TACOM

Lethality, Survivability, Mobility, and Sustainment for America's Army

Target Counting and Classification Algorithms for Unattended Ground Sensors

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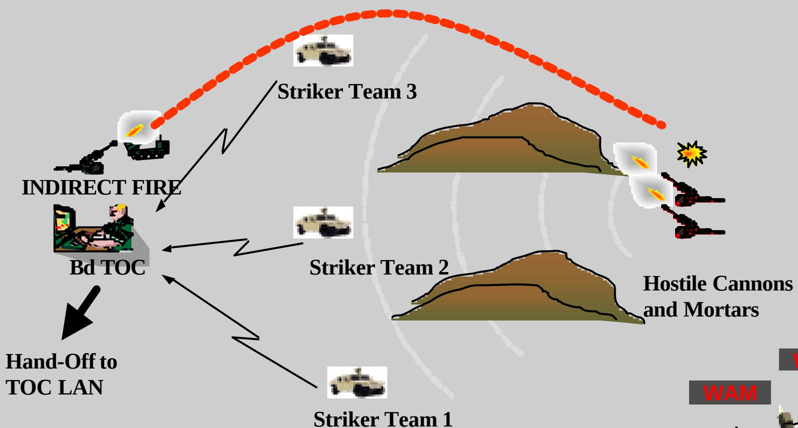
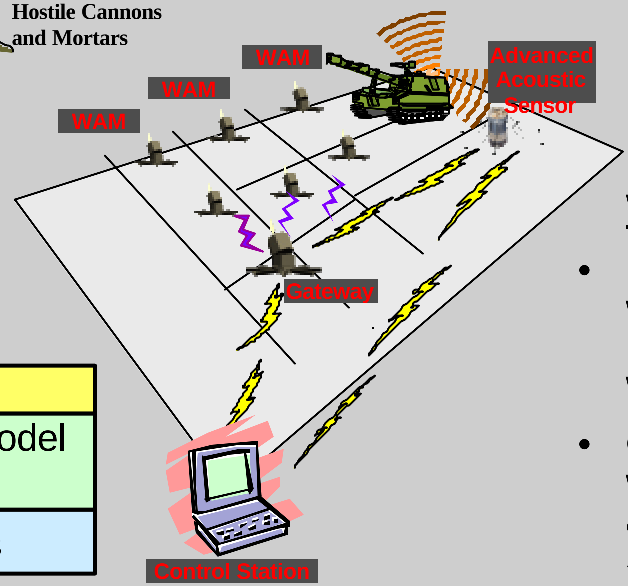
Advanced Acoustic/Seismic Systems
(IV.SN.2000.01)

Objective: Develop and demonstrate 1) acoustic sensor system which can accurately locate artillery and mortar fires, 2) integrated acoustic/seismic Tactical Decision Aid for sensor employment and improved algorithms for ground vehicle detection/tracking/ classification, 3) network architecture of randomly dispersed low cost sensors.





Pacing Technologies:

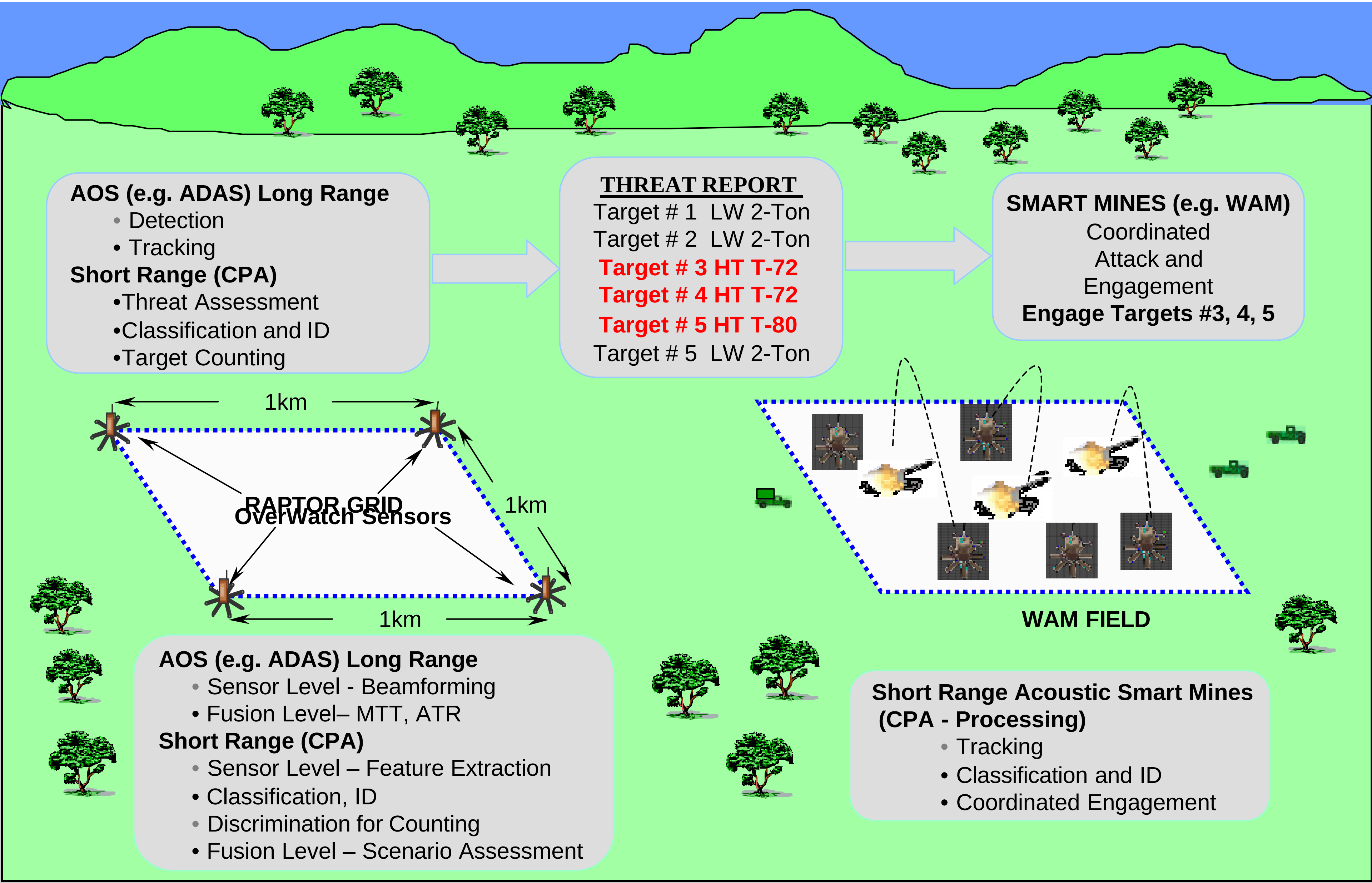
- Signal processing techniques
- Propagation model and Sensor Model Integration
- Networking of Distributed Sensors

War-fighter Payoffs:

- **Enable objective forces to deploy with built-in sensors to accurately locate & target enemy stand-off weapons.**
- **Over-the-hill sensing for early warning, better situational awareness & increased survivability of objective forces.**

Passive, NLOS Sensing & Targeting Capability for Future Combat System Force

Threat Decomposition Scenario



Acoustic Algorithm Development

- ARDEC Algorithm Development – 2 Areas
  - Target **Classification** and **ID**
    - Classification of ground vehicles based on the number of engine cylinders
    - Identification of targets according to type (i.e. BMP, T72, M1, …)
    - Classification as Heavy or Light, Wheeled or Tracked
  - Target **Counting** Algorithm
    - Development of an Acoustic "Trip-Line" concept
    - Monitor activity in a predetermined field of view using an adaptive beamforming algorithm
    - Count the number of targets that pass through the trip-line over time

Ground Target Classes

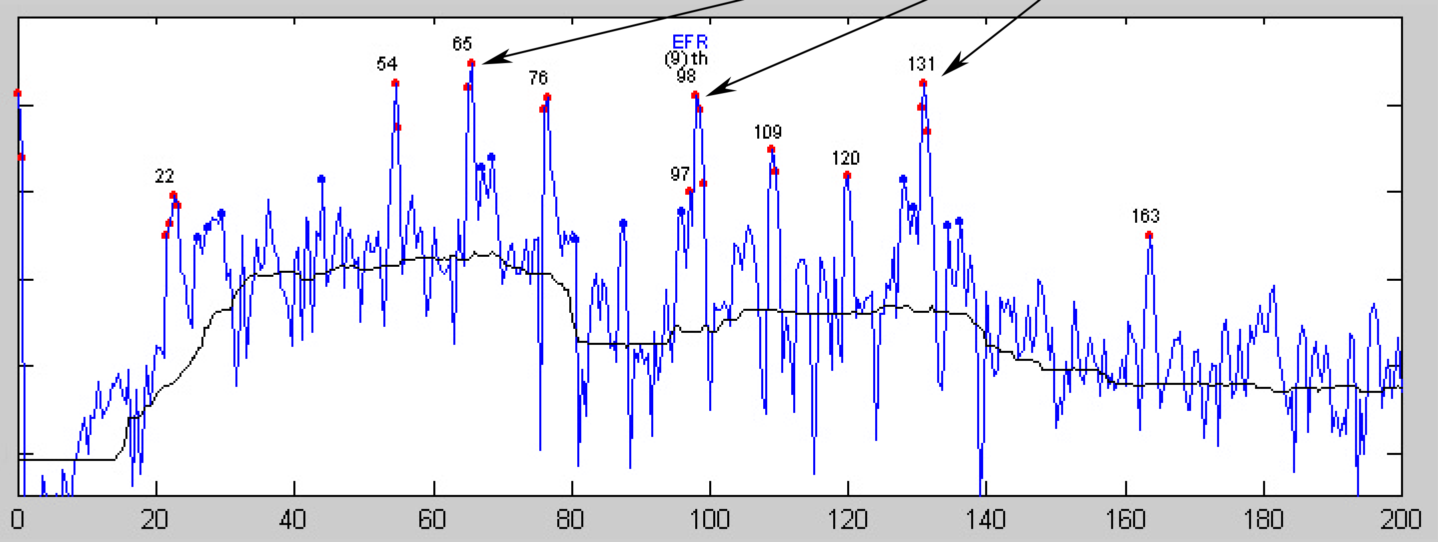
Feature Extraction

- Sort Harmonically Related Peaks in descending order of SNR
- Determine the harmonic number of the tallest peaks
- Use a subset of HLA harmonics as feature vector for classification
- Over 300 WAM signatures (54180 s) used to train classifier

Fundamental = 10.97 Hz

$$f(p_1, p_2, p_3) = [9 \quad 12 \quad 6]$$

HLA ®[22 54 65 76 88 98.5 109.5 120.5 131]
 # =[2 5 6 7 8 9 10 11 12]



Bayesian Template Approach

- *Perform feature extraction over signature database and calculate a priori probabilities. Ti = 6,8,12,Turbine, or M1, M60, M113, BMP, ZIL, BTR-80 ...*

$$P(T_i) = \frac{\#\text{ of HLA frames for class}}{\#\text{ of HLAs frames for all classes}}$$

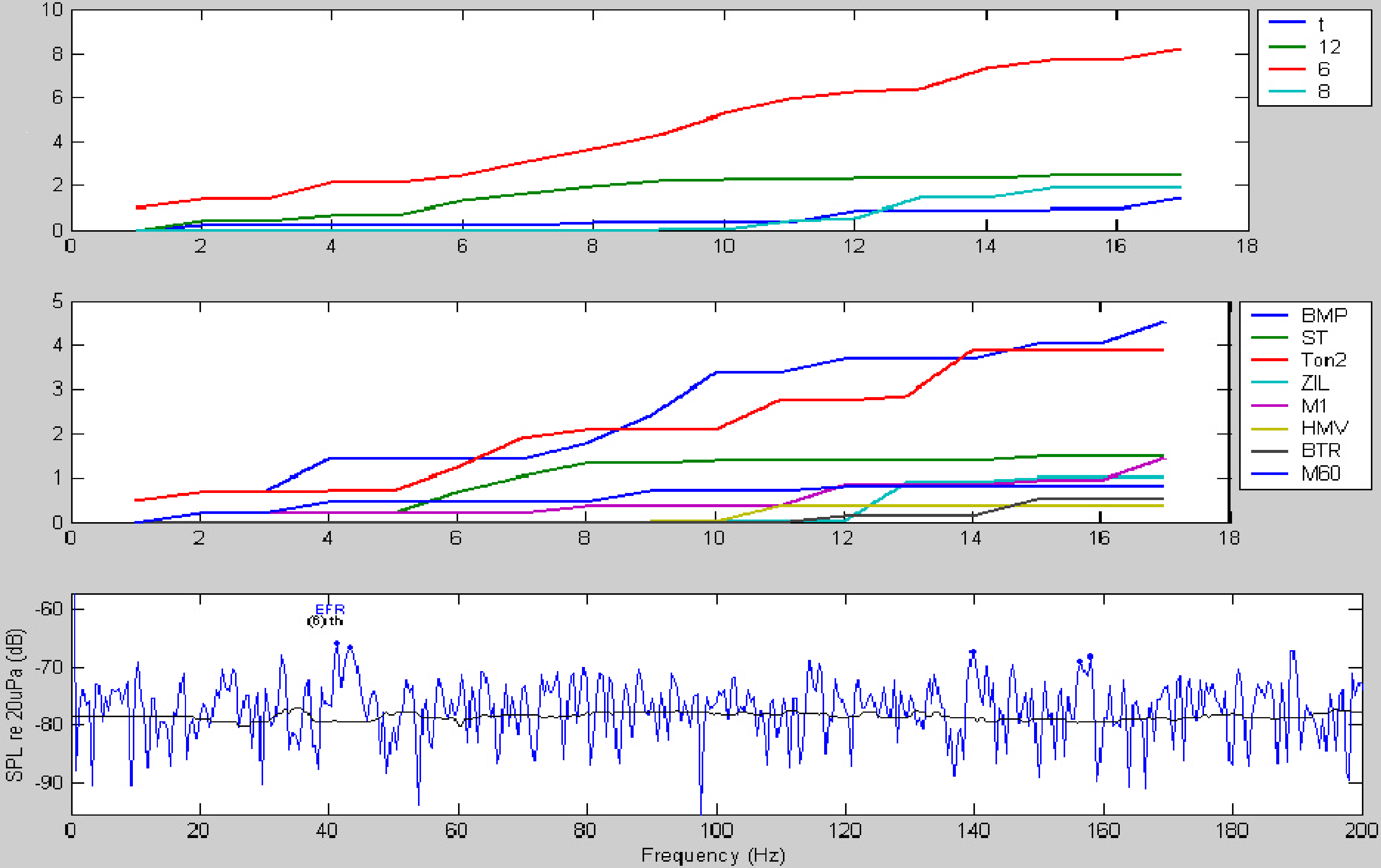
$$P(HLA \mid T_i) = \frac{\#\text{ of a HLA frames for class}}{\text{Sum of HLA frames for given class}}$$

- *Bayes Theorem: Find P(Ti /HLA) given some HLA using Bayes Theorem. Find Ti = 6,8,12,Turbine, or M1, M60, M113, BMP, ZIL, BTR-80 ...*

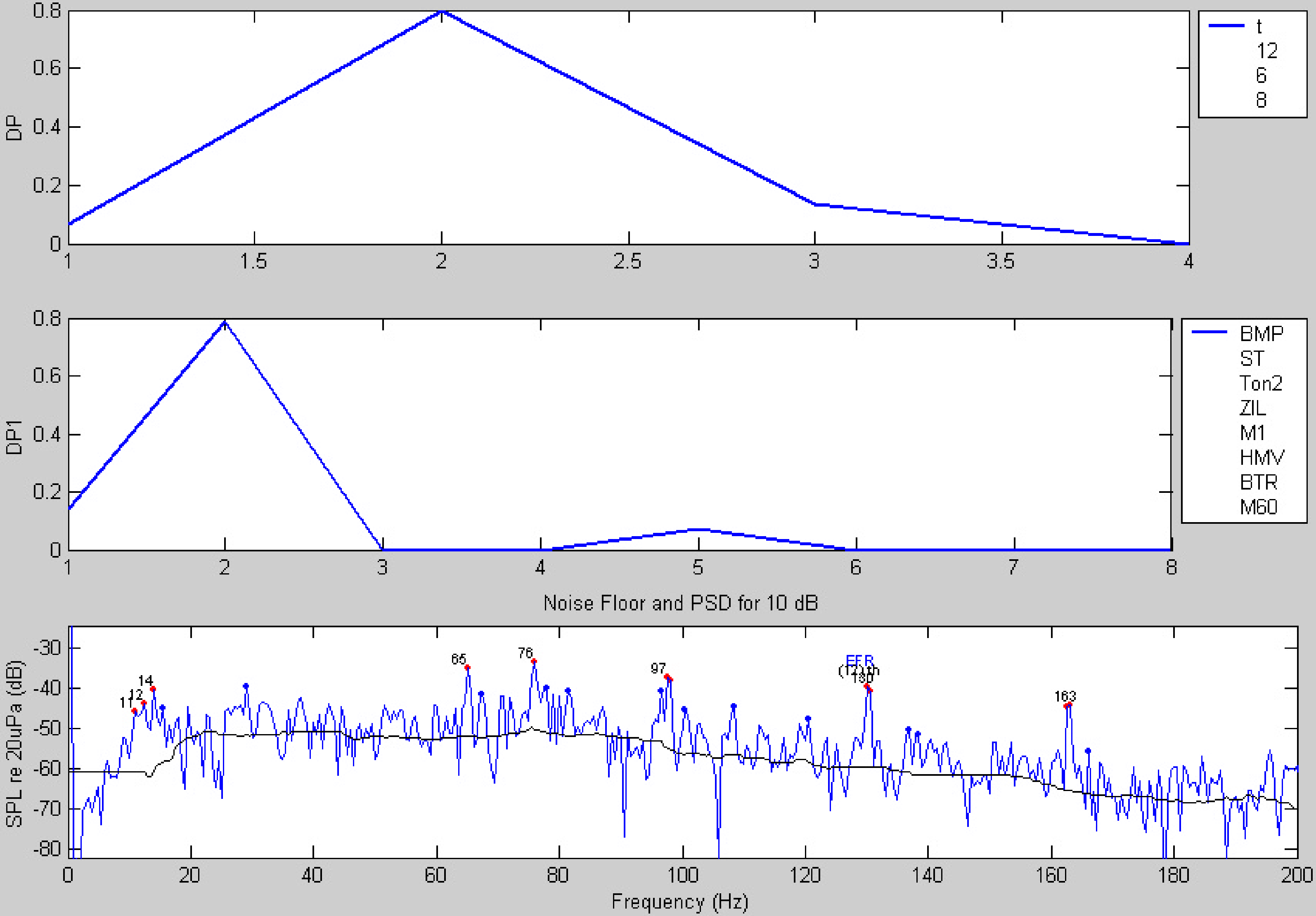
$$P(T_i \mid HLA) = \frac{P(HLA \mid T_i) \cdot P(T_i)}{\sum_{j}^{m} P(HLA \mid T_j) \cdot P(T_j)}, \quad 1 \le i \le m$$

- *Classification - Integrate Probabilities over time* $P(T_i \mid HLA, t)$

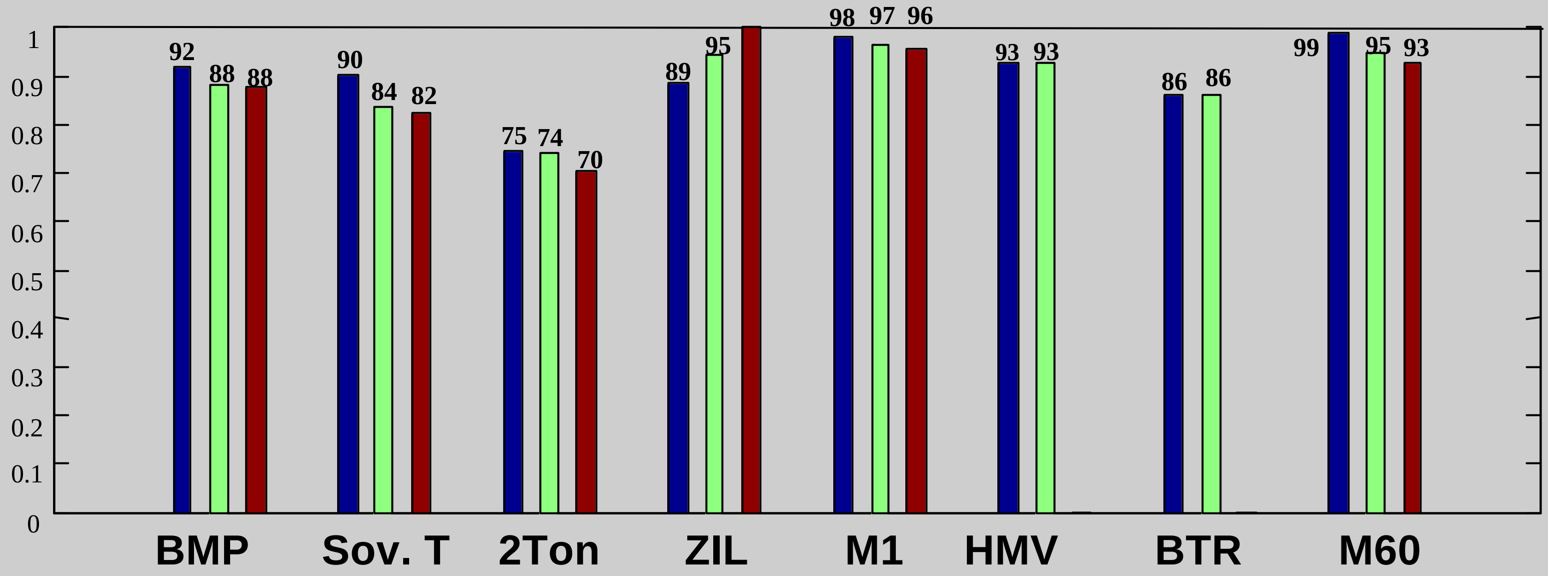
Classifier Example



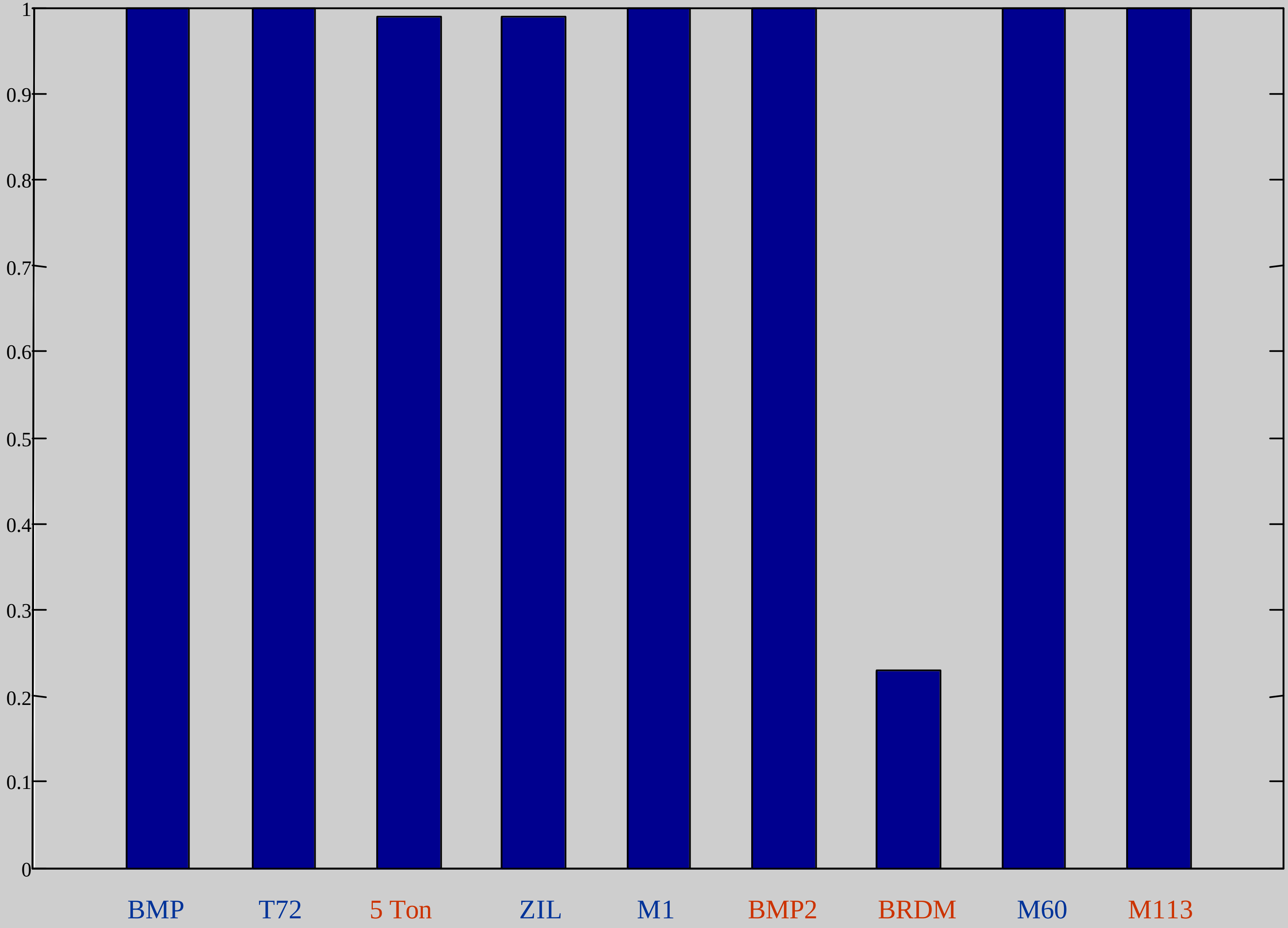
Classifier vs. 12 cyl T-72



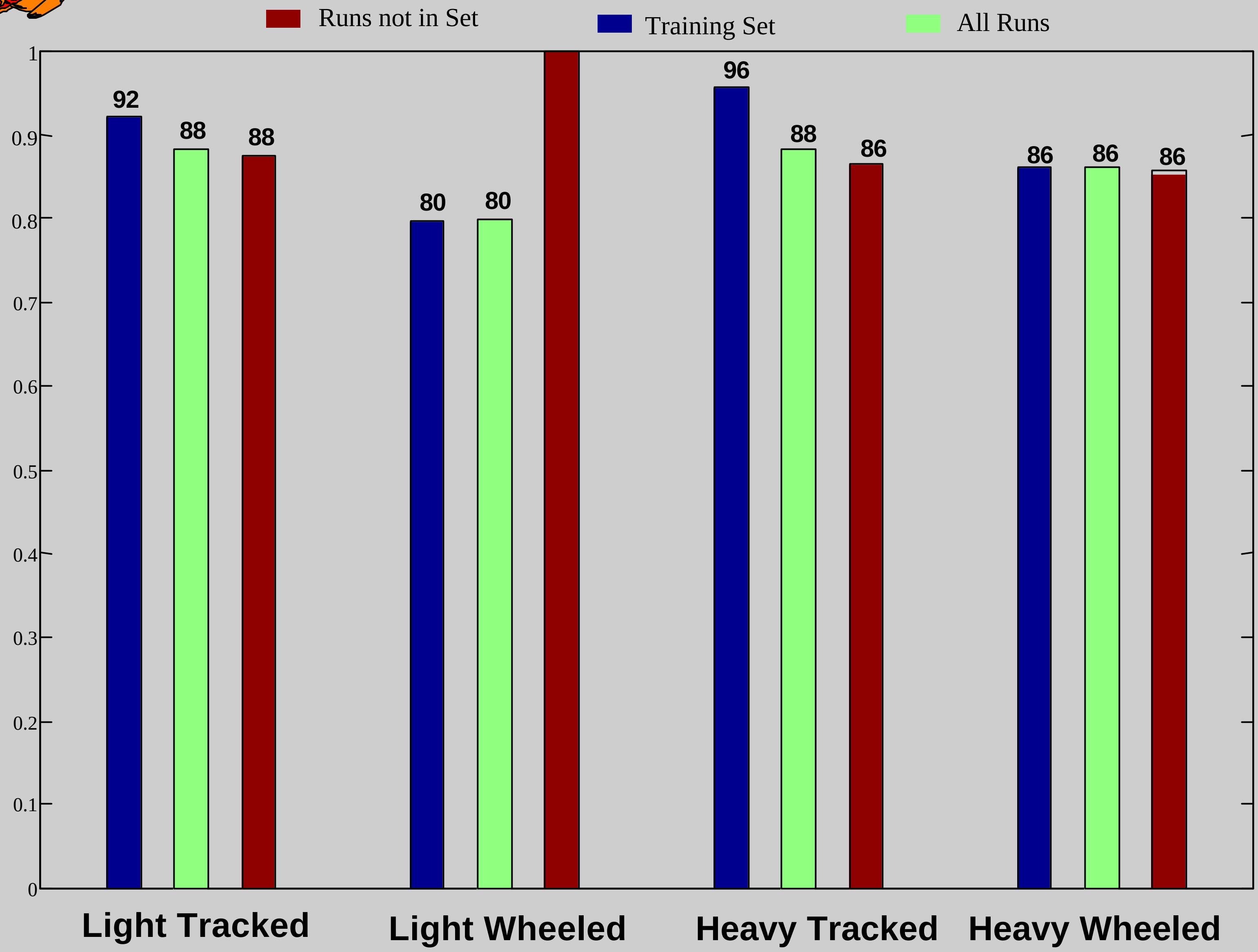
Classification/ID Algorithm Performance



Cylinder Classifier – Untrained ADAS Data

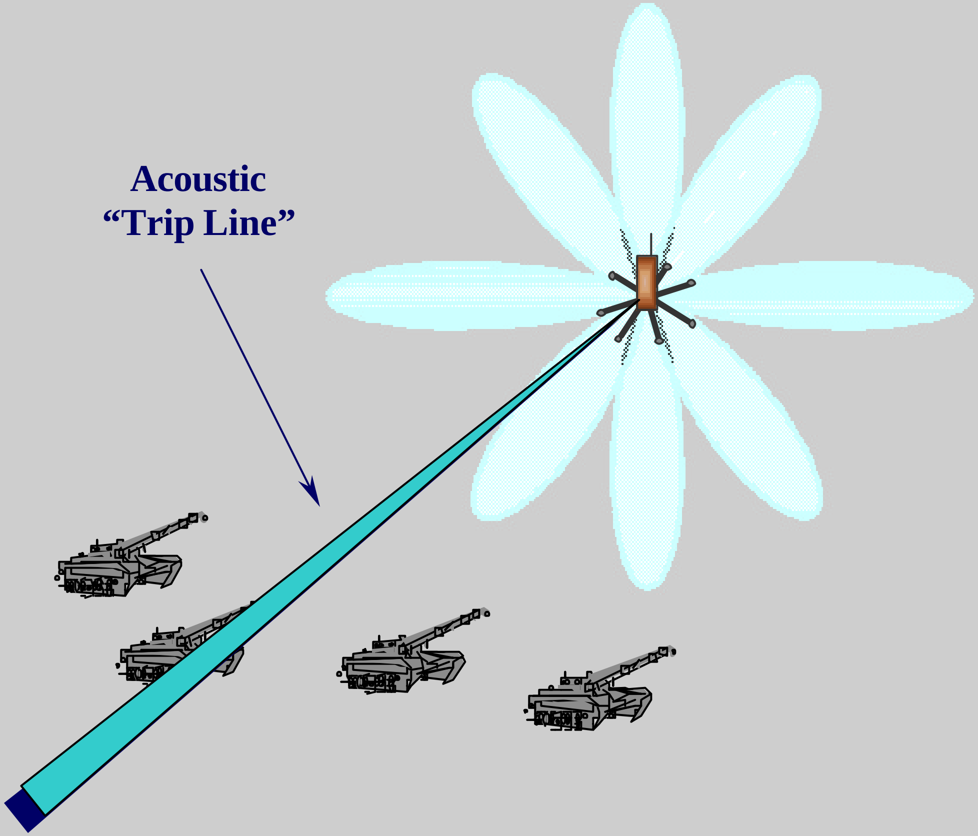


Target Classification - LW, LT, HW, HT



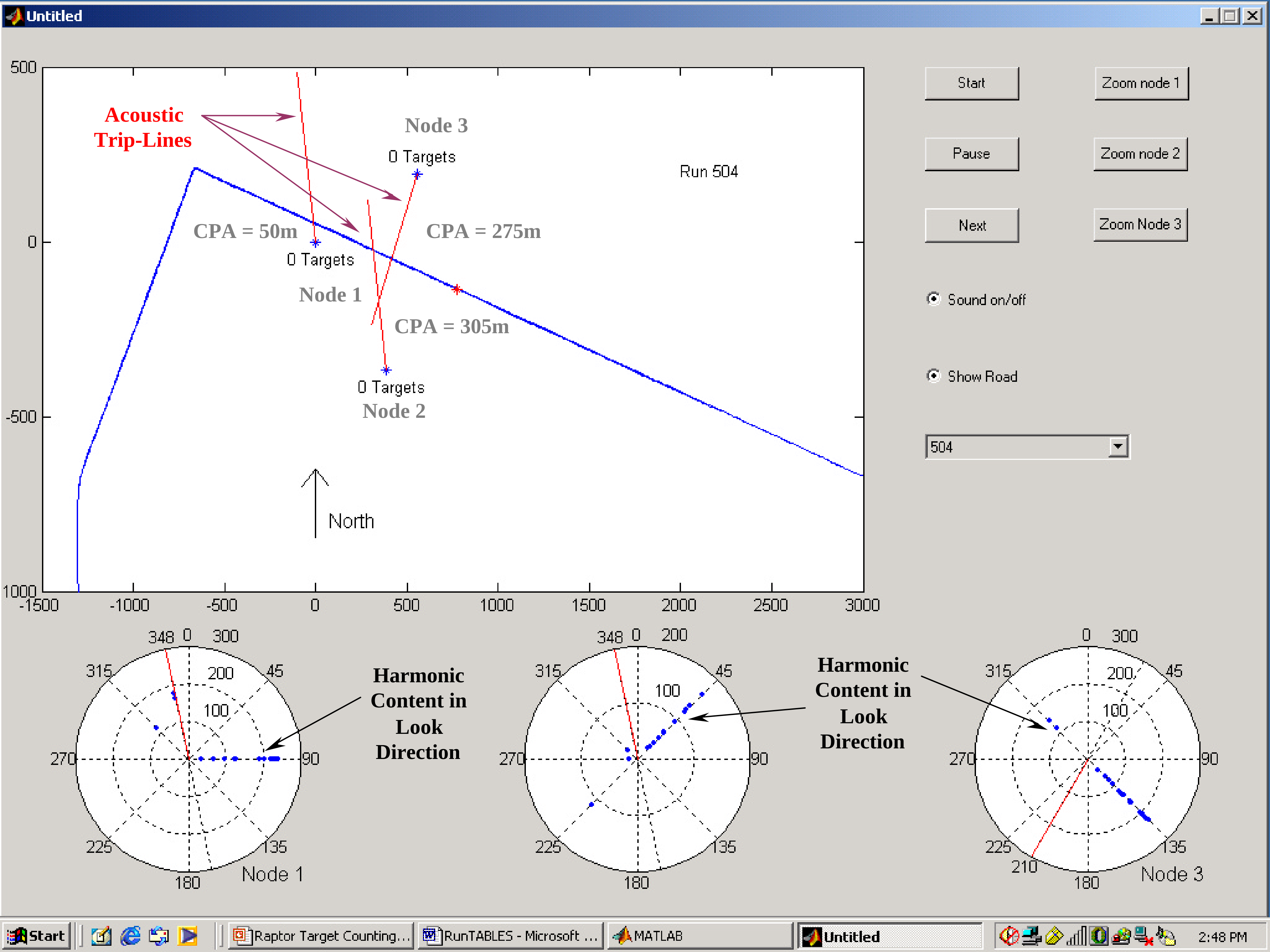
Target Counting Algorithm

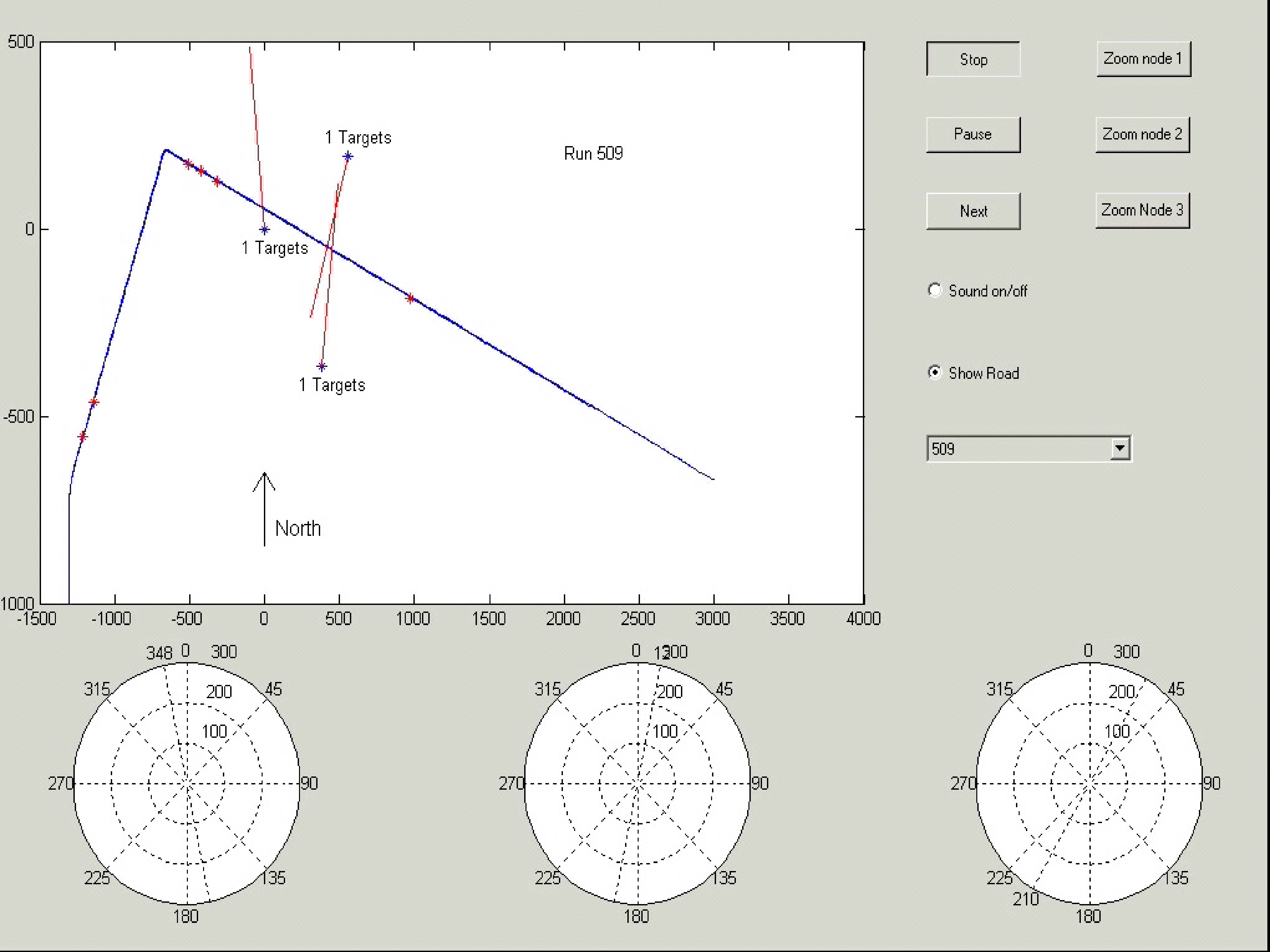
- Multiple Target Tracking Algorithm
  - Used to overcome difficulties associated with long range tracking of **closely** spaced targets of the **same type**
  - Tracks frequency components from different targets in bearing
  - Uses a combination of 2 beamforming algorithms
    - Conventional Beamformer
    - MVDR (max-likelihood type)
  - Developed and tested using ADAS data collected at SAFE II
  - Successfully demonstrated at YPG during the WAM data sharing collection exercise

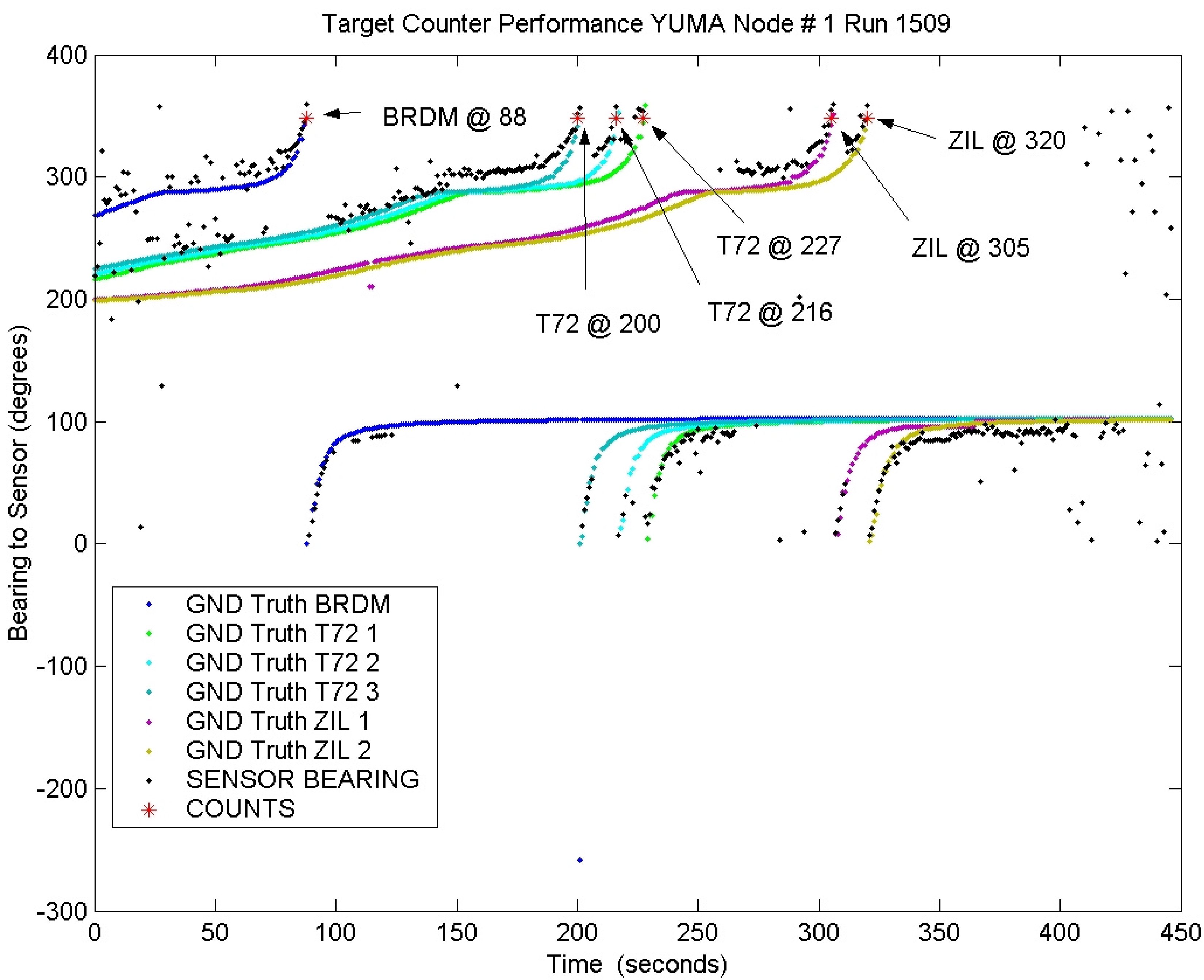


Target Counting Algorithm

- *MVDR Adaptive Beamforming Algorithm*
  - *Exhibits the ability to resolve signals separated by less than the natural beam width of the array*
  - *In order to obtain the accuracy needed to count targets that are very closely spaced ® single snapshot is used*
- *MVDR Þ Weights are Adaptively Computed*
  - *All-pass characteristic - Emphasize signals propagating from look direction*
  - *SUPPRESS noise and interfering signals propagating from other directions.*
  - *Sample of surrounding noise is added into the estimate, and then subsequently removed using a noise floor*
- *Used to Generate an Acoustic "Trip Line"*
  - *8 principal directions + look direction of the trip line.*


Untitled
Acoustic Trip-Lines
Node 3
0 Targets
Run 504
CPA = 50m
CPA = 275m
0 Targets
Node 1
CPA = 305m
0 Targets
Node 2
North
500
0
-500
-1000
-1500
-1000
-500
0
500
1000
1500
2000
2500
3000
Start
Zoom node 1
Pause
Zoom node 2
Next
Zoom Node 3
Sound on/off
Show Road
504
Harmonic Content in Look Direction
Harmonic Content in Look Direction
Node 1
Node 3
348
0
300
315
45
200
100
270
90
225
135
180
210
Start
Raptor Target Counting...
RunTABLES - Microsoft ...
MATLAB
Untitled
2:48 PM


500
0
-500
1000
-1500
-1000
-500
0
500
1000
1500
2000
2500
3000
3500
4000
1 Targets
1 Targets
1 Targets
Run 509
North
Stop
Zoom node 1
Pause
Zoom node 2
Next
Zoom Node 3
Sound on/off
Show Road
509
348
0
300
315
200
45
100
270
90
225
135
180
0
300
315
200
45
100
270
90
225
135
180
0
300
315
200
45
100
270
90
225
210
135
180



Target Counter Performance YUMA Node # 1 Run 1509
BRDM @ 88
T72 @ 200
T72 @ 216
T72 @ 227
ZIL @ 305
ZIL @ 320
Bearing to Sensor (degrees)
Time (seconds)
400
300
200
100
0
-100
-200
-300
0
50
100
150
200
250
300
350
400
450
GND Truth BRDM
GND Truth T72 1
GND Truth T72 2
GND Truth T72 3
GND Truth ZIL 1
GND Truth ZIL 2
SENSOR BEARING
COUNTS

Preliminary Performance

Run	Description	Node 1	Node 2	Node 3
502	BRDMx1	1/1------100%	1/1------100%	1/1------100%
503	BRDMx1	1/1------100%	1/1------100%	1/1------100%
504	T72x1	1/1------100%	1/1------100%	1/1------100%
507	BRDMx1, BTR, T72x3	5/5------100%	3/5-------60%	2/5-------40%
508	BRDMx1, T72x3, ZILx2	6/6------100%	6/6------100%	5/6-------83%
509	BRDMx1, T72x3, ZILx2	6/6------100%	6/6-------100%	6/6------100%
512	BMPx3, T72x3, ZILx2 BTRx1	8/9-------89%	8/9-------89%	8/9-------89%
514	M60x1	1/1------100%	1/1------100%	1/1------100%
515	M60x1	1/1------100%	1/1------100%	1/1------100%
516	M113x1	1/1------100%	1/1------100%	1/1------100%
519	HMMVx2, 5 TONx2	4/4------100%	4/4------100%	3/4-------75%
520	HMMVx2, M113x2, M60x3, TRUCKx2	8/10------80%	9/10------90%	7/10------70%
522	M60x3, TRUCKx2	4/5-------80%	5/5------100%	2/5-------40%
526	ZILx1	1/1------100%	1/1------100%	1/1------100%
536	BTRx1, BMPx2, ZILx2	5/5------100%	5/5------100%	4/5-------80%
Total		**53/57-----93%**	**53/57----92%**	**44/57-----77%**

Concluding Remarks

- **Classification** – Cylinder and Target ID
  - Statistically resolved templates – HLA information used to develop a "time reinforced" Bayesian discrimination and ATR algorithm
  - Tested against 1200+ signatures in database, 30+ scenarios at Picatinny
  - Achieved a 90+% accuracy for cylinder classification and target ID when tested in field

- **Target Counting** Algorithm
  - MVDR-like beamformer used to create an adaptive "trip-line"
  - Uses conventional and adaptive beamforming algorithms to extract features used to count targets as they cross the "trip-line"
  - Tested against 150+ signatures in database, 500+ scenarios at Picatinny and YPG