EO Spotter	IR
Resolution	640 × 480	640 × 480	320 × 256
HFOV	0.92°	0.22°	0.80°

Automatic Target Recognition - Dataset

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Automatic Target Recognition – Data Generation

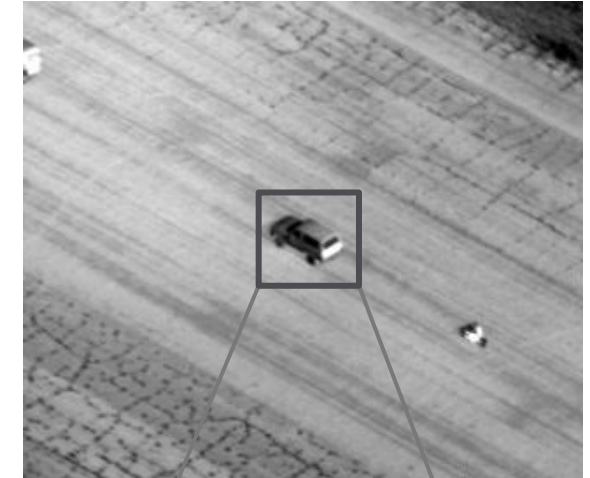
The same physical target can be detected by ATR in some sensor streams, but missed in others.



Missed



Detected



Detected

Used Models	
Model Variant	Training Data
yolov8n	VisDrone
yolo11n	COCO
yolo8s	COCO
yolo8x	COCO

Automatic Target Recognition – Data Generation



Detections at
geometrically
corresponding
positions

Same physical
target

Project target position
into other streams
using sensor geometry

Automatically generated sample



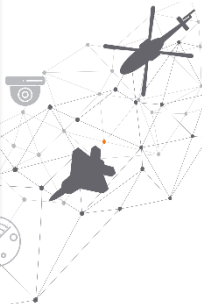
Image Crop



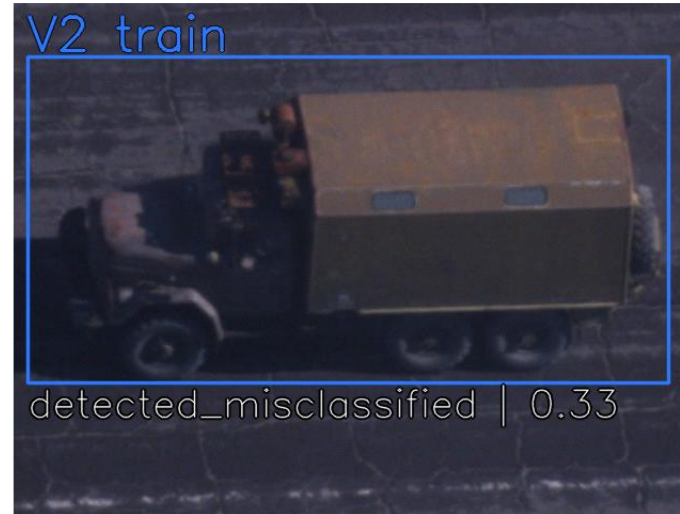
Bounding Box

ATR result

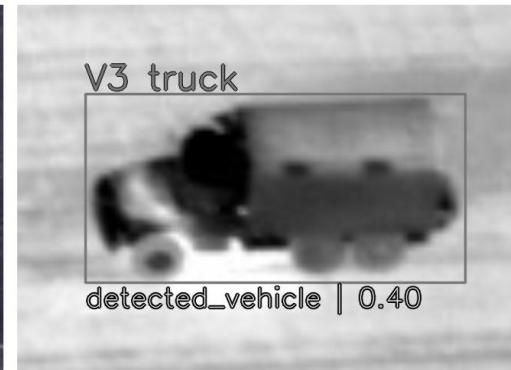
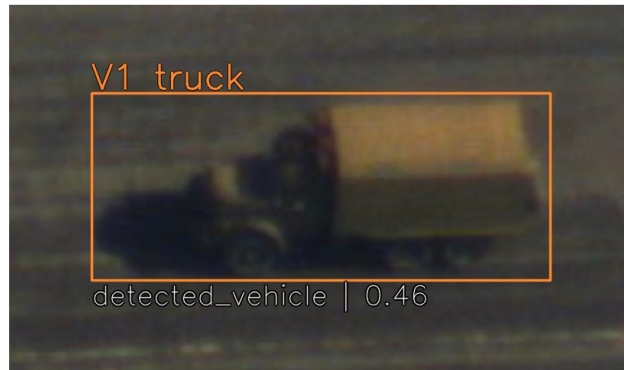
- Detected (correctly classified)
- Detected (misclassified)
- Missed
- Model used



Automatic Target Recognition – Data Generation

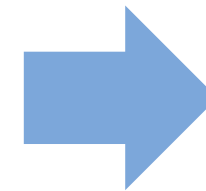
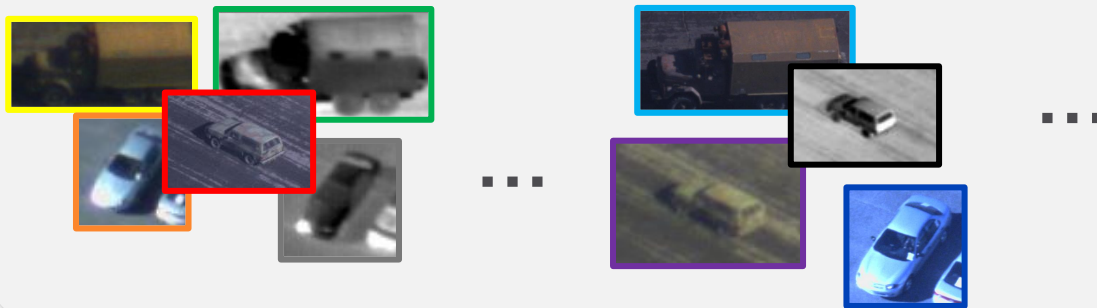


Automatic Target Recognition – Data Generation



334,267
data samples
generated

Large automatically generated dataset



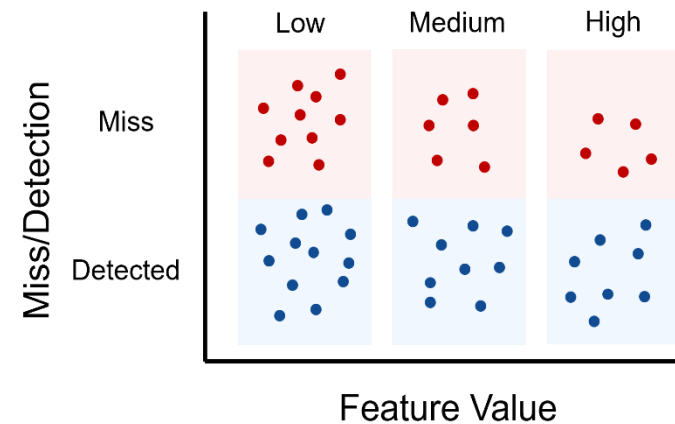
**Statistical ATR Performance
Analysis**

Automatic Target Recognition – Data Analysis

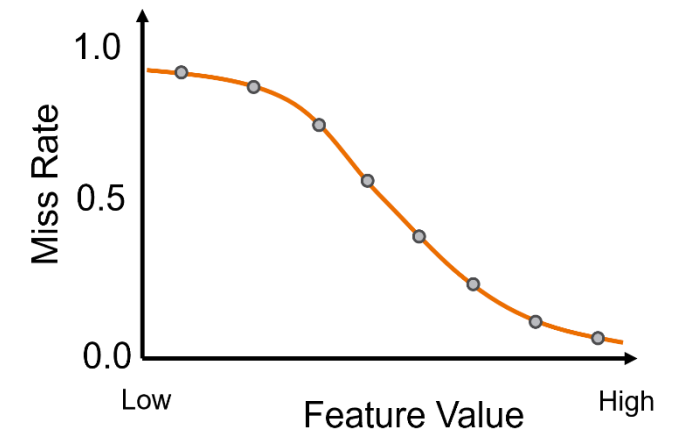
Analysis Method

- 334,265 target samples provide a **robust statistical basis**
- **24 image features** extracted from target and surrounding background regions
- Samples **grouped into feature-value bins** and **miss rate calculated for each bin**
- Resulting **trends reveal the influence of individual image characteristics** on ATR performance

Sort Samples into Corresponding Bin

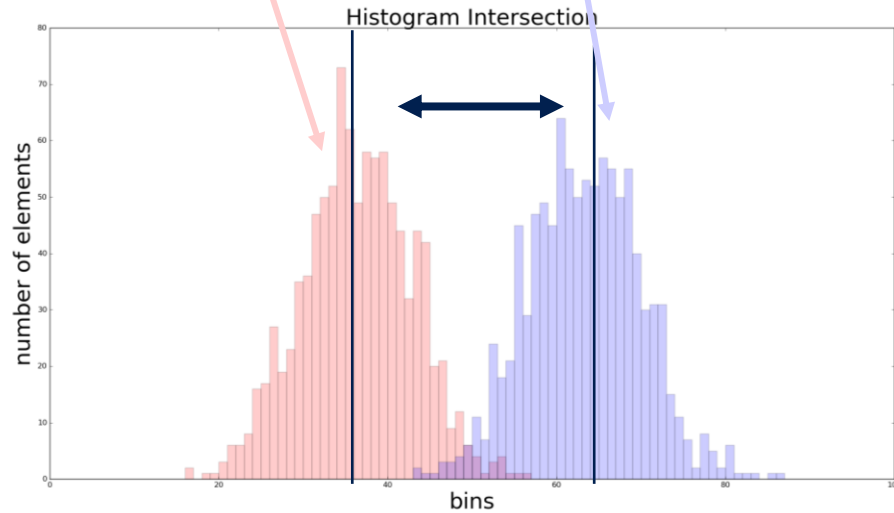


Performance Trend Analysis



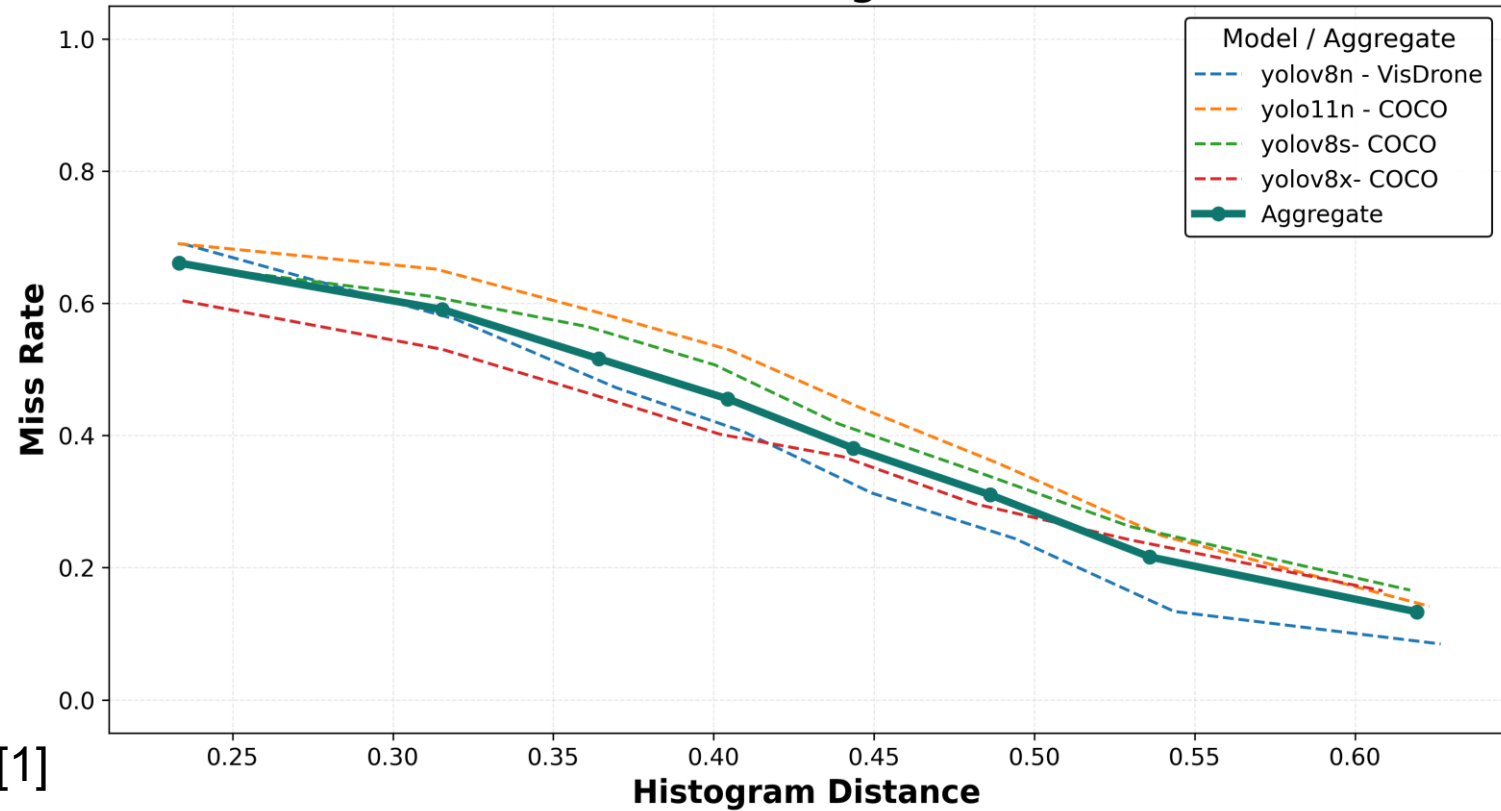
Target-to-Background Histogram Distance shows the strongest influence on miss rate among the investigated features

Automatic Target Recognition – Target-to-Background Histogram Distance



[1]

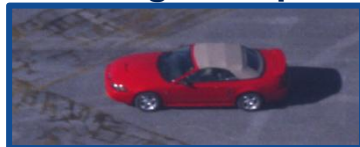
Miss Rate vs Histogram Distance



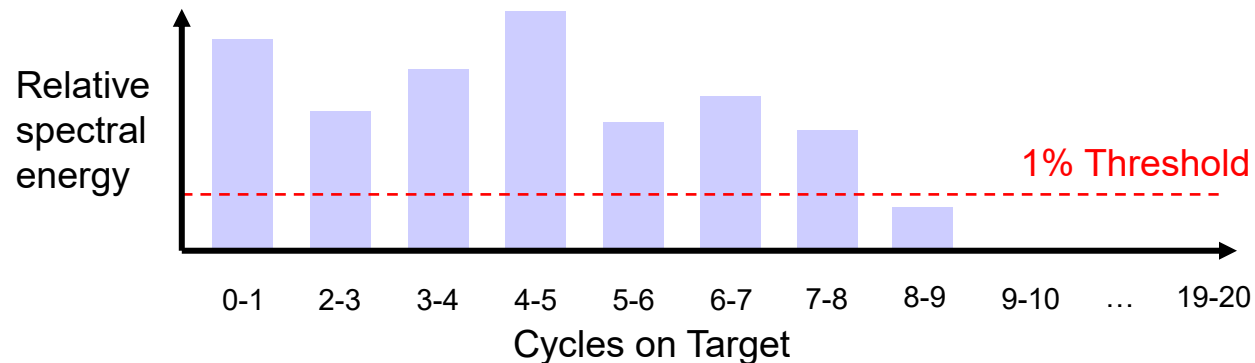
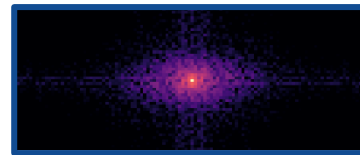
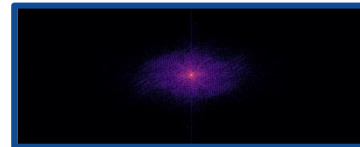
Automatic Target Recognition – Spatial Effects

Pixels on Target $\neq$ Spatial Information

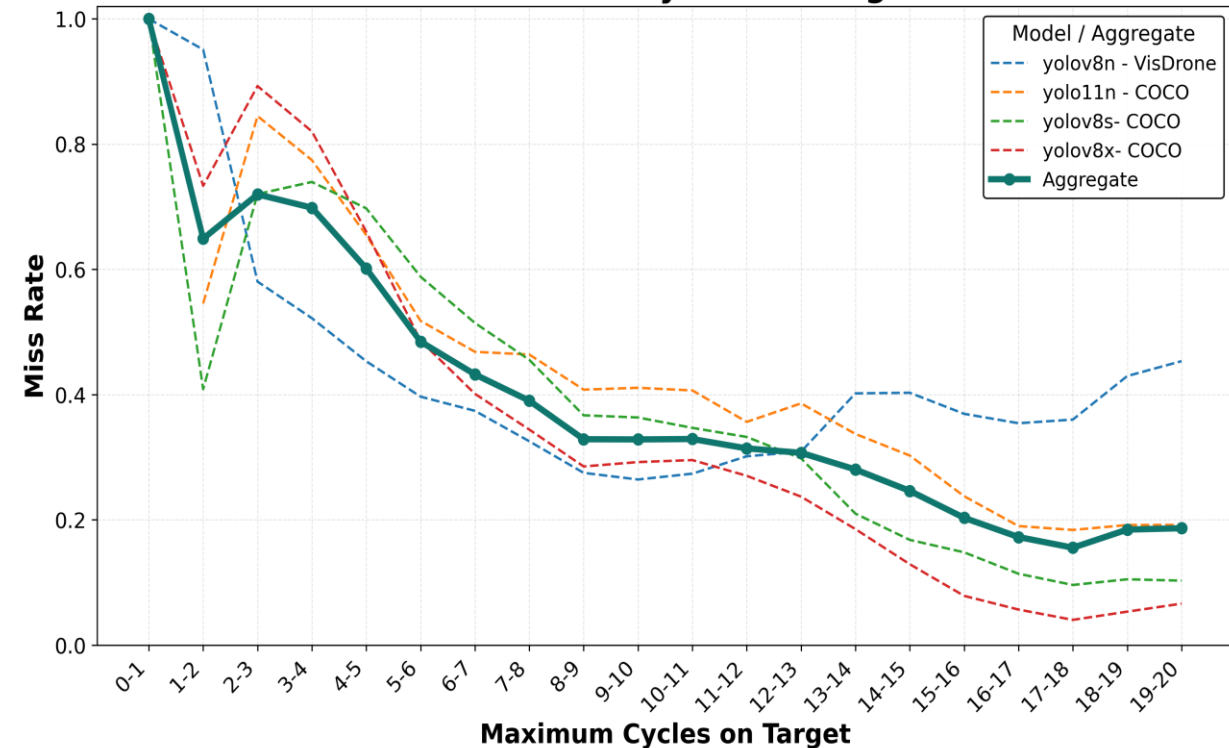
Target Crop



2D FFT



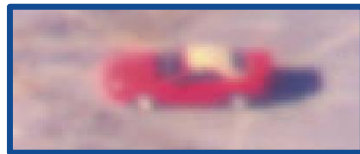
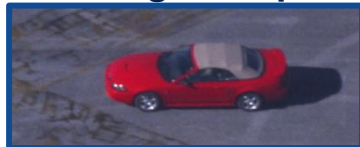
Miss Rate vs Cycles on Target



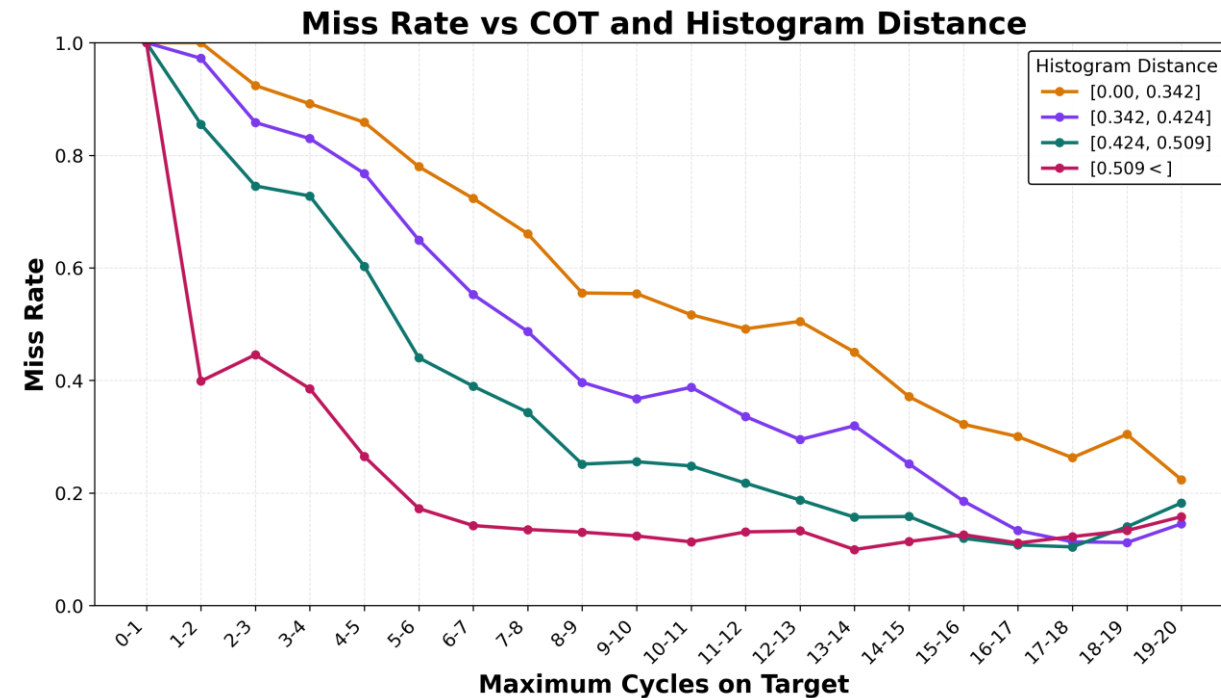
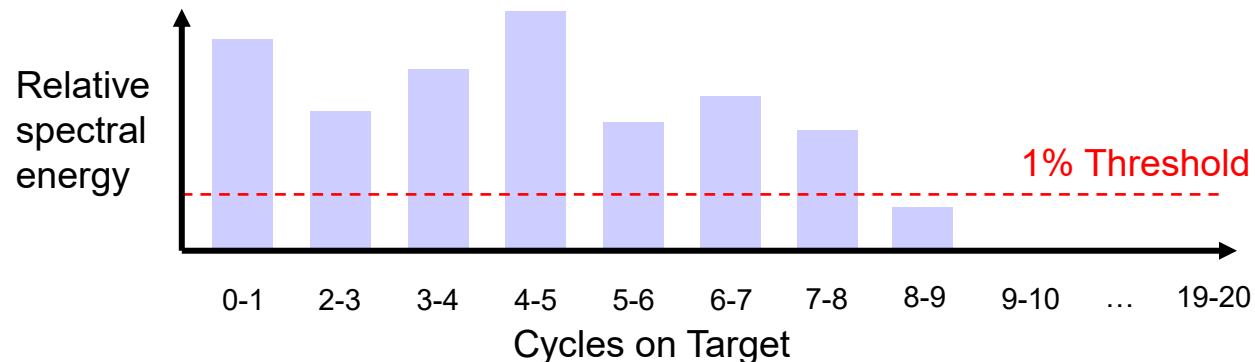
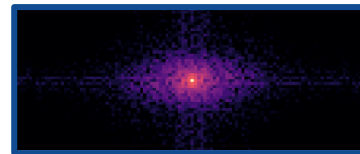
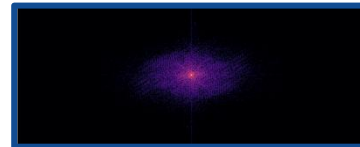
Automatic Target Recognition – Spatial Effects

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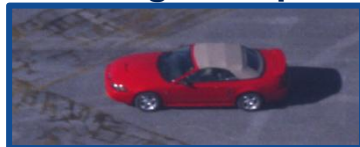
2D FFT



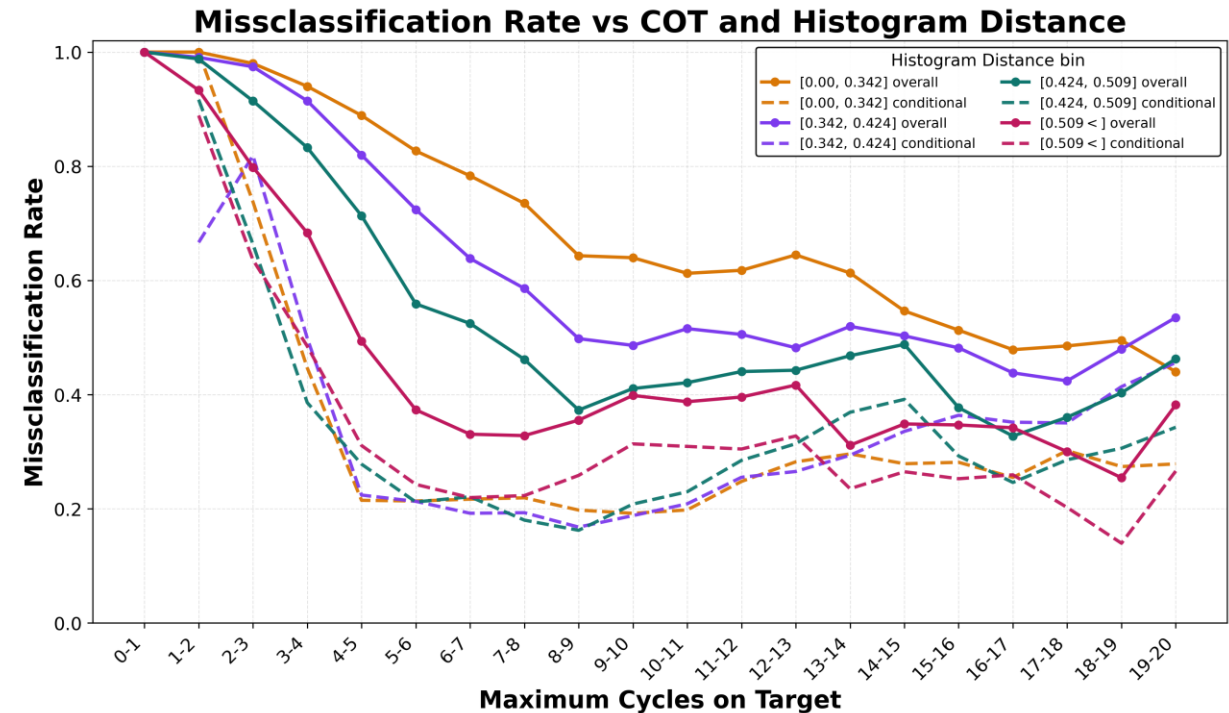
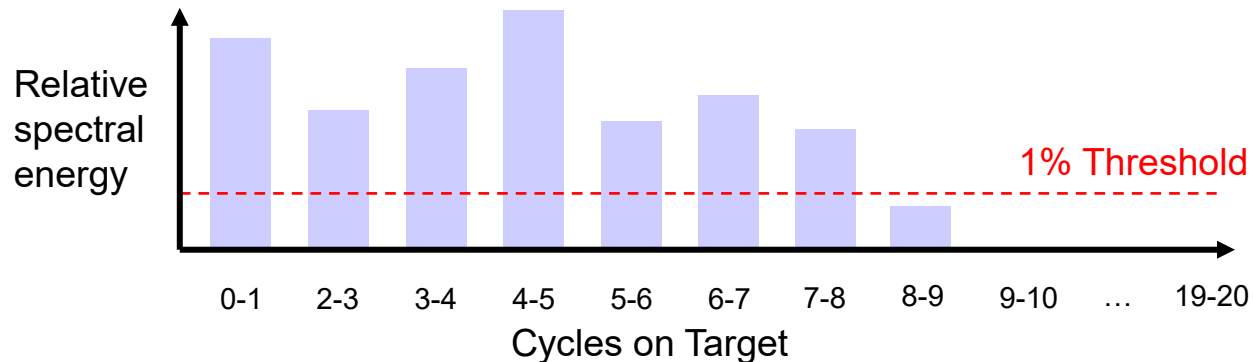
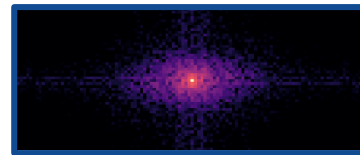
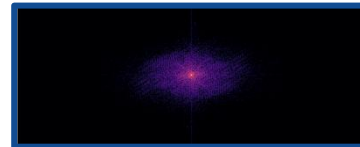
Automatic Target Recognition – Spatial Effects

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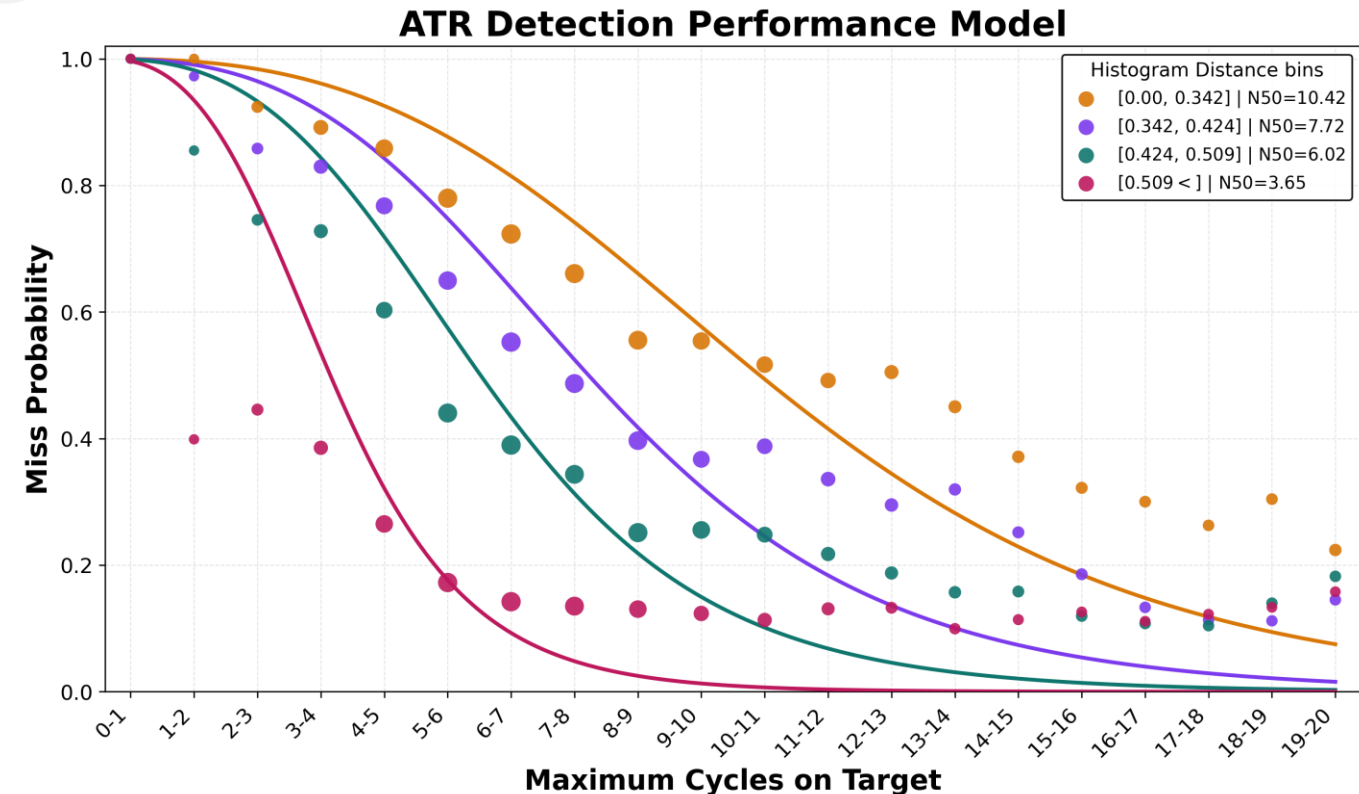
Automatic Target Recognition – Performance Modelling

Adapt Johnson Criteria curves for human observers to ATR

Bin	Histogram Distance	N_{50} Detection	N_{50} Classification
1	[0.00, 0.342]	10.42	12.58
2	[0.342, 0.424]	7.72	9.50
3	[0.424, 0.509]	6.02	7.76
4	[0.509 <]	3.65	5.61

$$P_D = \frac{\frac{N}{N_{50}} E}{1 + \frac{N}{N_{50}} E}$$

$$E = 2.7 + 0.7 \left(\frac{N}{N_{50}} \right)$$



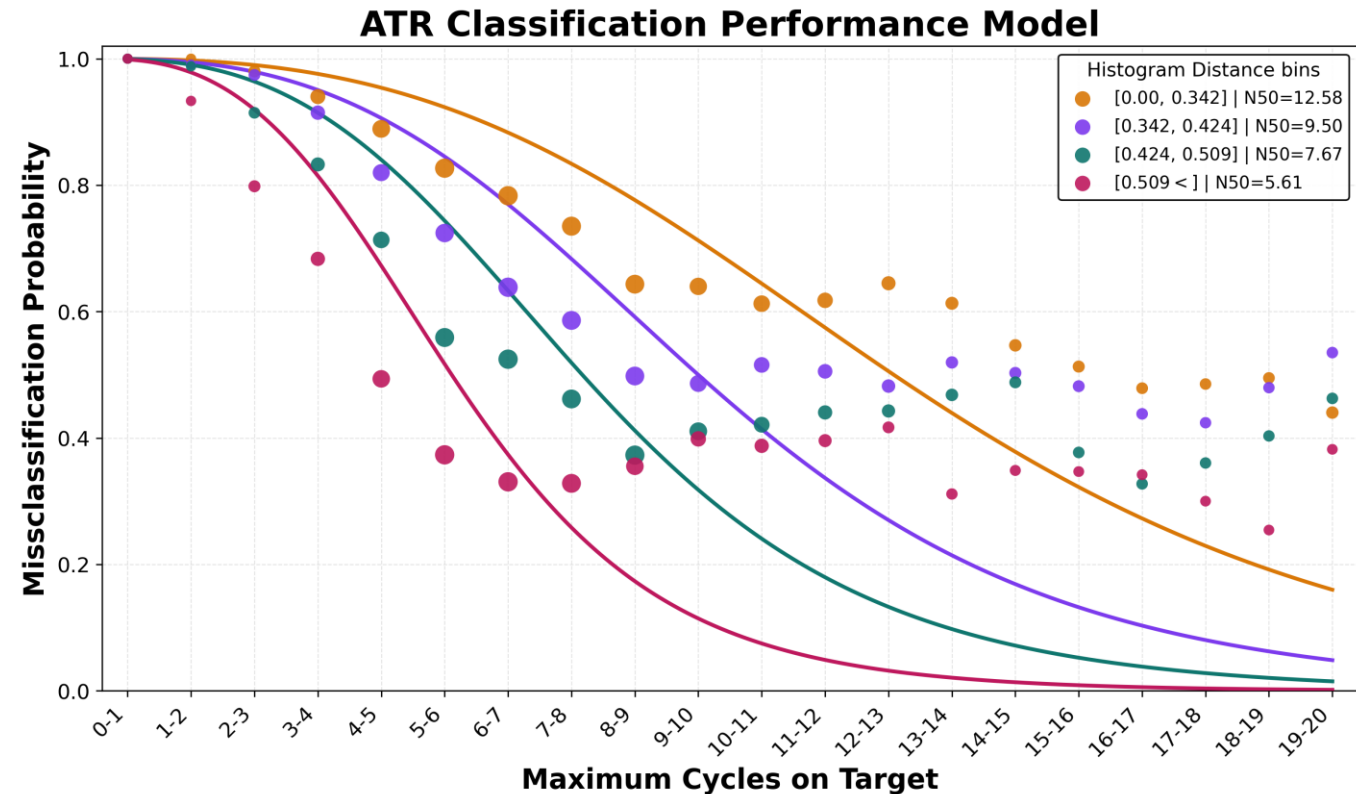
Automatic Target Recognition – Performance Modelling

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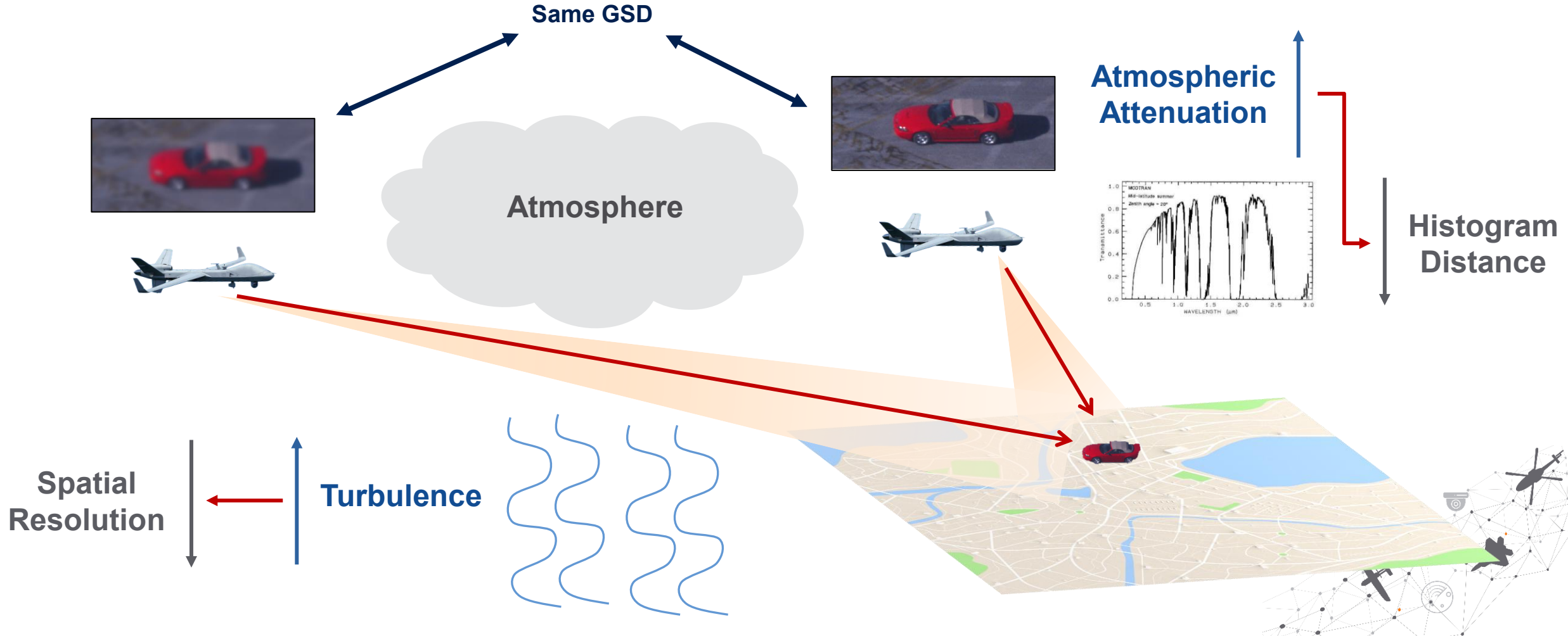
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Impact of the Atmosphere on Detection Performance



EO/IR Sensor Performance Model

1 Mission Inputs

- Target & Background
- EO/IR spectral band
- Atmosphere
- Task: Detection/Classification

2 Expected Image Quality

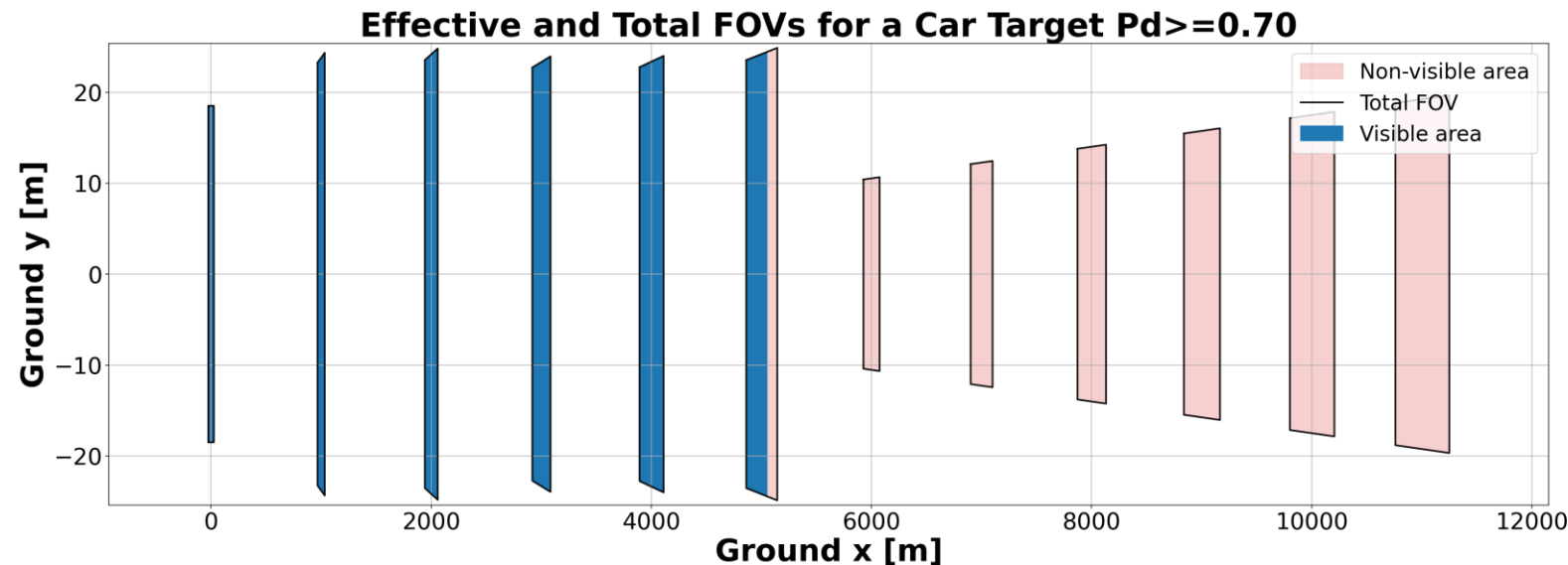
- Target-background Histogram Distance
- Spatial detail (COT)

2 ATR Performance

- Detection / Classification probability

4 Sensor Optimization

- Select configuration that maximizes usable coverage





Adrian Albert (*Research Assistant*)

Institute of Flight Systems
University of the Bundeswehr Munich
Neubiberg, Germany
adrian.albert@unibw.de

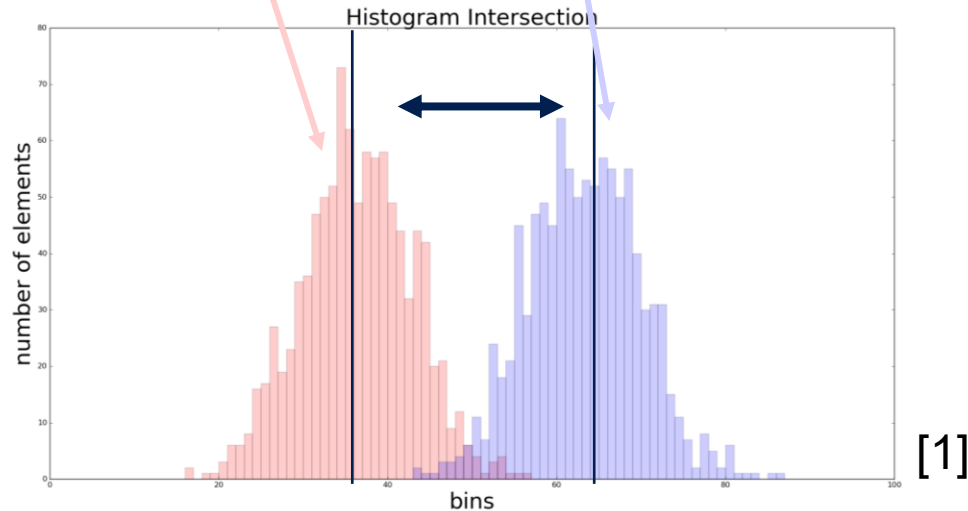
Peter Stütz (*Professor for Aeronautical Engineering*)

Institute of Flight Systems
University of the Bundeswehr Munich
Neubiberg, Germany
peter.stuetz@unibw.de

[1] : <https://mpatacchiola.github.io/blog/2016/11/12/the-simplest-classifier-histogram-intersection.html>

Performance Models for Airborne EO/IR Sensor Deployment Planning Considering the Complete Image Chain

Automatic Target Recognition – Target-to-Background Histogram Distance



$$R_B = R_C \setminus R_T$$

$$p_T(k) = \frac{n_T(k)}{\sum_{j=1}^N n_T(j)}, \quad p_B(k) = \frac{n_B(k)}{\sum_{j=1}^N n_B(j)}, \quad k = 1, \dots, N,$$

$$\sum_{k=1}^N p_T(k) = \sum_{k=1}^N p_B(k) = 1$$

Bhattacharyya Distance

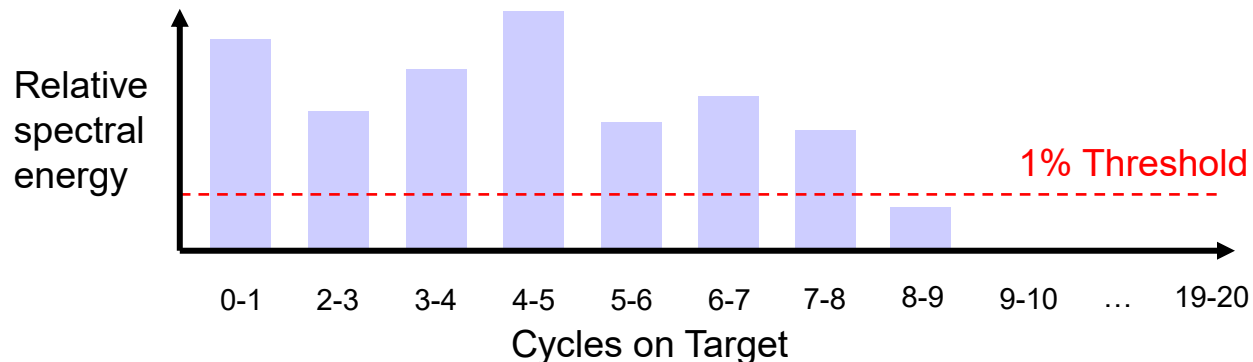
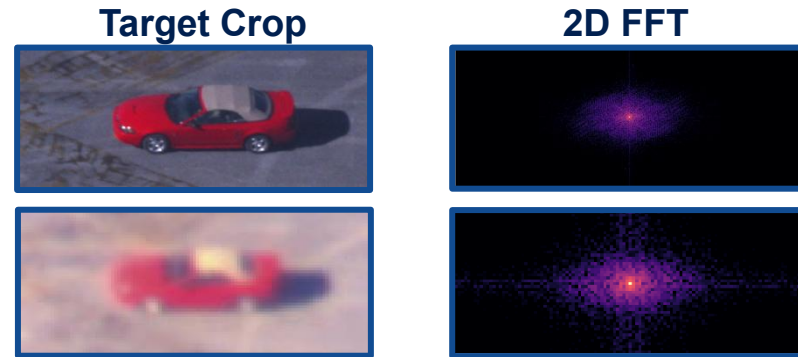
$$BC(p_T, p_B) = \sum_{k=1}^N \sqrt{p_T(k)p_B(k)}.$$

$$D_{\text{hist}} = \sqrt{1 - BC(p_T, p_B)}.$$



Automatic Target Recognition – Spatial Effects

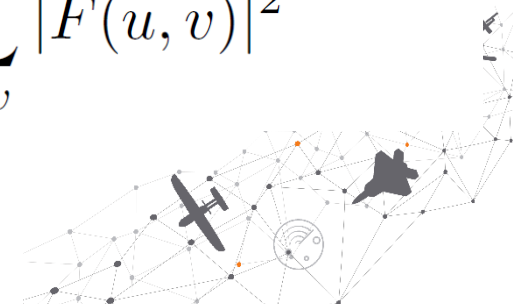
Pixels on Target $\neq$ Spatial Information



$$E(u, v) = |F(u, v)|^2$$

$$C(u, v) = L_T f_r(u, v)$$

$$R_E(C_1, C_2) = \frac{\sum_{C_1 \leq C(u, v) < C_2} |F(u, v)|^2}{\sum_{u, v} |F(u, v)|^2}.$$



Atmosphere

Atmospheric Transmission

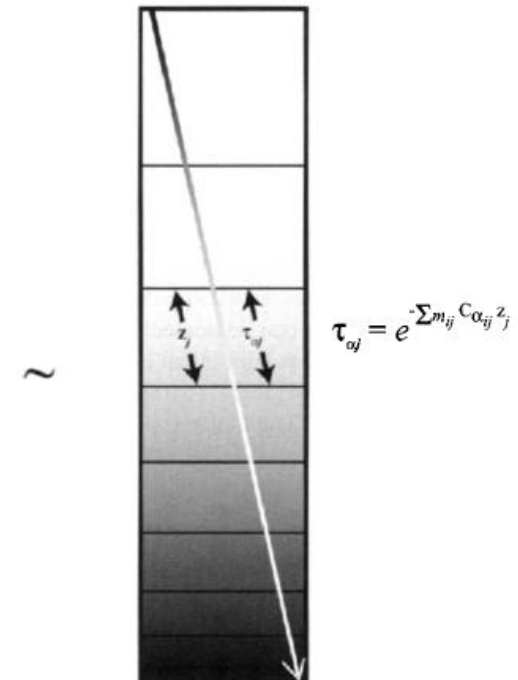
$$L_{\text{sensor}}(\lambda) = \tau(\lambda)L_0(\lambda) + L_{\text{path}}(\lambda)$$

$$\Delta L_{\text{sensor}} \approx \tau(\lambda)\Delta L_0$$

$$\tau(\lambda) = \prod_{i=1}^N \tau_i(\lambda) = \exp \left(- \sum_{i=1}^N \beta_i(\lambda) z_i \right)$$



(a) Continuously varying atmosphere.



(b) Approximation to atmosphere (a) with nine layers, each of which is homogeneous.



Atmosphere

Atmospheric Turbulence

$$\text{MTF}(u) = \exp \left[-3.44 \left(\frac{Du}{r_0} \right)^{5/3} \right]$$

$$u = \frac{\lambda F v}{D}$$

$$r_0 = \left[0.423 \left(\frac{2\pi}{\lambda} \right)^2 \sec(\zeta) \int_0^H C_n^2(h) \left(\frac{h}{H} \right)^{5/3} dh \right]^{-3/5}$$

