

## Robust Target Acquisition using Consecutive Range Doppler Maps

Hartmut Schimpf<sup>1</sup>, Johann Billner<sup>2</sup>

<sup>1</sup> FGAN-FHR/MHS, Neuenahrer Straße 20, 53343 Werthhoven, Germany

<sup>2</sup> Wehrtechnische Dienststelle WTD 81 – GF 340, Kalvarienberg, 91171 Greding, Germany

### Introduction

The computation of Range Doppler Maps (RDMs) is a natural step during the creation of SAR (or DBS) images. While the antenna footprint passes over a scenario the continuous data stream is split into packages that contain a fixed number of pulses which undergo the necessary Doppler treatment to achieve cross-range resolution. The outcome is a series of consecutive RDMs that have to be projected to a grid on the ground to create the final combined SAR ground map. This can either be the usual multi-look map which results from incoherent averaging of all signals within each resolution cell of the ground grid. It can also be a “single-look complex” (SLC) map in which case only one signal per resolution cell must be retained depending on a certain criterion (e.g. maximum total backscatter power). The RDMs by their nature are SLC. However, their size corresponds only to the antenna footprint (or, rather, the Doppler unambiguous range) and therefore comprises only a small portion of the scenario, moreover they need not to be projected to a ground grid.

For a reconnaissance drone or a seeker that makes use of the SAR/DBS principle, it is a natural thing to use consecutive RDMs instead of projected ground maps [2]. The main reasons are that the ATR algorithm should work in real time, and that the requirements for motion compensation are less stringent. Creating projected maps using flight attitude data of insufficient precision may introduce a loss of effective resolution and a blurring of the target images.

An ATR algorithm that works in real time on consecutive RDMs may create detection and classification decisions based on each individual RDM. Depending on the length of the synthetic aperture, an object on the ground normally appears in several consecutive RDMs. Therefore, the algorithm may as well combine the results of individual RDMs by means of a chain logic or by computing the “evolving mean” [9] of test feature vectors, thus providing more reliable results.

The SET-069 data pool provides SLC data of scenario “S1” which contains an array of a total of 17 objects. Two of these objects are a “T72” tank and a “BMP” armoured personnel carrier for which there exist also ISAR tower/turntable data in the SET-069 pool. In this paper it is analysed whether ATR features derived from these ISAR data can be used to classify objects in the S1 airborne scenario. For this purpose, the data are processed into consecutive RDMs, and the results compared with those based on the SLC data (i.e. projected maps) from the pool.

### Description of the SAR and ISAR data

#### Scenario

The target array was deployed on a grassy plain with approximately flat and horizontal surface. There were 4 flights performed under the same depression angle of 20°, but with different headings. The flight altitude was 1300ft (400m), the antenna was side-looking to the **left**. In the vicinity south of target array there were some isolated groups of trees and bushes, some of them had additional vehicles located next to them. These are not documented for SET-069 purposes, but can be considered as “false targets of opportunity”.

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## Robust Target Acquisition using Consecutive Range Doppler Maps

scene	heading
-5	225°
-6	45°
-7	315°
-8	135°

### Range Doppler Maps (RDMs)

The radar used for the airborne measurements was the MEMPHIS [5] with a chirp bandwidth of 200MHz which corresponds to a range resolution of 0.75meters. The flight velocity was 140knots ( $70\text{ms}^{-1}$ ), the effective PRF= $1500\text{s}^{-1}$ , the slant range to antenna boresight  $R=1140\text{m}$ . This results in a cross-range resolution of

$$\Delta_{cross} = \frac{\lambda \cdot R \cdot PRF_{eff}}{2v \cdot N_{FFT}} = \frac{105\text{m}}{N_{FFT}}$$

In order not to reduce the resolution more than necessary,  $N_{FFT}=256$  was chosen, resulting in  $\Delta_{\perp}=0.41\text{m}$  (no square pixels). The antenna beamwidth ( $3^{\circ}$ ) fills about 2/3 of the Doppler unambiguous range of 105m. Each target on the ground is visible in 6 to 7 consecutive RDMs, i.e. there are 6 to 7 independent opportunities for each target to be detected and classified.



**Fig.1** multi-look SAR image of target array S1

channel was not used for analysis.

### Single look complex (SLC) SAR data

In order to create the projected SLC ground maps, the series of RDMs as described above, was projected to a ground grid with square cells of dimension 0.75m by 0.75m in order not to create a distorted map. Multi-look images (fig.1) were created by non-coherent averaging in the fully calibrated HH, HV=VH, and VV channels. To create the SLC map only the one return per grid cell was retained which had the highest total power ( $|HH|^2 + 2*|HV|^2 + |VV|^2$ ). Each SLC pixel thus contains the full scattering matrix. As the ISAR data were measured with V transmit polarization only (giving rise to VV and VH channels), the HH

### ISAR data

For the measurement of the data that are used here (data pool folder "TT\_20deg\_FGAN"), the fully polarimetric MEMPHIS radar [5] was located on top of a tower at a height of 47 meters. Three targets (T72, ZSU 23-4 and BMP) were positioned on a turntable at a distance of about 154m, giving rise to a slant range of 161m and a depression angle of  $17^{\circ}$ . Slight tilting of the turntable resulted in an effective depression angle of  $20^{\circ}$ , the same as for the airborne scenario.

The MEMPHIS 35 GHz radar transmitted linear V polarisation, and received H and V simultaneously thus providing orthogonal VV and VH channels. The basic waveform is a linear chirp with 200 MHz bandwidth. In order to achieve higher range resolution, this chirp was combined with a stepped frequency mode with 8 steps of 100 MHz increment [6].

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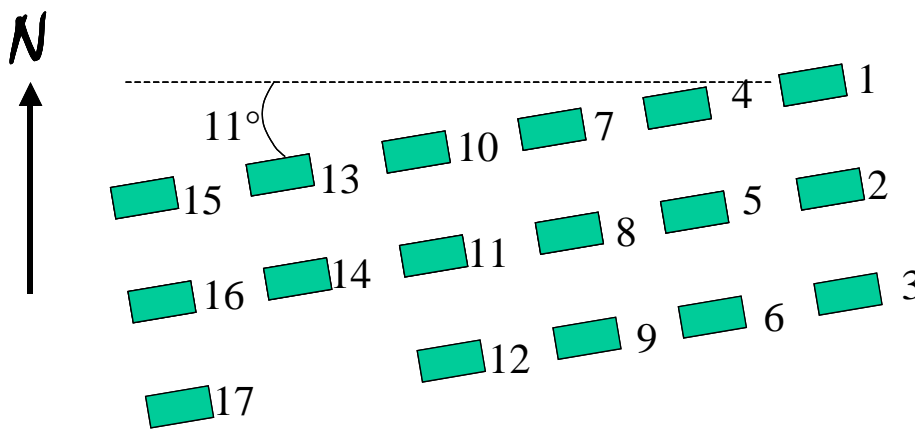
However, in order for the ISAR data to be compatible with the SAR data, processing of the 200MHz chirp only was sufficient here.

A full revolution of the turntable lasted 130 seconds, the effective PRF was  $2300s^{-1}/8$  such that a 64-point Doppler FFT results in a cross-range resolution of 0.42m, sufficiently close to the SAR cell size.

For this analysis, only scene -05 was used due to time constraints. As the heading was  $225^\circ$ , side-looking to the left means a viewing vector in direction  $135^\circ$ . The targets on the turntable were rotating counter-clockwise (front  $0^\circ$ , right side  $90^\circ$  etc.). Therefore, taking into account the orientation of the array, the target aspect angle as seen from the antenna was either  $56^\circ$  (front right) or  $236^\circ$  (rear left).

**The target array**

17 objects were deployed as shown in fig.2. Their orientation of all vehicles was about  $11^\circ$



**Fig.2** layout of the target array

south of west w.r.t. their long side, the spacing between the objects was roughly 30m. They were all facing east, but this information cannot be used in an ATR scheme, because the determination of target orientation via Hough transform or pattern matching cannot distinguish between front and rear aspect.

The objects are listed in table 1.

<i>Object #</i>	<i>description</i>	<i>symbol</i>
1	Civilian bus	Red *
2	Confusor type 1	Green *
3	Reference point	Red +
4	Confusor type 2, camouflaged	Red O
5	Confusor type 2	Green O
6	Confusor type 3	Blue *
7	Confusor type 4, camouflaged	Red ◊
8	Confusor type 4	Green ◊
9	Confusor type 5	Cyan *
10	Confusor type 6	Magenta *
11	Confusor type 7	Black *
12	Decoy I	Green +
13	<b>BMP2</b>	<b>Green</b>
14	<b>T72</b>	<b>Red</b>

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15	Decoy IV	<b>Blue +</b>
16	Decoy III	<b>Black +</b>
17	Decoy II	<b>Magenta +</b>

**Table 1** description of the target array and coding symbols for subsequent figures

The confusers were light or heavy tanks or missile launchers, their identity will not be disclosed due to security classification reasons. Some of the objects are shown in fig.3.

		
T72 (#14)	BMP2 (#13)	Bus (#1)
		
Reference point (#3)	Decoy I (#12)	Detail of decoy I
		
Detail of decoy IV (#15)	Bus (#1)	Decoy II (# 17)

**Fig.3** some details of the target array

**ATR features**

All feature values were computed on the basis of 2-D ISAR images with 0.75m (range) by 0.42m (cross-range) pixels. They were taken from a list prepared by the NATO SET-TG14 working group [4]. For geometrical, statistical, and structural features, the total power map ( $|VV|^2 + |VH|^2$ ) was used, for the polarimetric features the VV and VH power map were used in parallel. More details are to be found in [3]

- ft1 = range extent of 20 strongest scatterers
- ft2 = cross-range extent of 20 strongest scatterers
- ft3 = ft1\*ft2 (= area of the “minimum bounding rectangle” (MBR))

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- $ft4 = \text{mean/std.dev.}(\text{total power|MBR})$
- $ft5 = (\text{powersum } 10 \text{ strongest scatterers}) / \text{powersum}(\text{MBR})$
- $ft6 = \log_{10}(\text{pmax}(1)/\text{pmax}(5))$  (ratio between strongest and 5<sup>th</sup> strongest scatterer within the MBR)
- $ft7 = \log_{10}(\text{pmax}(1)/\text{pmin})|\text{MBR}$  (ratio between strongest and weakest scatterer within the MBR)
- $ft8 = \max(\text{pvv/pvh})|_{\text{dB}} - \min(\text{pvv/pvh})|_{\text{dB}}$  (span of parallel/cross channel separation)
- $ft9 = \text{slope}(\text{pmax vs.dif})|_{\text{dB}}$
- $ft10 = \text{shift}(\text{pmax vs.dif})|_{\text{dB}}$

(in  $ft9$  and  $ft10$  “pmax” stands for the 10 strongest scatters within the MBR, sorted in descending order, “dif” contains the related channel differences  $\text{pvv/pvh}$ , shift and slope refer to a least squares line fit that is applied to these 10 pairs of values).

The rationale for the selection of this set of features is not that they constitute a “best” set. Rather they are considered to be a “generic” set with representatives from several feature types, namely geometric, statistical, scatterer power related (or structural), and polarimetric. Of course, some of these features are more or less correlated with others. This can be assessed either by determining all the mutual cross correlation coefficients, or by a principal component analysis (PCA), cf.[7]. Therefore, only certain subsets out of these 10 features will form meaningful sets of ATR features.

**Classification**

**Preparations**

A total of 60 consecutive RDMs was processed. The target array was to be found in RDMs #12 to RDM #29. As the array itself contained enough confusors and competitors, no additional false targets from the surroundings were taken into account. Table 2 shows which targets were present in which RDM:

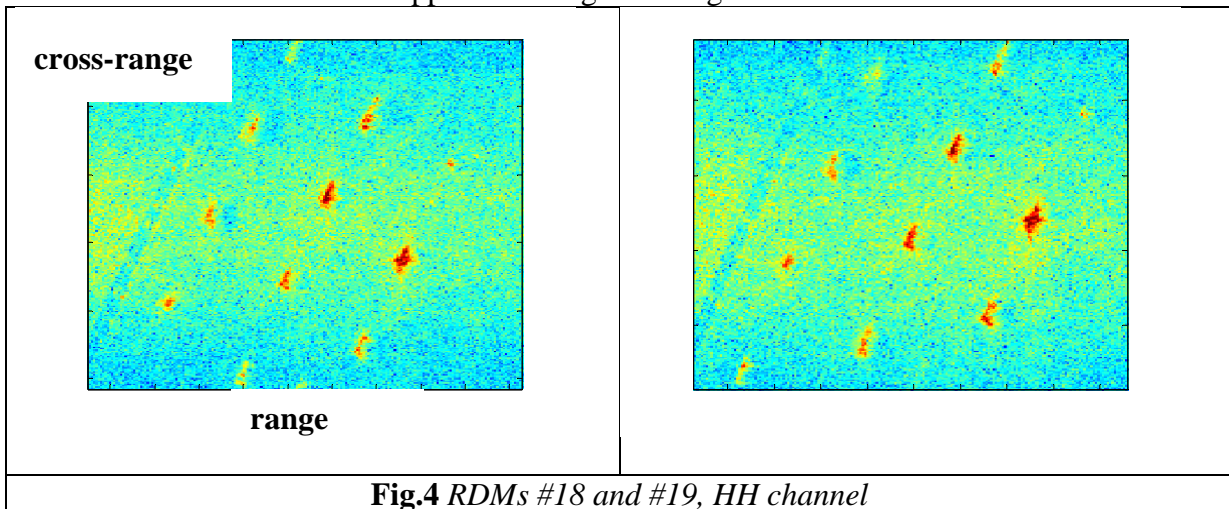
RDM\Tgt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12	♦																
13	♦	♦															
14	♦	♦	♦	♦													
15	♦	♦	♦	♦	♦		♦										
16	♦	♦	♦	♦	♦	♦	♦										
17	♦	♦	♦	♦	♦	♦	♦	♦		♦							
18		♦	♦	♦	♦	♦	♦	♦	♦	♦	♦						
19		♦	♦	♦	♦	♦	♦	♦	♦	♦	♦		♦				
20					♦	♦	♦	♦	♦	♦	♦	♦	♦	♦			
21					♦	♦		♦	♦	♦	♦	♦	♦	♦	♦		
22						♦		♦	♦	♦	♦	♦	♦	♦	♦	♦	
23									♦		♦	♦	♦	♦	♦	♦	
24									♦		♦	♦	♦	♦	♦	♦	♦
25												♦	♦	♦	♦	♦	♦
26												♦		♦	♦	♦	♦
27															♦	♦	♦
28																♦	♦
29																	♦

**Table 2** listing of targets in all 18RDMs in which the target array is (partly) visible

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The positions of all objects within each RDM were determined, around each position a “region of interest” (ROI) was defined with size (Range $\pm$ 7, Doppler $\pm$ 20), and each ROI labeled with the appropriate target ID. ATR test features were computed for each ROI (a total of 112) the same way as they are computed from the ISAR generated tower/turntable images. In addition, ROIs for all 17 objects were defined in the SLC map, and included in the list of opportunities for comparison. Thus, a total of 129 ROIs (i.e. 129 sets of 10 feature values to create test feature vectors from) was available for analysis.

Fig.4 for illustration shows blow-ups from RDMs #18 and #19 (HH channel). The antenna beam in Doppler direction is clearly visible. RDM #18 contains targets #2 to #11, RDM #19 targets #2 to #11 plus #13. One sees how the antenna footprint sweeps across the array, target #2 almost disappearing at the upper edge, while #13 enters the beam from below. It is interesting to see that most targets show such a high T/C that they are visible outside the 3dB-area as far as the end of the Doppler unambiguous range.



In a next step, the feature **reference** vectors for the BMP and the T72 have to be determined. For this purpose, three data sets of each vehicle were processed, namely -06, -07, -08 for the T72, and -19, -20, -21 for the BMP. This corresponds to 3 articulations of each reference target (for details, see [3]). The ISAR processing with the parameters as described above resulted in 558 values out of 360° aspect angle interval, i.e. one value every 0.65°. As former analysis [10] has shown that averaging over several available articulations of the same target type provides more stable references, the three data sets per target were now averaged. Thus we finally have a set of 558x10 feature values for both BMP and T72.

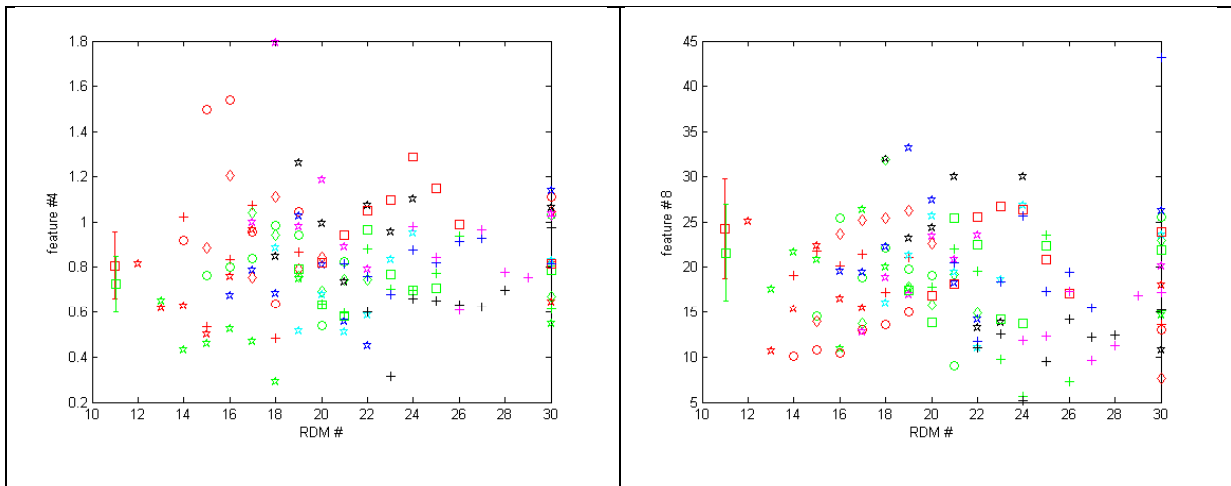
Next, the expected aspect angle has to be determined. In former evaluations [1][8] it could be demonstrated that an independent knowledge of the target aspect angle can increase the classification performance. As was described above, the aspect angle is either 56° (value #87) or 236° (value #366) due to the front/rear ambiguity. Therefore we have to take an interval of  $\pm 10^\circ$  ( $\pm 16$  values) around each of these two values (which reflects the error in determining the target aspect) and perform an aspect angle averaging over all 66 values for each of the ten features. Because for the Euclidian distance in feature space also the standard deviation (for normalization) is needed, the pertinent 10 values are also computed over these two  $\pm 10^\circ$  intervals.

### Results

Let us first look at the behaviour of individual features across all RDMs. This gives a feeling about how strong the variability is from one RDM to the next, how pronounced the differences between different targets are, and whether the SLC case behaves different from the RDM case. For this purpose, we have to code the 17 objects by means of different

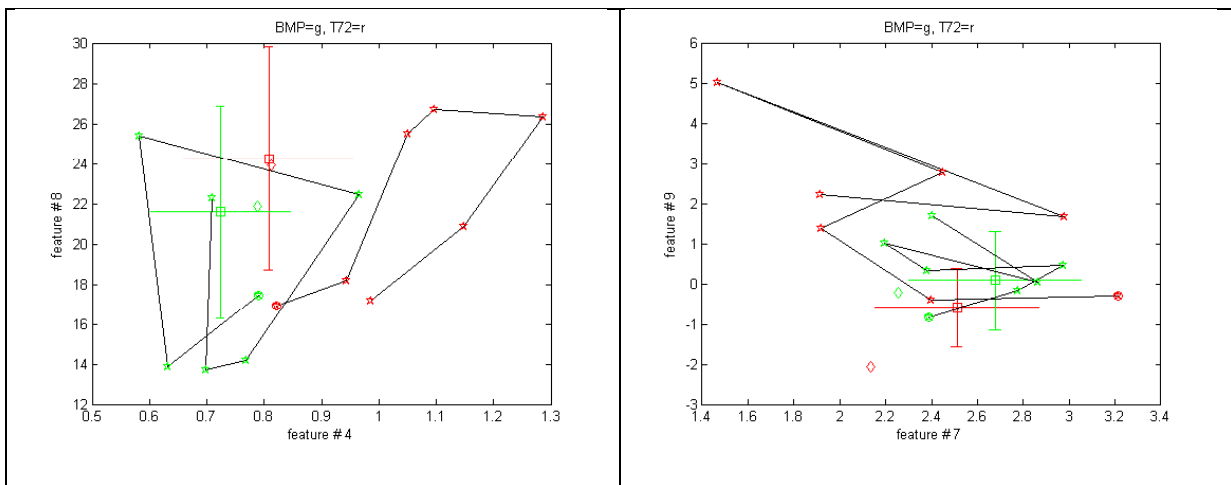
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symbols which will be used without change throughout the rest of the paper (3<sup>rd</sup> column in table 1). As an example, fig.5 shows features #4 (the statistical feature) and #8 (polarimetric). One immediately can see that there is no striking difference between the RDM case and the SLC case. All values fall into the same range. This is not only true for the bulk of values, but also for the values of individual targets (one striking exception is target #7). The variability may be quite strong, but this differs from target to target. One also sees that the range of test values is much larger than the  $\pm$ std.dev.-range of the references. However, w.r.t. the T72 and the BMP, the separation seems to work quite well.



**Fig. 5** behaviour of test feature values (#4 left, #8 right) across RDMs. In position 11, the reference values together with their standard deviations are shown, in pos.30 the SLC case is shown

Another possible illustration is to look at the tracks of individual targets in a 2-dimensional feature space. Let us again choose features #4 and #8 (fig.6, left). The references are marked with their  $\pm$ std.dev.-error bars, the tracks start at “o”. The SLC cases are indicated by a “diamond”. Both are fairly close to their references. Only T72 and BMP are shown to avoid confusion. One sees again a rather strong variability, but also a tendency of separation. – For comparison, also the case ft.9 vs. ft.7 is shown (right). The variability is not quite as strong, and the separability seems to be reduced, mainly due to feature #9.



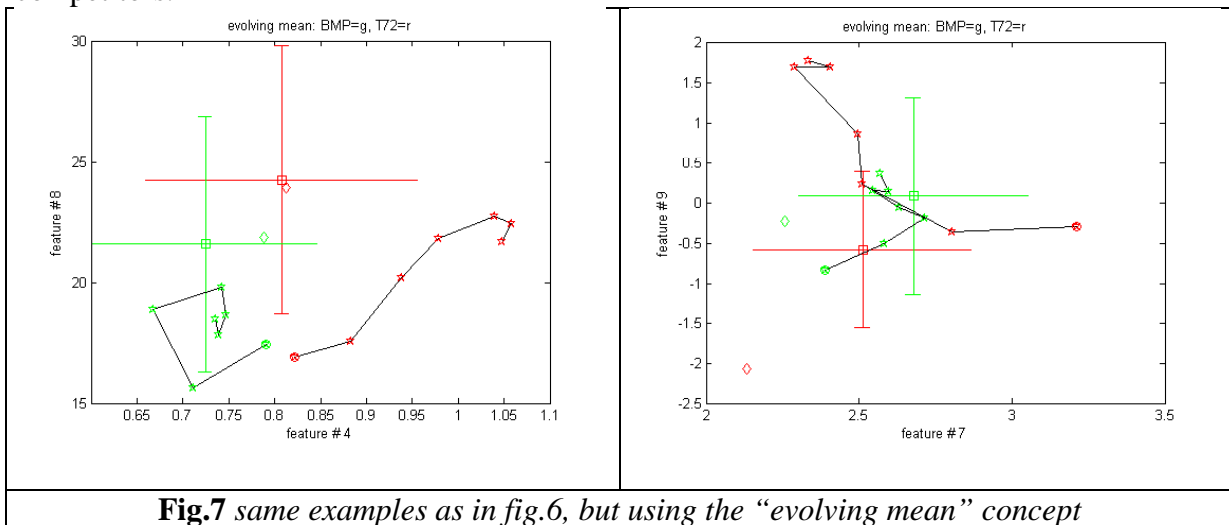
**Fig.6** tracks of BMP (green) and T72(red) in 2-dim feature space: ft.8 vs. ft.4 (left) and ft.9 vs. ft.7 (right). Tracks start at “o”, SLC is indicated by “◇”. References are characterized by their error bars.

When one sees the rather strong variability of feature values across RDMs one may ask whether and how one can get an advantage out of using RDMs instead of one SLC map.



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Certainly one gets a set of independent values as the seeker passes across a series of consecutive RDMs. We had already mentioned the possibility of introducing a count logic for the individual classification results [11]. Here, we want to analyse the concept of the “evolving mean” (EM) which was introduced earlier [12]. The EM concept means that the ATR algorithm makes use of all feature values of a target under test that are known to him at a certain instant, by computing the mean value from the first to the present RDM. This stabilizes the test vector by reducing a possible strong variability. We want to assess the effect by again looking at the same examples as in fig.6 (fig.7). In all cases the desired behaviour is recognizable, although the smoothed tracks do not always approach the reference as does the BMP for all four features. The T72 does this only for features 7 & 8, whereas for features 4 & 9 it rather recedes for later RDMs. However, the way the EM concept finally influences the classification result, can only be assessed in comparison to the behaviour of the competitors.



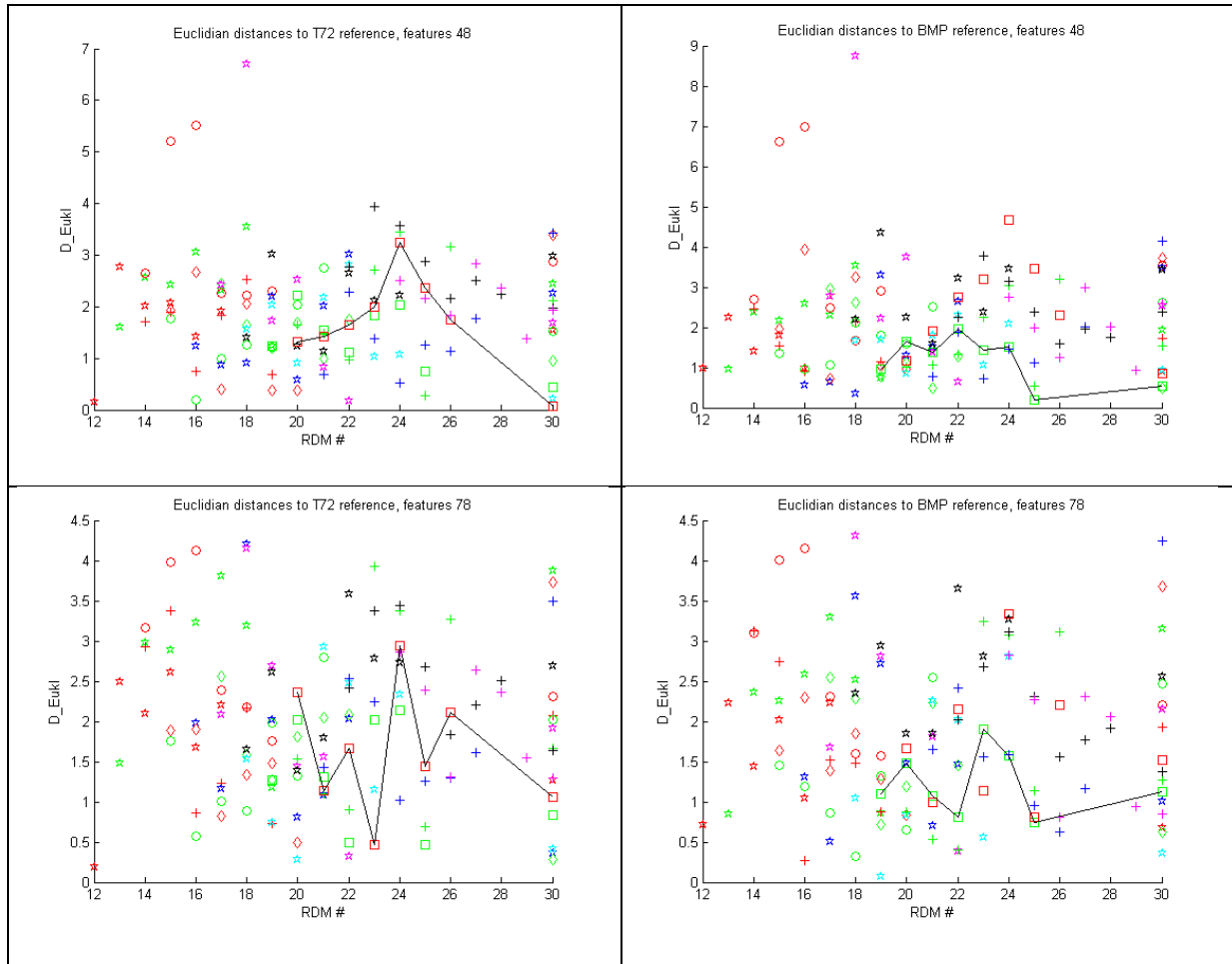
**Fig.7** same examples as in fig.6, but using the “evolving mean” concept

The classification itself is done by using the “Euclidian distance” (ED) between the test feature vectors and the two reference feature vectors for classes “BMP” and “T72” ( $N$  is the number of features that comprise the respective feature set,  $\alpha$  is the target aspect angle, determined independently as described above,  $\sigma_i$  are the standard deviations that serve for normalization):

$$d_{eukl}(\alpha) = \sqrt{\sum_{i=1}^N \frac{(f_i(\alpha) - F_i^{ref}(\alpha))^2}{\sigma_i^2}}$$

In the case of the RDMs, only those objects are tested that are presently visible within the RDM under test. This means that type and number of competitors (or confusors) may vary depending on the layout of the target array and on the flight direction (here, only one flight direction -  $225^\circ$  - is analysed). In the SLC case, the whole scenario is tested at the same time, i.e. both T72 and BMP have 16 competitors against which they have to be classified.

Let us now look at the Euclidian distances for all 129 tested ROIs and both references. As examples, we choose two sets of two features each, namely fts.4&8, and fts.7&8. The values that belong to the respective “main candidate” are connected by a black line to facilitate its identification.

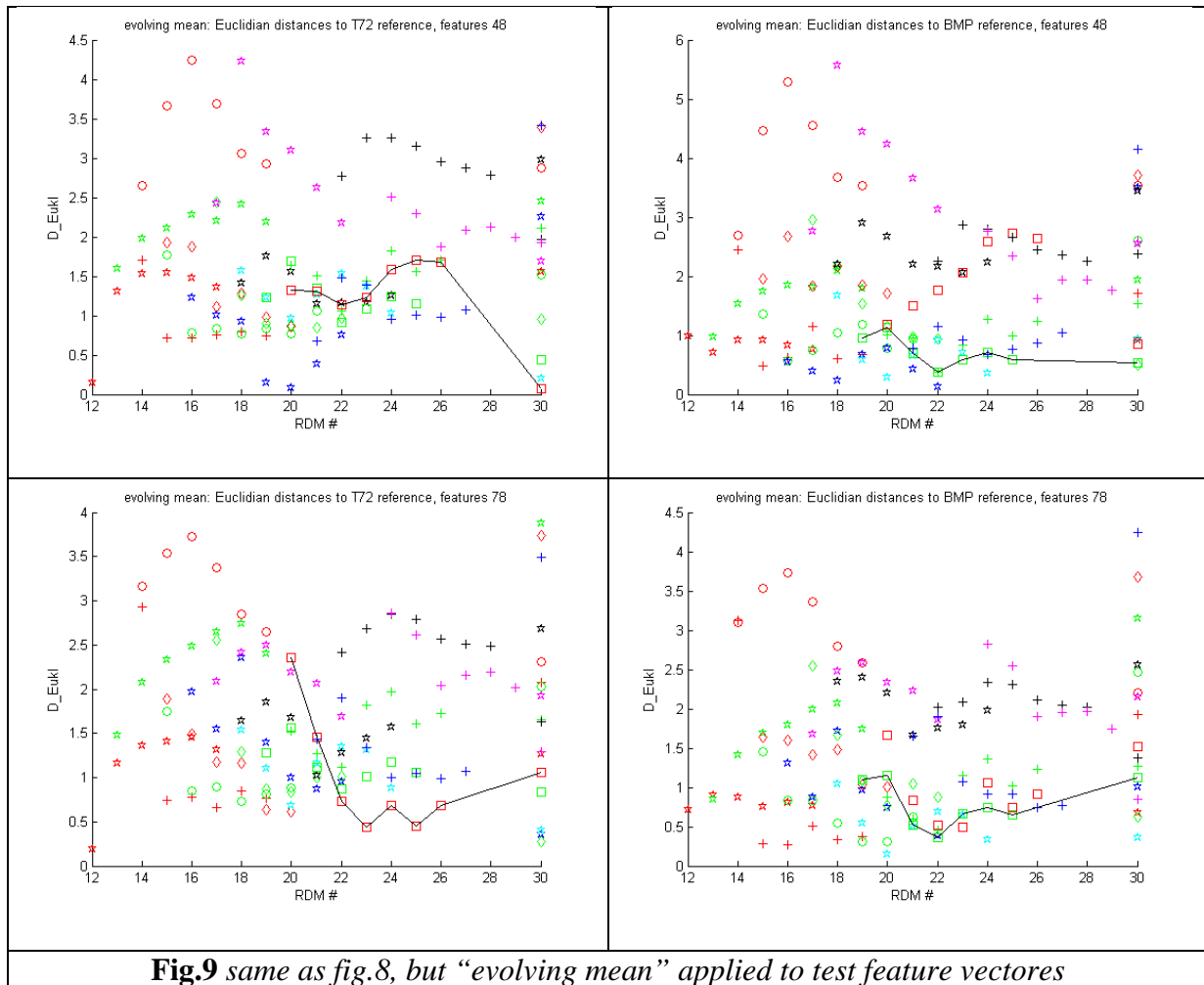


**Fig.8** Euclidian distances for all ROIs w.r.t. „T72“ reference (left) and “BMP” reference (right) for two sets of two features each

Obviously, the first set (4&8) performs better on the SLC than on the RDMs. Both the T72 and the BMP (together with target #8, though) would be classified correctly (i.e. have the smallest ED) against all 16 competitors. For the second set (7&8) they would only reach rank 5 and 6, respectively. In the RDM case, the BMP would be classified correctly for both feature sets in RDMs 24 and 25. The T72 only once has rank 1 (RDM #23, fts.7&8), twice rank 2 (RDM #26, fts.4&8, RDM #21, fts.7&8).

How would applying the EM concept change the classification behaviour? We show the same examples again in fig.8: the rankings for the T72, fts.4&8 remain essentially unchanged, i.e. no correct classification. For fts.7&8, however, the T72 has rank 1 in 5 out of 7 RDMs (#22-26)! The BMP gets rank 1 in RDMs 23 and 25, and rank 2 in RDMs 21,22,24 (fts.4&8). For fts.7&8 it gets rank 1 in even 3 RDMs (21,22,25), and rank 2 in RDMs 23 and 24. One can conclude from this, that the EM concept has a potential to improve the classification performance, but that it depends critically on the respective set of features.

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**Fig.9** same as fig.8, but “evolving mean” applied to test feature vectors

### Summary and conclusions

Using a basic ATR scheme based on sets of generic classification features of different types (geometric, statistical, structural and polarimetric) it was tried to identify two targets (main battle tank T72 and APC BMP) within a scenario consisting of 17 objects (light and heavy tanks, missile launchers, one bus, and different decoys). This was done in parallel using either a series of consecutive “Range Doppler Maps” or the corresponding “single look complex” SAR ground map. In each RDM the BMP had up to 10, the T72 up to 9 competitors, In the SLC case both had even 16 competitors. In 6 RDMs, both T72 and BMP were present at the same time. - The feature references for the BMP and the T72 were taken from tower/turntable (ISAR) measurements which had been performed using the same radar at the same depression angle, and which had been processed with the same parameters of resolution and polarimetry. It could be demonstrated that

- using ISAR references to recognize targets in a SAR scenario is a viable method
- RDMs and SLC ground maps produce test feature values within the same range and therefore do not show a fundamental difference in ATR performance
- the advantage of consecutive RDMs, however, lies in the possibility of combining the several looks that one gets on each target. This makes it possible to apply an additional scheme like “chain logic” or “evolving mean” and thus increase the classification performance. In the case of the “evolving mean” this could be demonstrated for certain sets of features.
- “robustness” of the ATR process is increased by
  - averaging several target articulations to obtain a target reference

- independently determining the target aspect angle thus refining the reference feature vector
- combining several independent looks from consecutive RDMs (using the “evolving mean” concept, for instance)

The work presented here, so far is based only on one pass over the scenario. In order to confirm the results and support the conclusions, the same analysis has to be repeated using the additional 3 passes for three different headings that are available in the data pool.

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**Robust Target Acquisition using Consecutive Range Doppler Maps**

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# **Robust Target Acquisition using Consecutive Range Doppler Maps**

**Hartmut Schimpf**

FGAN Forschungsinstitut für Hochfrequenzphysik und Radartechnik (FHR)  
D-53343 Wachtberg – Werthhoven, Neuenahrer Straße 20, GERMANY

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NATO School, Oberammergau, May 10-12, 2005

**FGAN**

Division MHS Millimeter Wave and Seeker Radar

**FHR**

# Overview

- Introduction
- Description of the SAR and ISAR data
- The target array
- ATR features used for classification
- Classification results
- Summary and conclusions

# Introduction

The computation of Range Doppler Maps (RDMs) is a natural step during the creation of SAR (or DBS) images.

A series of consecutive RDMs projected to a grid on the ground yields the final combined SAR ground map:

- SLC (selection criterion!)
- multi-look



# Introduction, cont'd

Reasons in favor of RDMs:

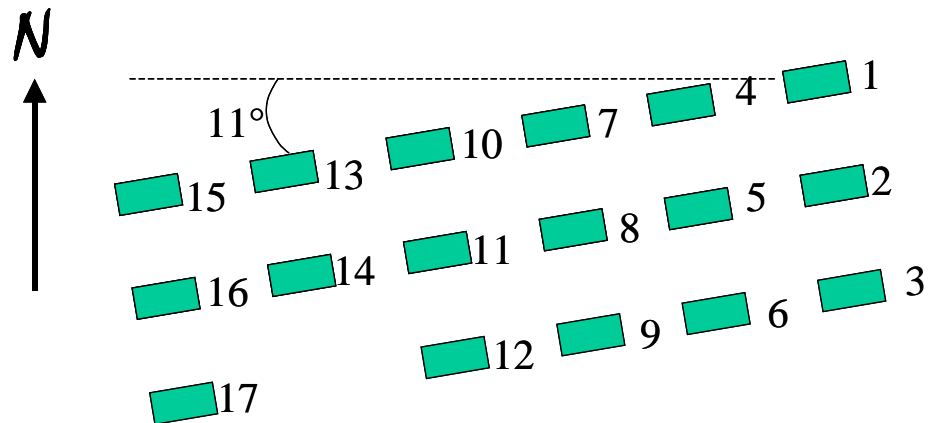
- the ATR algorithm has to work in real time
- the requirements for motion compensation are less stringent
- they need not to be projected to a ground grid (however, each RDM comprises only a small portion of the scenario)
- an object on the ground normally appears in several consecutive RDMs  $\Rightarrow$  several independent opportunities for detection/classification may be combined by means of a “chain logic” or by computing the “evolving mean” of test feature vectors

# Description of the SAR and ISAR data

(**SAR**: S1    **ISAR**: TT\_20deg\_FGAN)

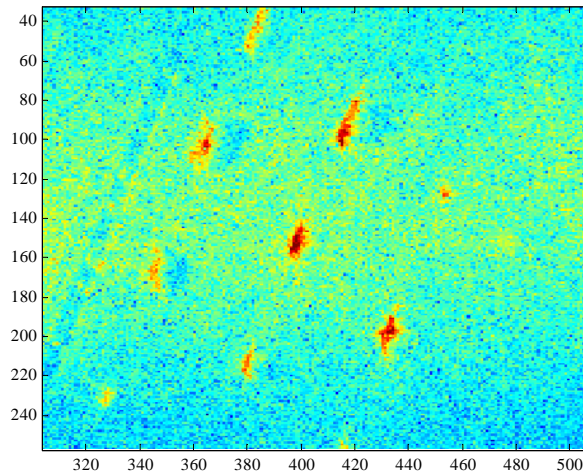
	<b>ISAR</b>	<b>RDMs</b>	<b>SLC</b>
Depression angle	20°	20°	20°
$\Delta_{\perp}$	0.42m	0.41m	0.75m
$\Delta_{\parallel}$	0.75m	0.75m	0.75m
polarization	VV, VH	VV, VH, (HH)	VV, VH, (HH)
geometry	rotation ccw (90°=r)	side-looking to the left, Heading 225°	

# The target array

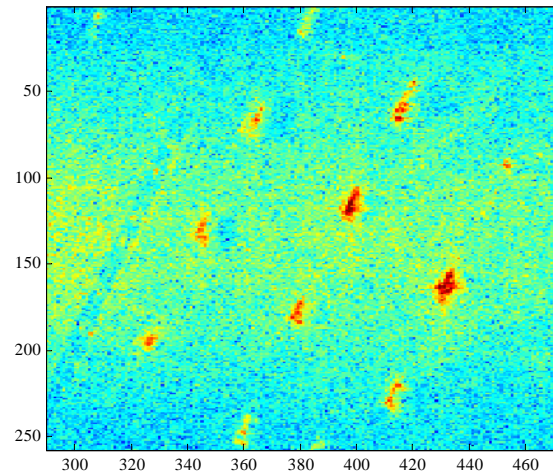


<i>Object #</i>	<i>description</i>	<i>symbol</i>
1	Civilian bus	Red *
2	Confusor type 1	Green *
3	Reference point	Red +
4	Confusor type 2, camouflaged	Red O
5	Confusor type 2	Green O
6	Confusor type 3	Blue *
7	Confusor type 4, camouflaged	Red ◊
8	Confusor type 4	Green ◊
9	Confusor type 5	Cyan *
10	Confusor type 6	Magenta *
11	Confusor type 7	Black *
12	Decoy I	Green +
13	BMP2	Green □
14	T72	Red □
15	Decoy IV	Blue +
16	Decoy III	Black +
17	Decoy II	Magenta +

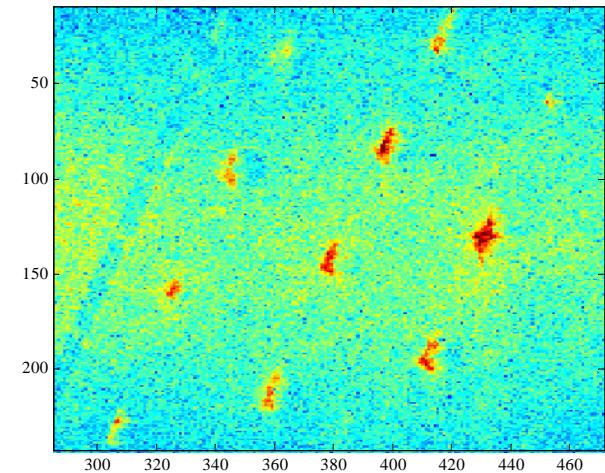
# Consecutive Range Doppler Maps



RDM #17



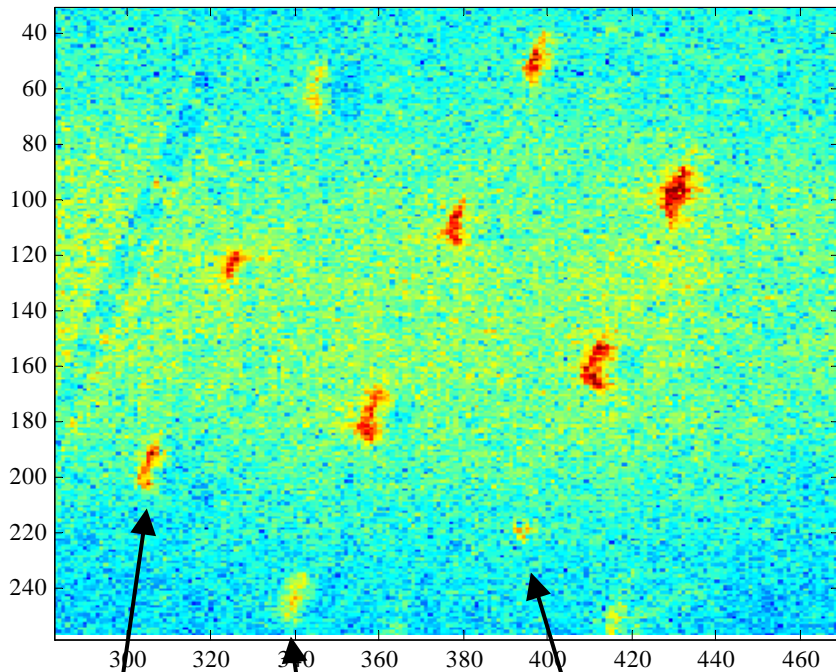
RDM #18



RDM #19

# Comparison between RDM and SLC (HH)

RDM #20

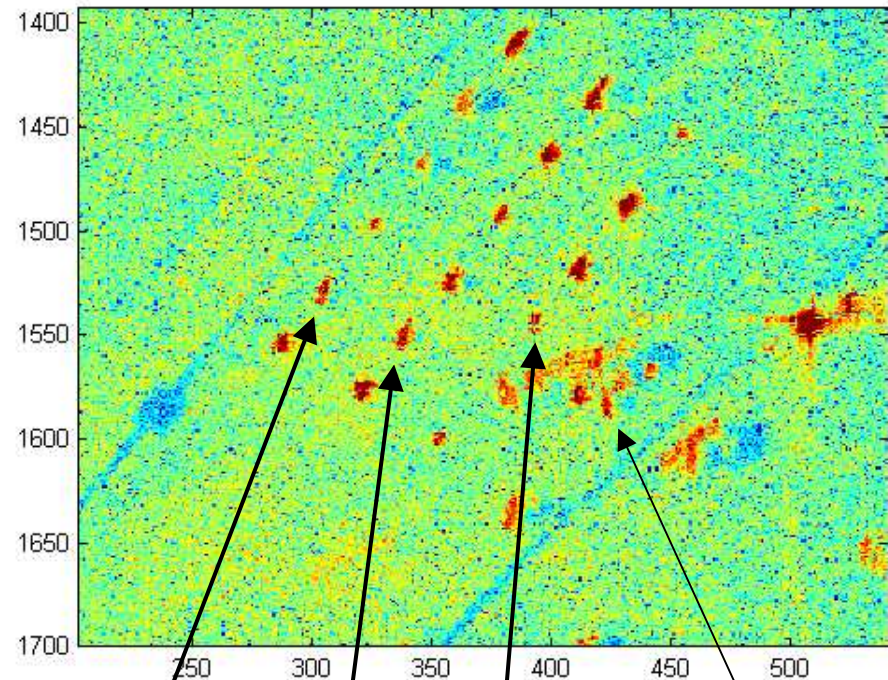


BMP

T72

Decoy I

SLC



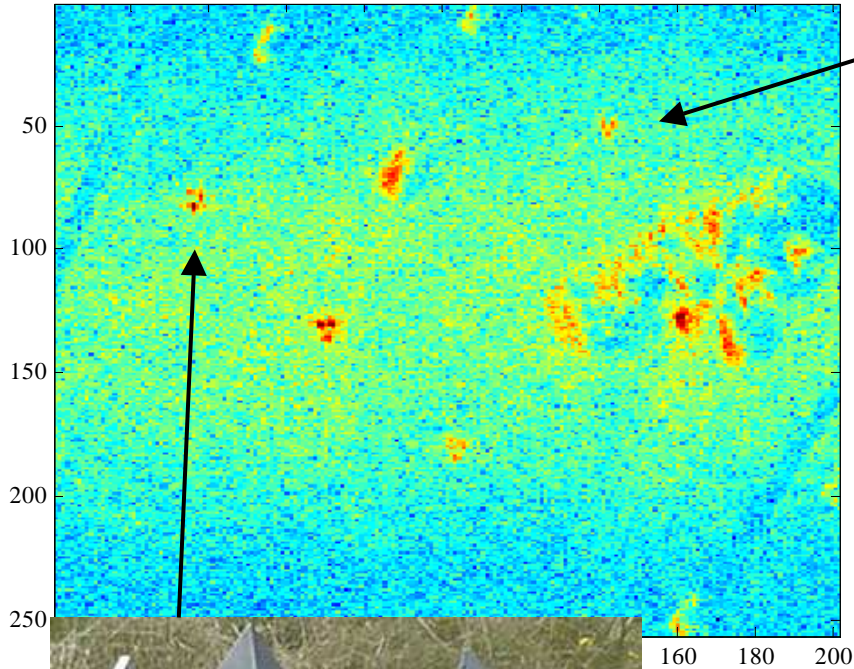
BMP

T72

Decoy I

False targets

# Decoys



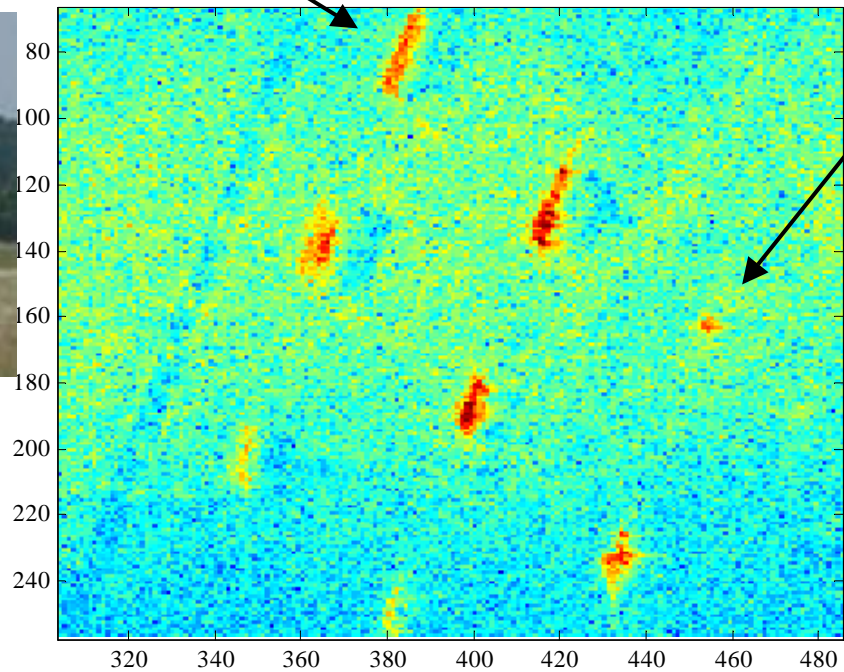
Decoy I



Decoy IV

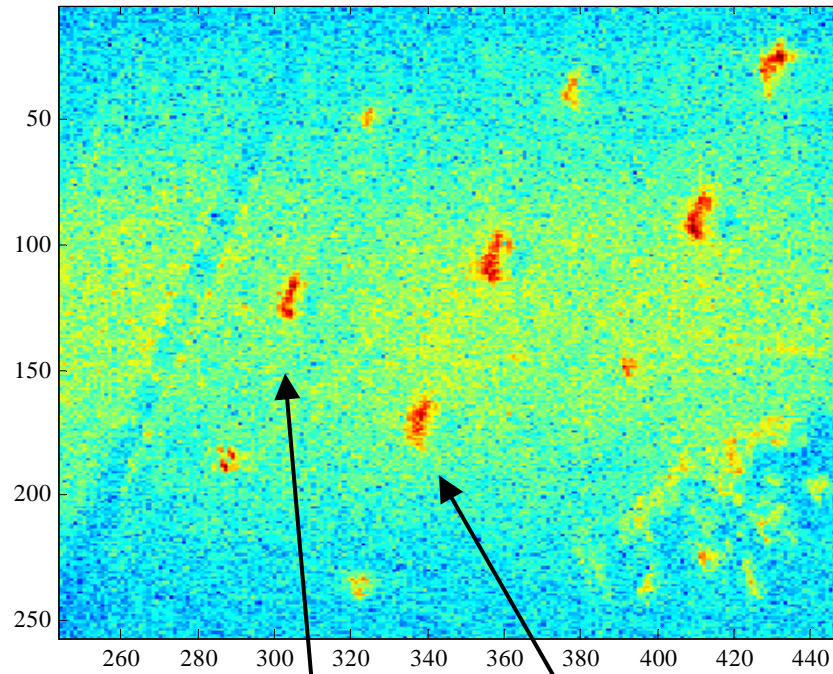


# Targets in RDMs



# Targets in RDMs

RDM #22



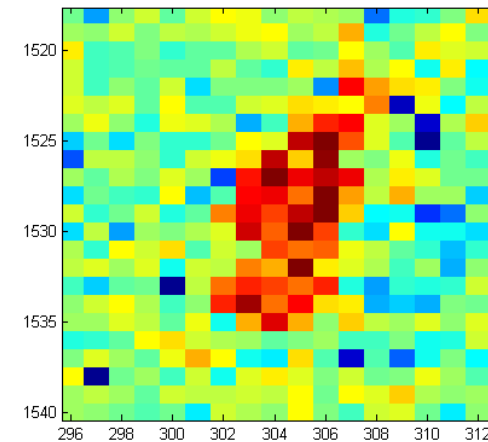
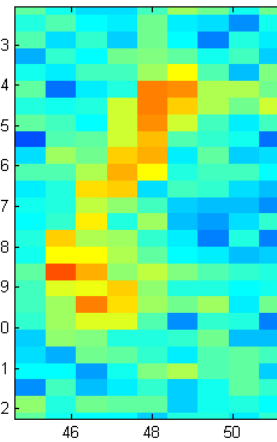
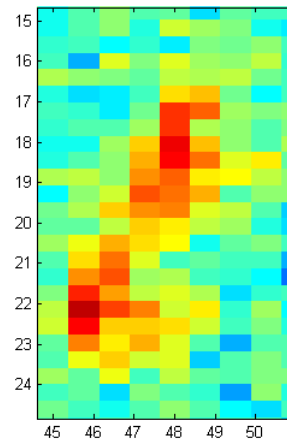
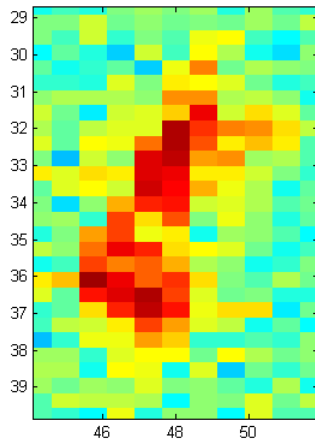
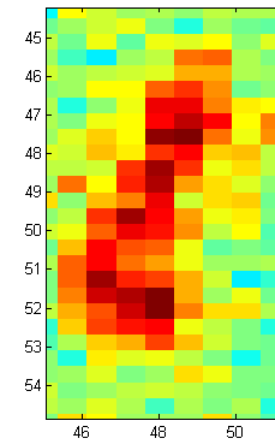
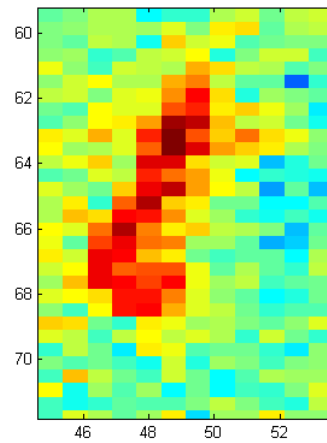
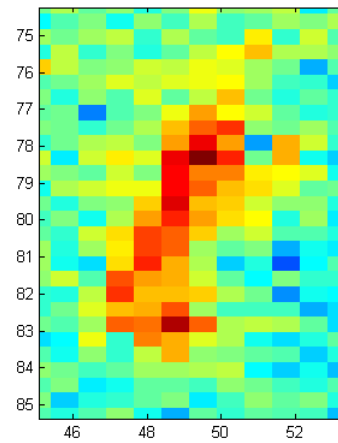
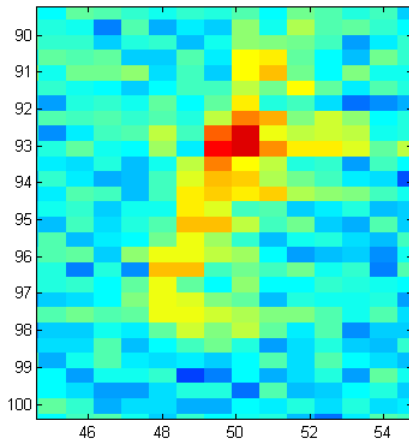
BMP

T72

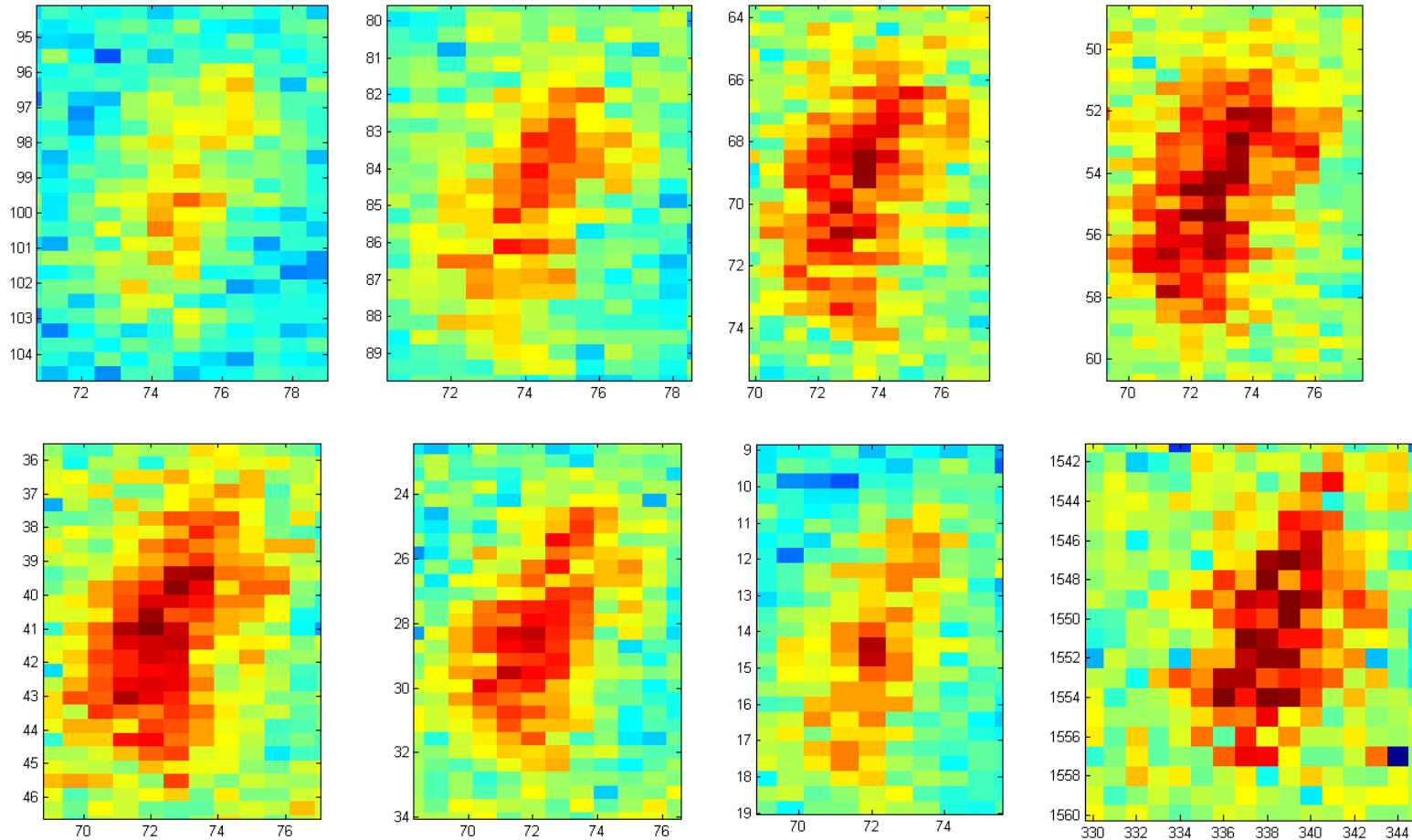




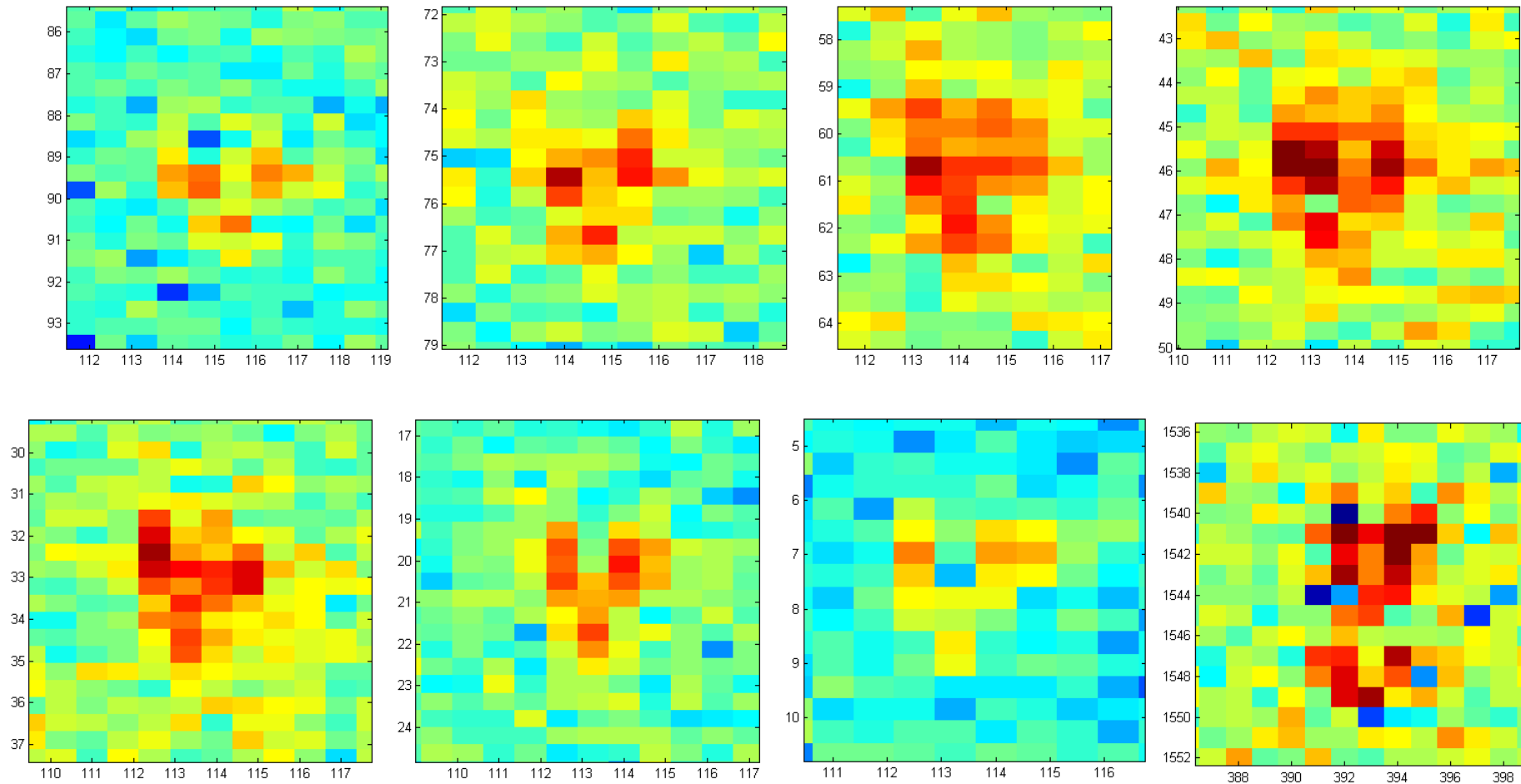
# Consecutive images of targets tgt.#13 (BMP), RDMs 19-25, SLC



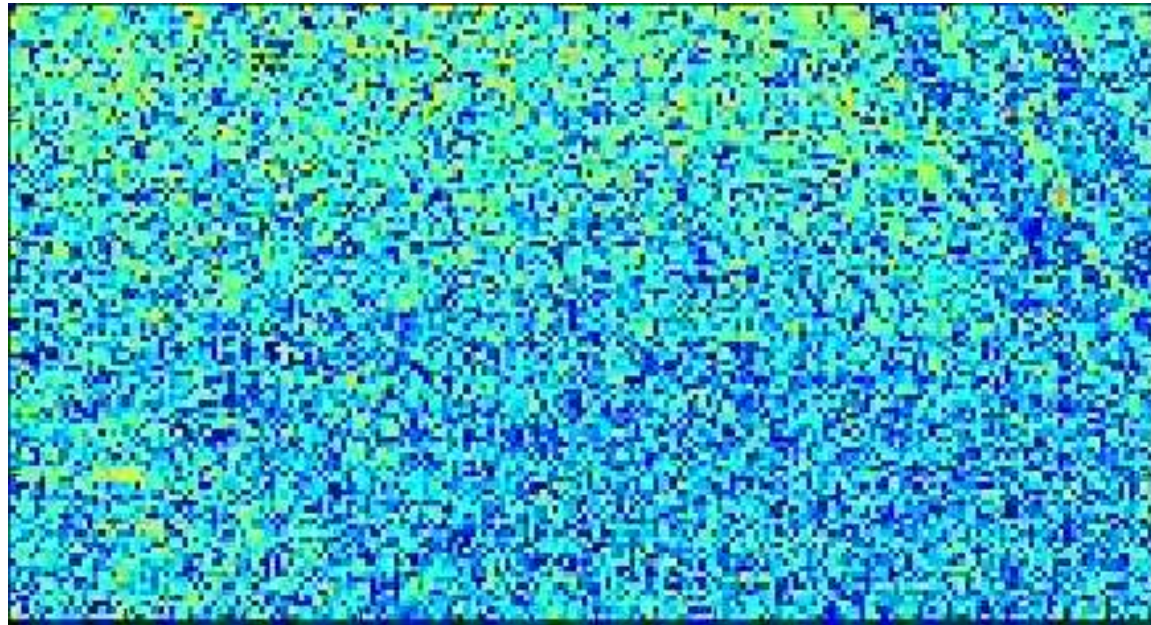
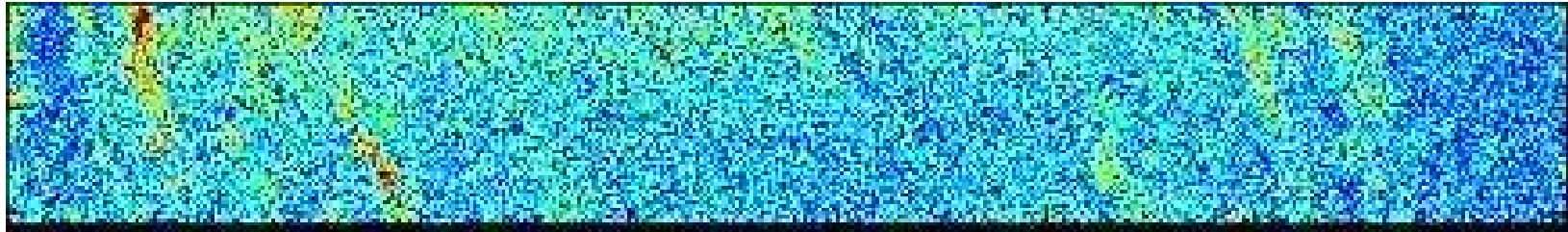
# Consecutive images of targets tgt.#14 (T72), RDMs 20-26, SLC



# Consecutive images of targets tgt.#12 (decoy I), RDMs 20-26, SLC



# RDM movie



# ATR features used for classification

- ft1 = range extent of 20 strongest scatterers
- ft2 = cross-range extent of 20 strongest scatterers
- ft3 = ft1\*ft2 (= area of the “minimum bounding rectangle” (MBR))
- ft4 = mean/std.dev.(total power|MBR)
- ft5 = (powersum 10 strongest scatterers) /powersum(MBR)
- ft6 =  $\log_{10}(p_{\max}(1)/p_{\max}(5))$  (ratio between strongest and 5<sup>th</sup> strongest scatterer within the MBR)
- ft7 =  $\log_{10}(p_{\max}(1)/p_{\min})|_{\text{MBR}}$  (ratio between strongest and weakest scatterer within the MBR)
- ft8 =  $\max(p_{vv}/p_{vh})|_{\text{dB}} - \min(p_{vv}/p_{vh})|_{\text{dB}}$  (span of parallel/cross channel separation)
- ft9 =  $\text{slope}(p_{\max} \text{ vs. dif})|_{\text{dB}}$
- ft10 =  $\text{shift}(p_{\max} \text{ vs. dif})|_{\text{dB}}$

Geometric  
Statistical  
Structural  
polarimetric

# Classification methodology and results

# Target visibility

Each object was visible in 6-7 consecutive RDMs:

RDM\Tgt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12	♦																
13	♦	♦															
14	♦	♦	♦	♦													
15	♦	♦	♦	♦	♦		♦										
16	♦	♦	♦	♦	♦	♦	♦										
17	♦	♦	♦	♦	♦	♦	♦	♦		♦							
18		♦	♦	♦	♦	♦	♦	♦	♦	♦	♦						
19		♦	♦	♦	♦	♦	♦	♦	♦	♦	♦		♦				
20					♦	♦	♦	♦	♦	♦	♦	♦	♦	♦			
21					♦	♦		♦	♦	♦	♦	♦	♦	♦	♦		
22						♦		♦	♦	♦	♦	♦	♦	♦	♦	♦	
23									♦		♦	♦	♦	♦	♦	♦	
24									♦		♦	♦	♦	♦	♦	♦	♦
25												♦	♦	♦	♦	♦	♦
26												♦		♦	♦	♦	♦
27															♦	♦	♦
28																♦	♦
29																	♦

# Test feature vectors

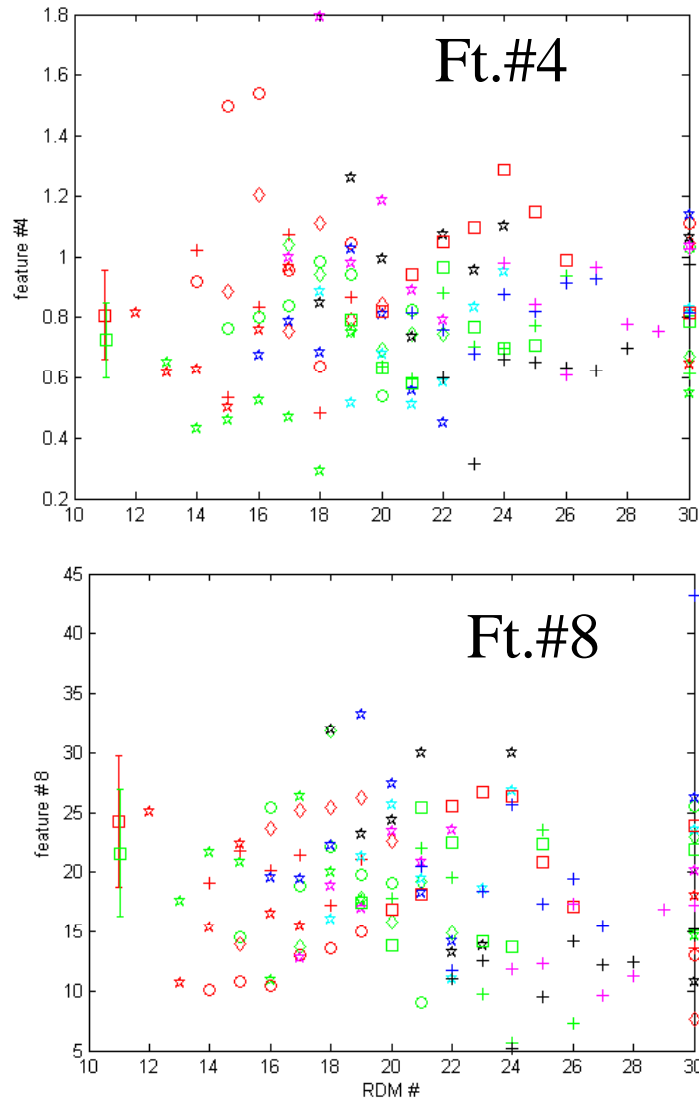
- Within each RDM, „regions of interest“ (ROIs) were defined with size (Range $\pm$ 7, Doppler $\pm$ 20)
- Within the SLC map, 17 ROIs were defined for comparison
- Test feature vectors were calculated for a total of 112+17 ROIs



# Reference Feature Vectors

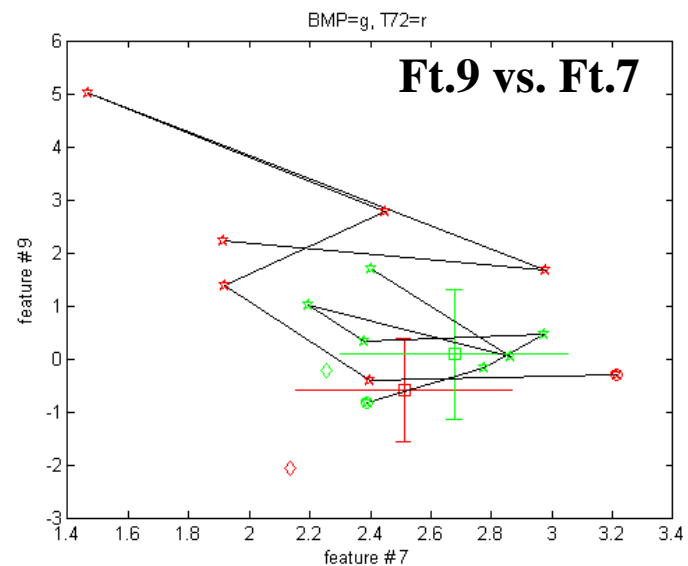
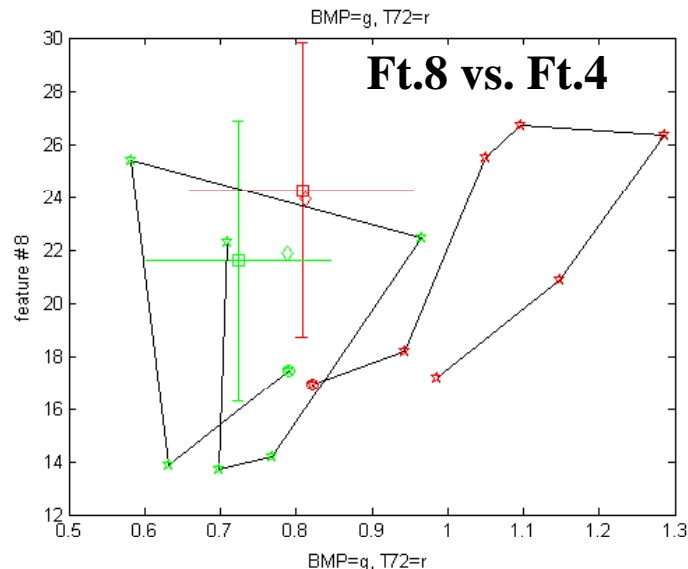
- three data sets of each vehicle were processed, namely -06, -07, -08 for the T72, and -19, -20, -21 for the BMP, resulting in 558 values per 360° aspect angle interval
- the target aspect angle is either 56° (value #87) or 236° (value #366) due to the front/rear ambiguity ⇒ extract ±10° (±16 values) around each of these two angles
- Feature references (10 each for BMP and T72) obtained by averaging 3 data sets (articulations) and 66 angular values

# Feature behaviour across RDMs



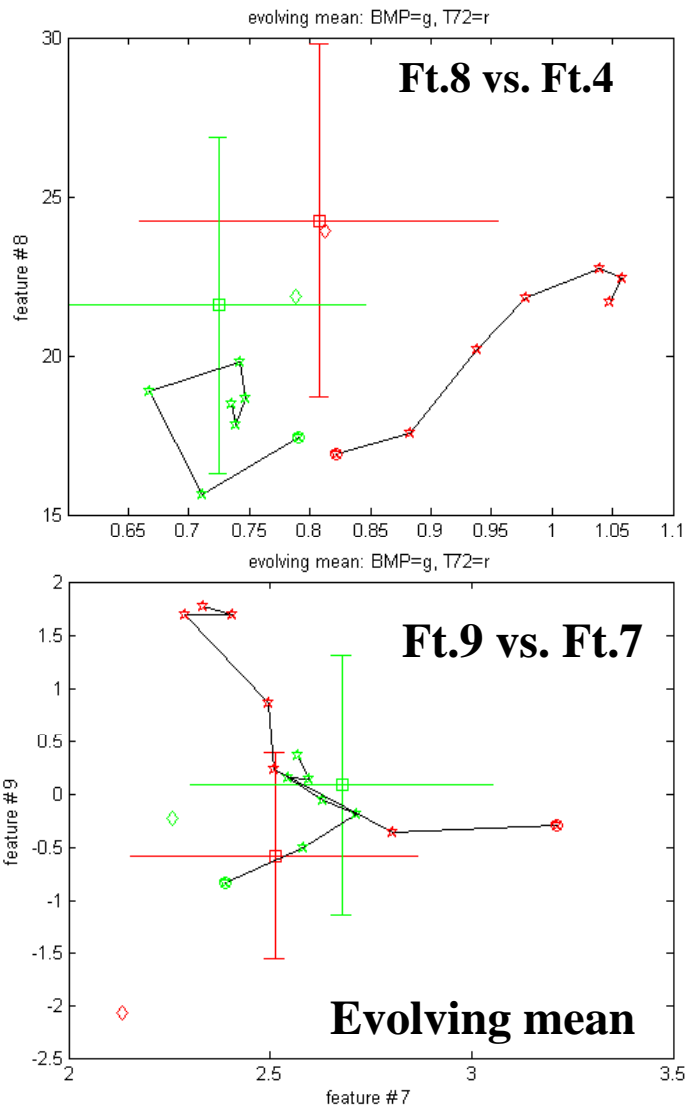
- no striking difference between the RDM case and the SLC case
- this is not only true for the bulk of values, but also for the values of individual targets (one striking exception is target #7)
- variability differs from target to target
- the range of test values is much larger than the  $\pm$ std.dev.-range of the references

# Tracks in feature space



- tracks are shown of BMP (green) and T72(red) in 2-dim feature space
- Tracks start at “o”, SLC is indicated by “◇”
- references are marked with their  $\pm$ std.dev.-error bars

# Combining consecutive RDMs

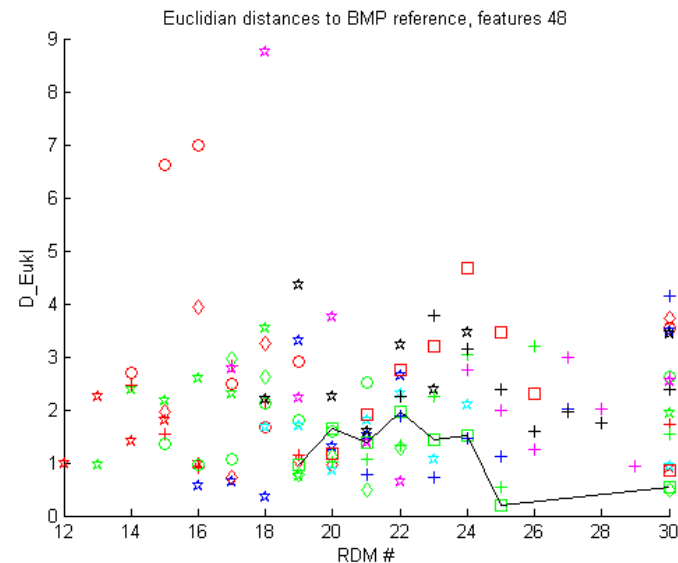
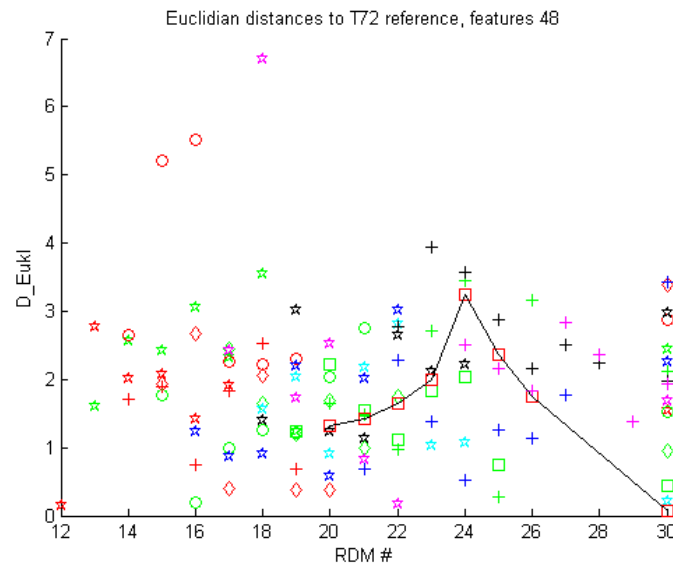


- Each RDM provides one independent opportunity per target
- Possible strong variations of test features from one RDM to the next can be mitigated by
  - „count logic“
  - „evolving mean“ (EM)

# Classification results

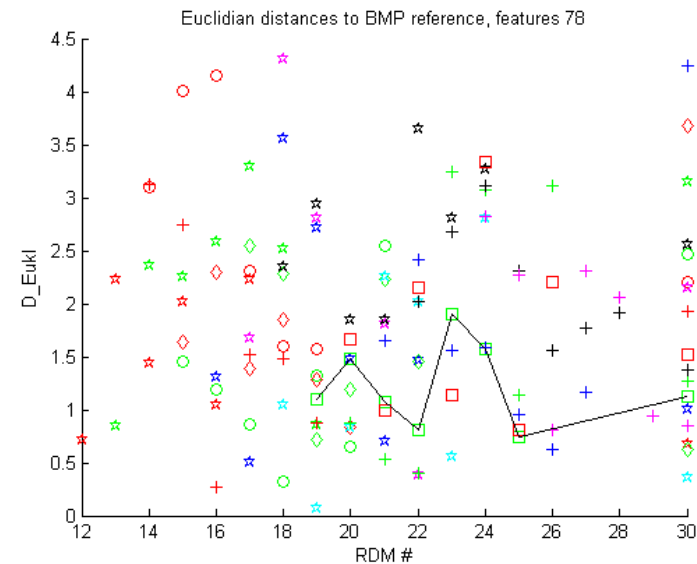
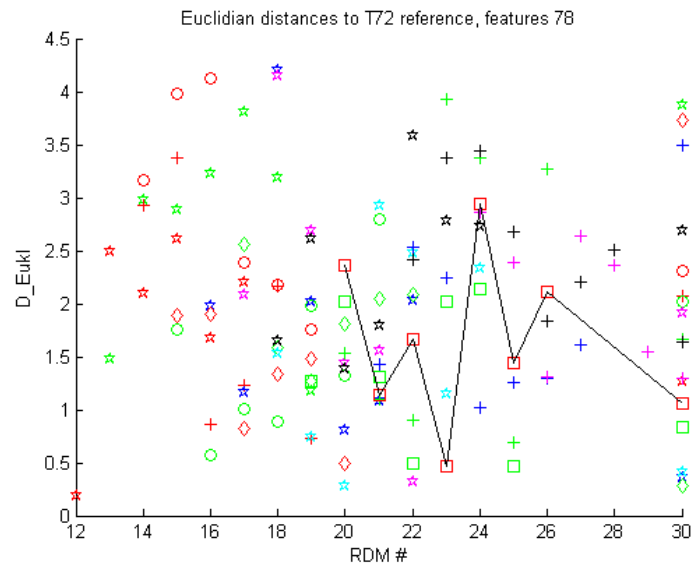
Classification is done by means of the Euclidian distance in feature space:

$$d_{eucl}(\alpha) = \sqrt{\sum_{i=1}^N \frac{(f_i(\alpha) - F_i^{ref}(\alpha))^2}{\sigma_i^2}}$$



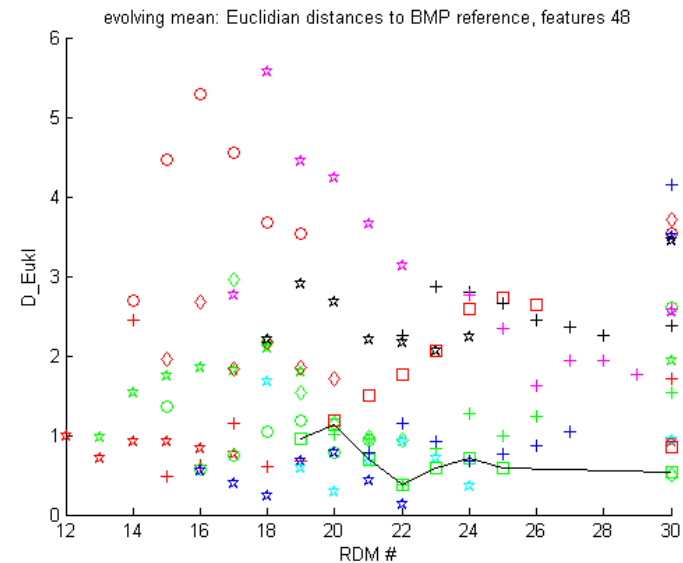
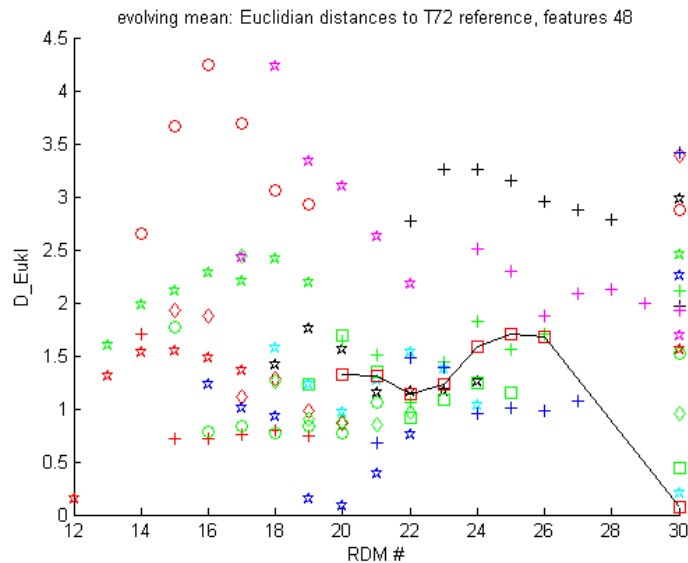
**Feature set 4&8 performs better on SLC than on RDMs**

# Classification results, cont'd



- For feature set (7&8) BMP and T72 would only reach rank 5 and 6 in SLC.
- In the RDM case, the BMP would be classified correctly for both feature sets in RDMs 24 and 25.
- The T72 only once has rank 1 (RDM #23, fts.7&8), twice rank 2 (RDM #26, fts.4&8, RDM #21, fts.7&8).

# Classification results, applying EM

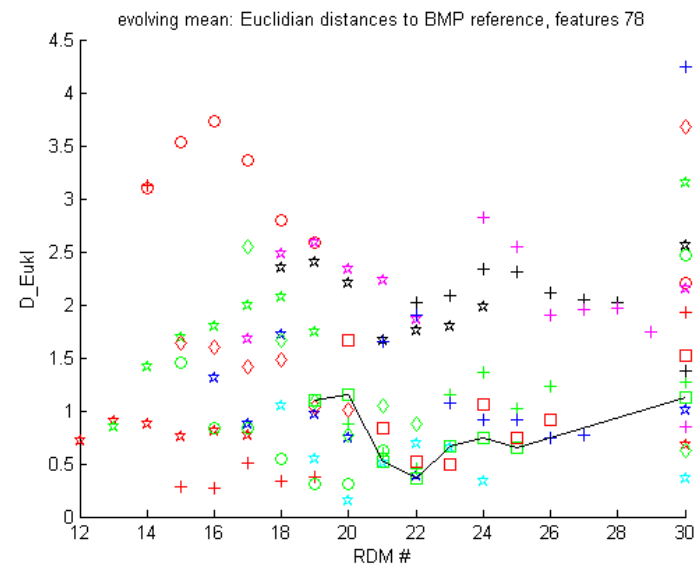
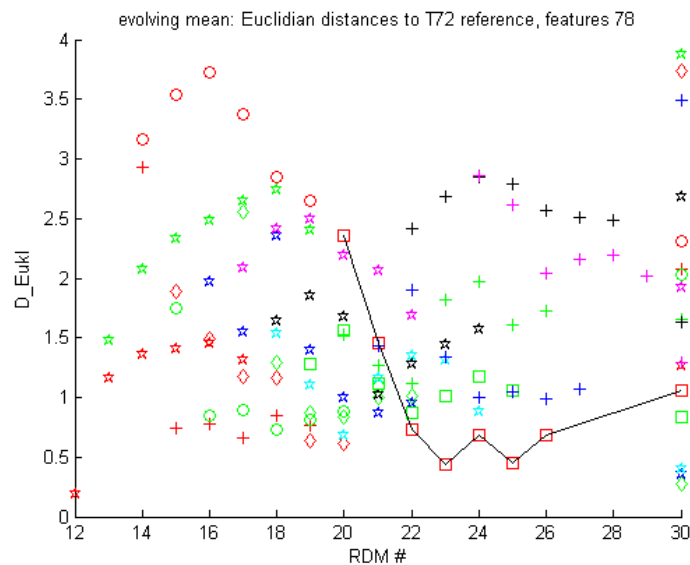


**For feature set 4&8:**

**the T72, gets no correct classification in the RDM case**

**The BMP gets rank 1 in RDMs 23 and 25, and rank 2 in RDMs 21,22,24**

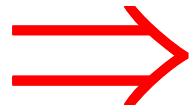
# Classification results, applying EM



For feature set 7&8:

the T72 has rank 1 in 5 out of 7 RDMs (#22-26)

the BMP gets rank 1 in 3 RDMs (21,22,25), and rank 2 in RDMs 23 and 24



the EM concept has a potential to improve the classification performance, but it depends critically on the respective set of features



# Summary and conclusions

Using a basic ATR scheme it could be demonstrated that :

- using ISAR references to recognize targets in a SAR scenario is a viable method
- RDMs and SLC ground maps produce test feature values within the same range and therefore do not show a fundamental difference in ATR performance
- the advantage of consecutive RDMs, however, lies in the possibility of combining the several looks that one gets on each target. This makes it possible to apply an additional scheme like “chain logic” or “evolving mean” and thus increase the classification performance. In the case of the “evolving mean” this could be demonstrated for certain sets of features.

# Summary and conclusions, cont'd

The “robustness” of the ATR process can be increased by:

- averaging several target articulations to obtain a target reference
- independently determining the target aspect angle thus refining the reference feature vector
- combining several independent looks from consecutive RDMs (using the “evolving mean” concept, for instance)

Over...!