Classification of Targets in SAR Images Using ISAR Data

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Classification of Targets in SAR Images Using ISAR Data

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ABSTRACT

Feature-based classification of targets in SAR images by using ISAR measurements was studied, based on polarimetric SAR and ISAR data acquired with the MEMPHIS radar system of FGAN-FHR. The data contained one T-72 battle tank, one BMP combat vehicle, and several confusers. The resolution was 75 cm. Nine features were studied of which four were analyzed: area, coefficient of variation, weighted-rank fill ratio and VV/VH ratio. Of these features the only one that resulted in certain separability was the weighted-rank fill ratio. But to classify the targets using only one feature is not reliable, especially considering the resolution. Neighbor number and HH/HV ratio were successfully used to separate the targets from natural clutter false alarms.

1.0 INTRODUCTION

Because of the growing use of unmanned aerial vehicles for reconnaissance, surveillance, and target acquisition applications, the interest in synthetic aperture radar (SAR) systems is increasing as well, mainly due to their all-weather capability. A study for the Dutch Ministry of Defense was initiated, in order to investigate the possible role for SAR imagery in ground surveillance applications. This study is performed within the framework of the NATO/SET-069 research group. With the participation in the SET-069 group, TNO gained access to high resolution SAR and ISAR data of several targets and scenes. These data are maintained by the SET-069 group in order to study automatic target recognition techniques making use of millimeter wave imagery.

FGAN-FHR contributed to the data set with data from the MEMPHIS Ka-band radar system, [1]. In 2002 MEMPHIS was used in an airborne side-looking configuration to record SAR images of the Greding proofing ground in Germany. During these experiments various targets were lined up, among which, one T-72 and one BMP. Four images were recorded from four perpendicular flight directions. A subset of one can be seen in Fig. 2a. The SAR data are fully polarimetric; HH, HV, and VV polarization channels are available. The depression angle is 20°. In 2004 MEMPHIS was used for tower/turntable ISAR measurements, [2]. Measured were a BMP infantry fighting vehicle, a ZSU-23-4 self-propelled antiaircraft gun, and a T-72 main battle tank. The ISAR data are VV and VH polarized. The depression angle is 17°.

Looking at the FGAN data, the idea came into being to set up a classifier to classify the T-72 and the BMP in the SAR data using their ISAR measurements as training data. Several techniques exist, such as feature based, [3]-[5], and template based, [6]-[7]. Due to the resolution of the SAR data (75 cm), a feature-based strategy was chosen. In this paper the FGAN SAR and ISAR data will be analyzed. Targets will be detected and the relevant target features will be extracted. Subsequently, the features will be compared to the features extracted from reconstructed ISAR images of the T-72 and the BMP, in order to pinpoint these vehicles in the SAR image.

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Raw SAR image

| Speckle Reduction | → | Area of Interest Selection | → | CFAR Detection | → | Cluster Operation | → | Clip Extraction |

| Classification | ← | Feature Extraction | ← | Aspect Angle Estimation | ← | Threshold Detection | ← | False Alarm Reduction |

| Feature Extraction | ← | Threshold Detection | ← | ISAR Image Reconstruction | ← | ISAR Database Search Operation |

User input

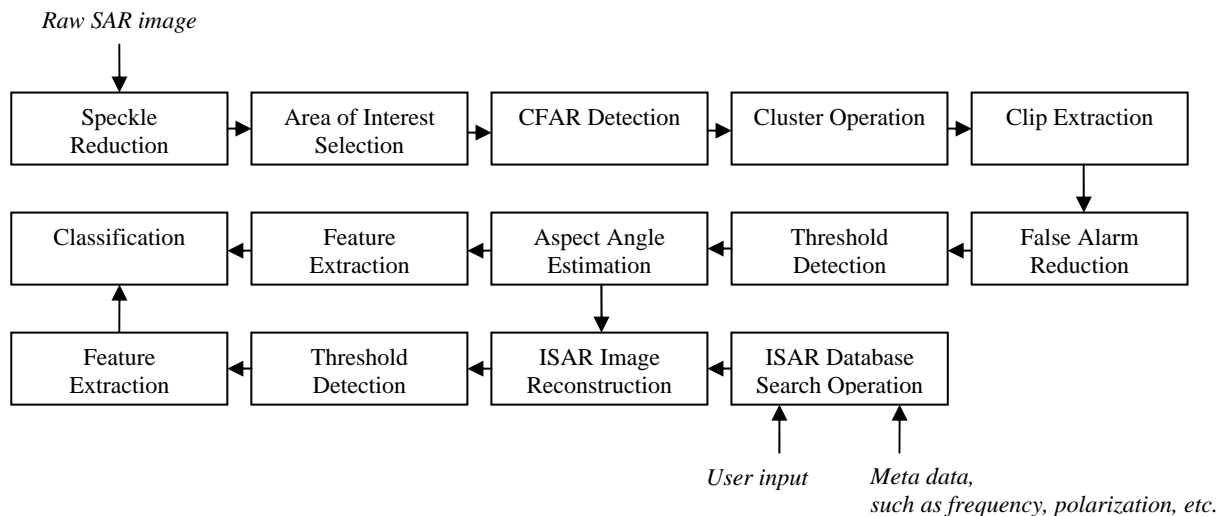Meta data, such as frequency, polarization, etc.

Figure 1: Schematic overview of the classifier.

In section 2, the complete classifier processing chain will be discussed in detail. In the following section, the database search operation and the ISAR image reconstruction will be described. In section 4, the relevant target features will be discussed and the classification will be done. Finally, the conclusions will be summarized in section 5.

2.0   SAR DATA PROCESSING OVERVIEW

The complete processing chain of the classifier is schematically shown in Fig. 1. The upper part deals with the processing of the SAR images and starts with a Polarimetric Whitening Filter (PWF) in order to reduce speckle, [8]. Subsequently, the area of interest is manually selected from the speckle-filtered image. The area of interest is presented in Fig. 2a.

In the next step, a two-dimensional Constant False-Alarm Rate (CFAR) detector is applied to the area of interest, [9]. The classical CFAR detector was implemented. The detected pixels are depicted in Fig. 2b. Subsequently, the detected pixels are clustered, see Fig. 2c. Clusters incorporating less than three pixels are rejected. Next, image clips enclosing the individual clusters are extracted. The image clips are indicated in Fig. 2d.

As can be seen in Fig. 2d, many false alarms due to natural clutter are present. Therefore, the clips containing only natural clutter should be marked and discarded in order to reduce the number of false alarms. From Fig. 2d it is clear that some clips can be easily rejected based on their geometrical extend. Smaller clips that are instigated by natural clutter should be marked by making use of other target characteristics, such as the *neighbor number* and the *HH/HV ratio*, [4]. These target characteristics proved to be the most robust features to separate target-clusters from clusters instigated by natural clutter:

- The neighbor number is the number of neighbor pixels of each detected pixel normalized to the total number of detected pixels. This feature indicates how well the detected pixels are lumped together. For natural clutter the neighbor number is relatively low, since detections due to natural clutter are usually widespread. For manmade objects, the detections are generally close together, resulting in a relatively high neighbor number.

- The HH/HV ratio is calculated by dividing the power of the detected pixels in the HH image by the power of the detected pixels in the HV image. Broadly speaking, backscatter from natural clutter has a large cross-polarized component, resulting in a relatively low HH/HV ratio. The performance of this feature is optimal if the data are properly calibrated.

The described target features are used to reduce the number of false alarms. The remaining image clips are indicated in Fig. 2e. As can be seen, the number of false alarms is reduced significantly. Nevertheless, two clusters outside the target area are still marked as target-clusters. Some of these clusters are probably due to other man-made objects than the targets; some buildings are present around the target area, see Fig. 3.

In the following processing steps, a threshold detector is applied to the remaining image clips, and the aspect angle of the targets is estimated by making use of a Radon transform, [4]-[5]. When the aspect angle is known, an ISAR image at a comparable aspect angle can be reconstructed. Finally, relevant target features are extracted from the target-clusters, which are fed to the classification procedure. The features and the target classification will be discussed in detail in section 4.

3.0 ISAR IMAGE RECONSTRUCTION

The ISAR data are put in a database. With the aid of the meta-data of the SAR images (e.g. the frequency, the polarization, and the depression angle), a search operation is applied to the database in order to find the corresponding ISAR data. By making use of the estimate of the aspect angle obtained with the Radon transform, the ISAR image is reconstructed.

The ISAR data are in the frequency domain, the spatial domain image can be reconstructed by performing a 2-dimensional inverse Fourier transform on the data, [10]. Prior to the Fourier transform, I and Q imbalances are removed, and a Hamming windowing function is applied in order to reduce the side lobe level. The range and azimuth resolution of the reconstructed images are given by:

$$\delta r = \frac{c}{2B},\tag{1}$$

and:

$$\delta Az = \frac{\lambda}{2\Delta\theta},\tag{2}$$

respectively, where c is the speed of light, B is the bandwidth, λ is the carrier wavelength, and $\Delta\theta$ is the aspect angle interval that is processed. The resolution of the reconstructed ISAR images is matched to the resolution of the SAR image (i.e. 75 cm).

As for the SAR image clips, a threshold detector is applied to the reconstructed ISAR images and relevant features are extracted. Subsequently, the target features are fed to the classification procedure.
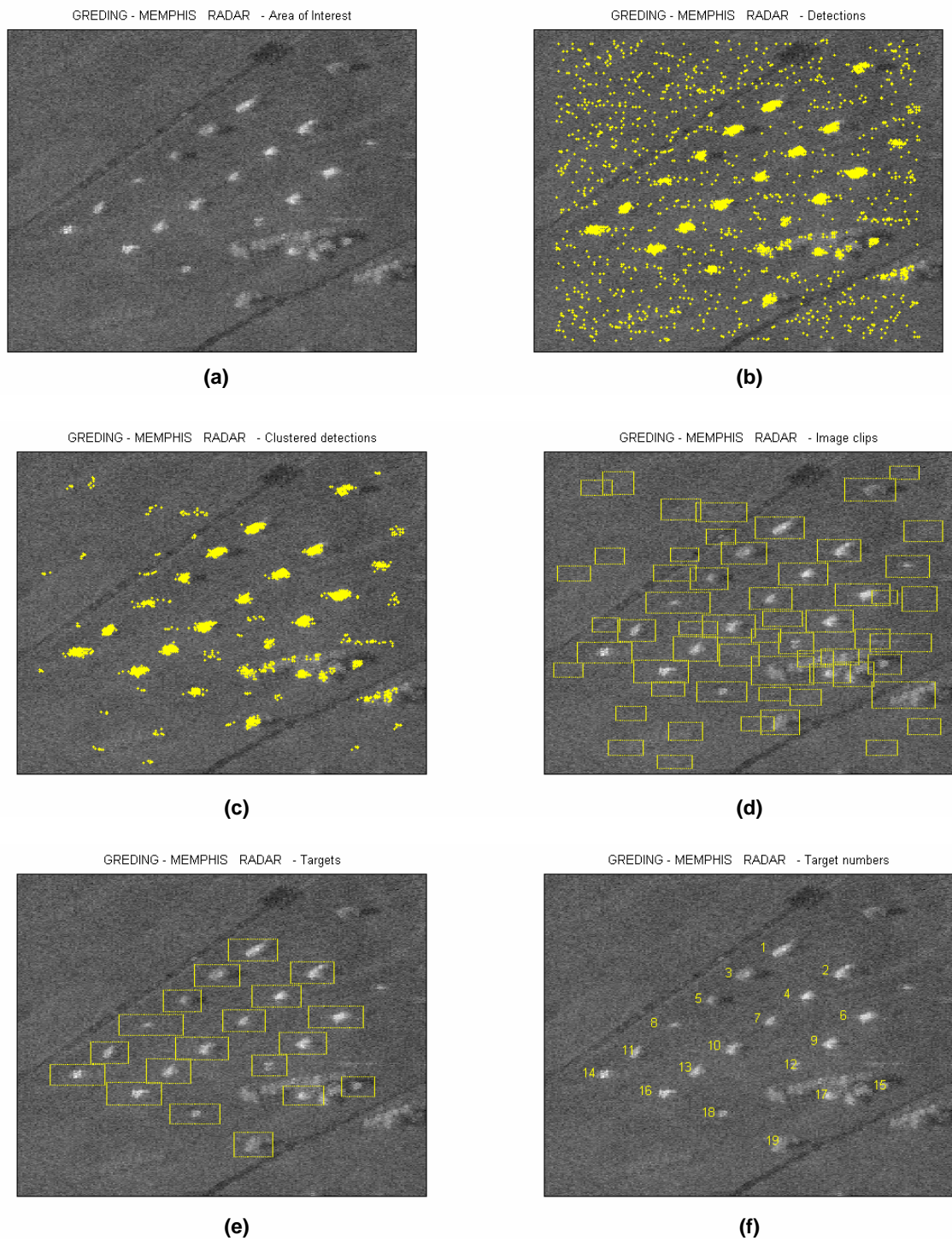
Figure 2: The area of interest (a), the detected pixels (b), the clustered pixels (c), the image clips enclosing the clusters (d), the clips marked as enclosing target-clusters (e), and the numbers of the target-clusters (f).

Figure 3: A picture of the T-72 at the Greding site. Note the building in the background.

4.0 TARGET CLASSIFICATION

For the classification procedure nine well-described features are considered, [4]:

- Mean power of the detected target pixels. Since the SAR data and the ISAR are not calibrated with respect to each other, thus in this case this feature is not suited for a quantitative comparison.

- Coefficient of variation (CVAR): the normalized variance of the power of the detected target pixels:

$$CVAR = \frac{\sigma}{\mu}. \tag{3}$$

- The *weighted-rank fill ratio* (WFR*n*), which is defined as the ratio of the power of the *n*% brightest target pixels and the total power of all target pixels.

- The area, which is defined as the number of detected target pixels. Obviously, this feature is a measure for the geometric extend of the target. This feature may be useful to reject targets that are neither the BMP nor the T-72. It is not suited to separate the BMP from the T-72, since these vehicles are comparable in size.

- The *neighbor number* and the *lacunarity index,* which are measures for the lumpiness and the regularity of the texture of the target pixels respectively. Since the resolution is rather poor, these features are not expected to have a strong separative capacity, which is confirmed in [5].

- The *HH/HV ratio* (or *VV/VH ratio*), this feature was already defined in section 2.

- *Odd bounce* and e*ven bounce*, designating the amount of odd bounce and even bounce scattering. These features require fully polarimetric data in order to be calculated (note that just the VV and VH channels are available for the ISAR data).

Finally, by summarizing the above, only the CVAR, the WFR, the area, and the VV/VH ratio are believed to be relevant target features.

RECONSTRUCTED ISAR IMAGE - T72

RECONSTRUCTED ISAR IMAGE - BMP

(a)   **(b)**
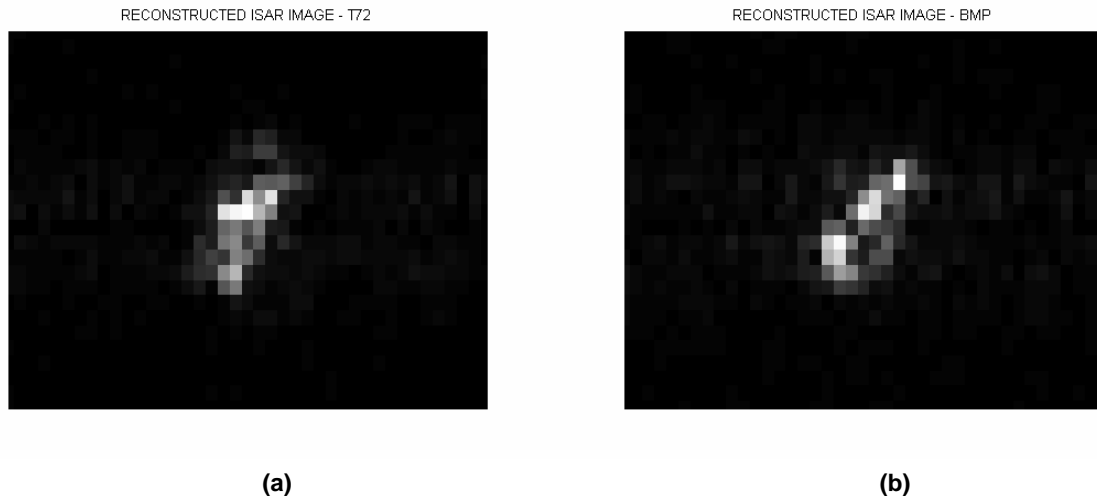
Figure 4: Examples of reconstructed ISAR images of the T-72 (a) and the BMP (b) at a depression angle of 40º.

Target classification is performed by plotting the relevant features in scatter diagrams. The scatter diagrams are composed by reconstructing several ISAR images. For an interval of 40° around the estimated aspect angle, ISAR images are reconstructed for every 2°. It must be noted that the Radon transform did not result in a reliable estimation of the aspect angle of the targets in the clips, contrary to [4]-[5]. But this is due to the lower resolution of the SAR image (75 cm). Therefore, the aspect angle was estimated manually at 40º from head-on. Two examples of reconstructed ISAR images are presented in Fig. 4. Subsequently, relevant features are extracted from each ISAR image and are plotted in the scatter diagrams, see Fig. 5. The numbers in the scatter diagrams refer to the target-clusters in the SAR image, see Fig. 2f.

In Fig. 5a a scatter diagram of the VV/VH ratio versus the CVAR is shown. The average VV/VH ratio is rather low, despite the fact that the data was calibrated [1]. Generally man-made objects return significantly more VV than VH. Another thing is that the VV/VH ratio does not show much separability for both targets. The scatter diagram also shows that the CVAR values for the T-72 and the BMP are mixed up too. Thus the CVAR feature is not suited to separate the T-72 from the BMP either. It is clear that, based on this scatter diagram, it cannot be decided which detected targets are the T-72 and BMP.

The scatter diagram of the WFR10 versus the number of detected pixels is presented in Fig. 5b. The values of the area of the T-72 and of the BMP are comparable, as was expected. Therefore, the area feature is indeed not suitable to make a separation between the T-72 and the BMP. The WFR10 is the only feature that shows some separability and seems to be the most appropriate to classify the targets. But to classify the targets based on just a single feature is highly unreliable, [5], especially considering the resolution. Therefore, it is unable to pronounce upon which target is the T72 and which the BMP.
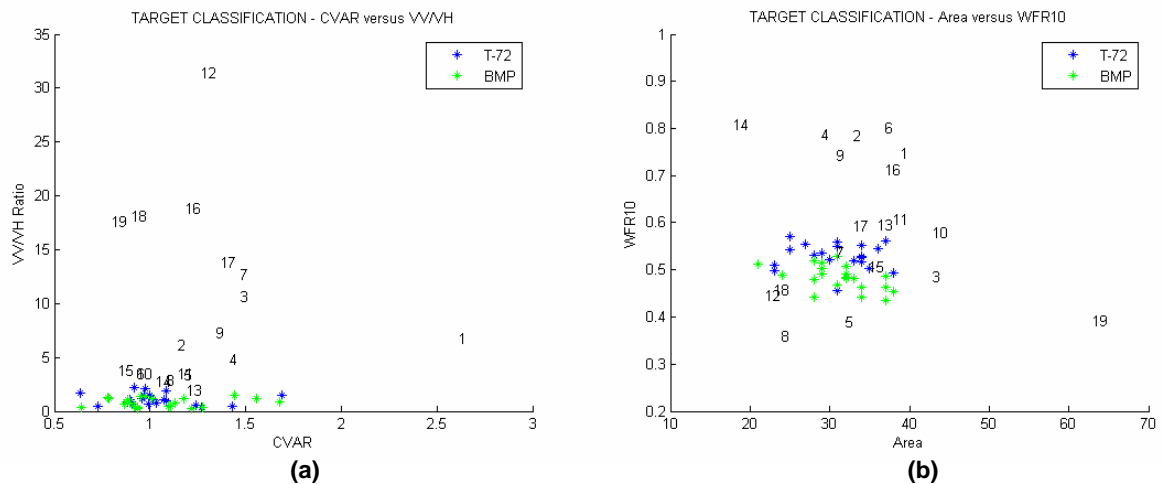
Figure 5: Scatter plots of the relevant target features; the CVAR versus the VV/VH ratio (a) and the area versus the WFR10 (b). The numbers refer to the target-clusters in the SAR image, see Fig. 2f.

5.0 SUMMARY AND CONCLUSIONS

In this paper a classifier was presented to classify targets in SAR images by using ISAR measurements and a feature based strategy. The classifier was applied to 75 cm resolution polarimetric SAR and ISAR data of one T-72, one BMP and several confusers, acquired by FGAN-FHR using their MEMPHIS radar system. The goal was to point out the T-72 and BMP in the SAR data. Due to the low resolution a template-based strategy was expected to be unsuccessful. The processing included speckle filtering, CFAR detection, clustering, false alarm reduction, aspect-angle estimation, feature extraction and finally classification.

The number of false alarms was reduced by making use of the neighbor number and HH/HV ratio features. These features proved to be very robust target features to separate target-clusters from clusters due to natural clutter.

For the classification process, nine features were studied of which four were further analyzed: area, coefficient of variation, weighted-rank fill ratio and VV/VH ratio. Of these features the only one that resulted in certain separability was the weighted-rank fill ratio. But to classify the targets using only one feature is not reliable, especially considering the resolution. Therefore, it is not feasible to pronounce upon which target is the T-72 and which one is the BMP.

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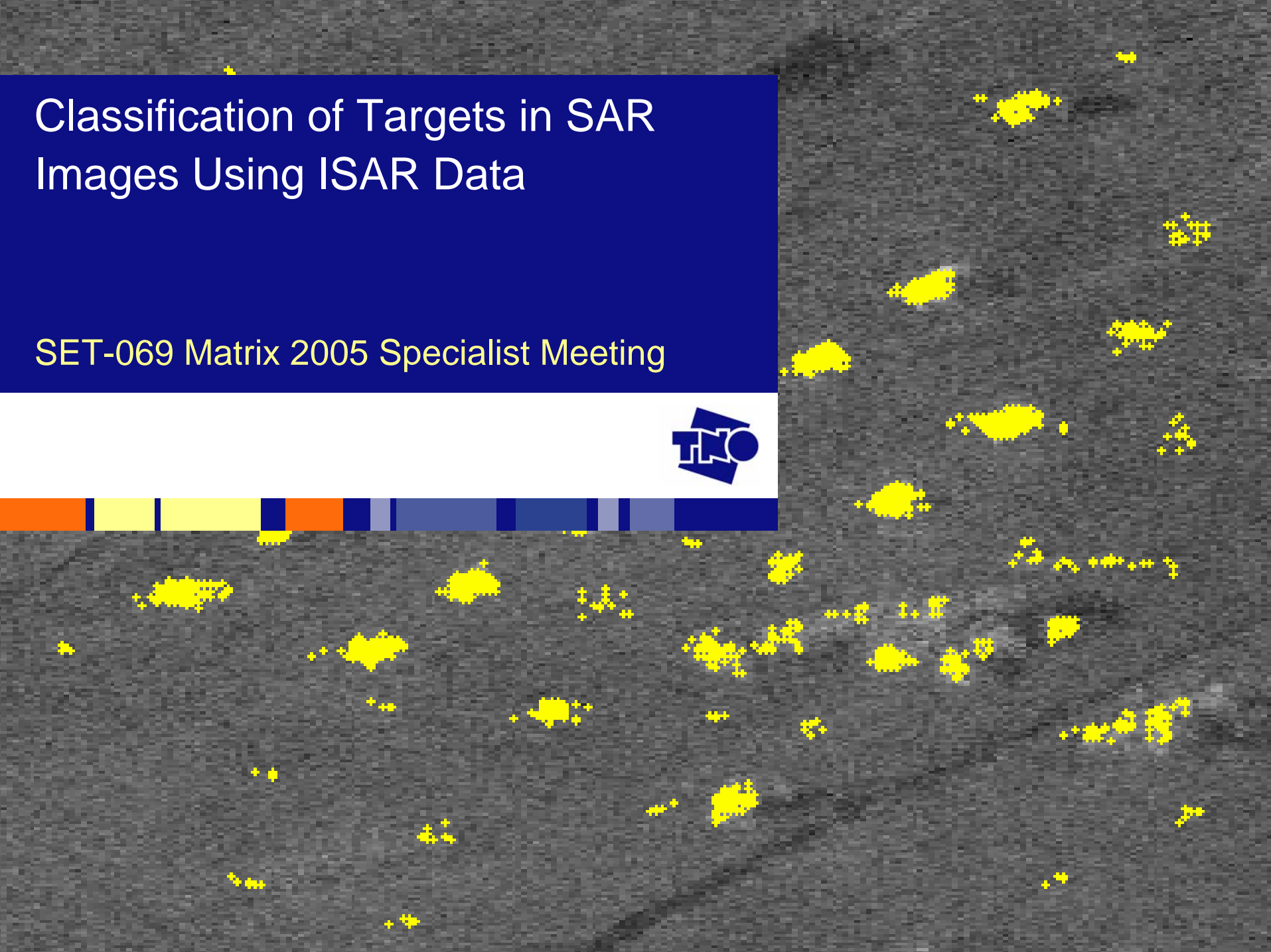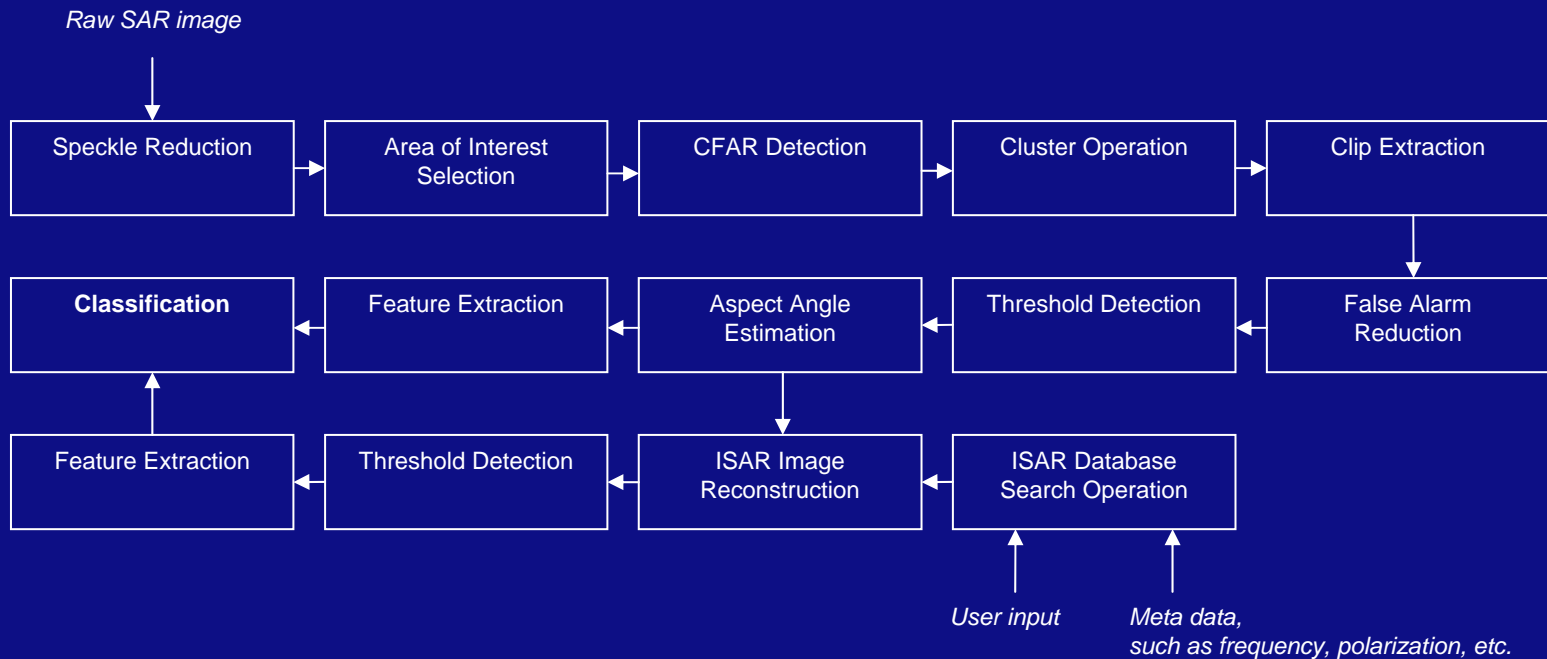
Contents

- SAR Data Overview
- Classifier Processing Chain
- SAR Image Processing
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- ISAR Image Reconstruction
- Classification
- Summary and conclusions

SAR Data Overview

- SAR images of the Greding proofing grounds
- Several targets, one T-72 and one BMP

- FGAN-FHR Ka-band MEMPHIS radar system
- Four perpendicular flight directions
- Fully polarimetric: HH, HV, VV
- Depression angle 20°
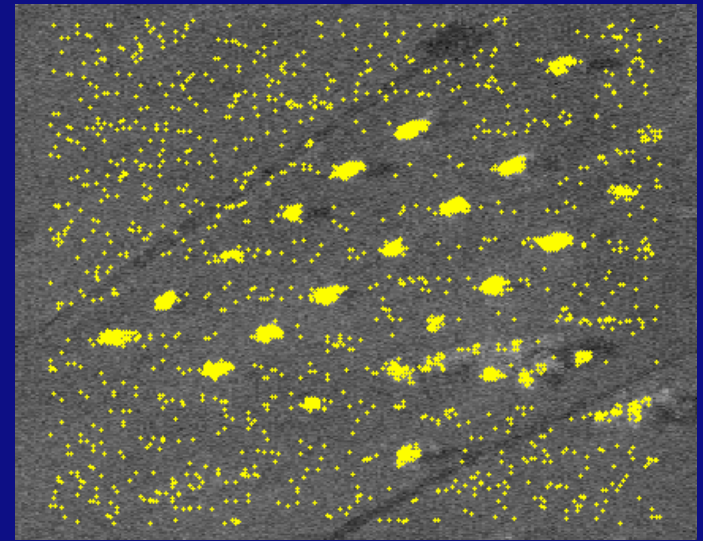- Resolution 75 cm

Classifier Processing Chain

Raw SAR image

Speckle Reduction	→	Area of Interest Selection	→	CFAR Detection	→	Cluster Operation	→	Clip Extraction

Classification	←	Feature Extraction	←	Aspect Angle Estimation	←	Threshold Detection	←	False Alarm Reduction

Feature Extraction	←	Threshold Detection	←	ISAR Image Reconstruction	←	ISAR Database Search Operation

User input

*Meta data,
such as frequency, polarization, etc.*

Classifier Processing Chain

Area of interest

Detections

- Speckle-filtered image
- Polarimetric Whitening Filter

- Classical CFAR detector
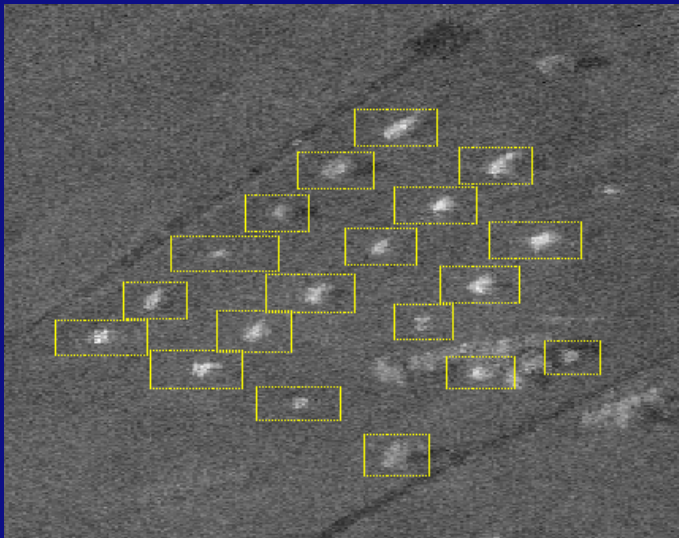
Classifier Processing Chain

Clustered Detections
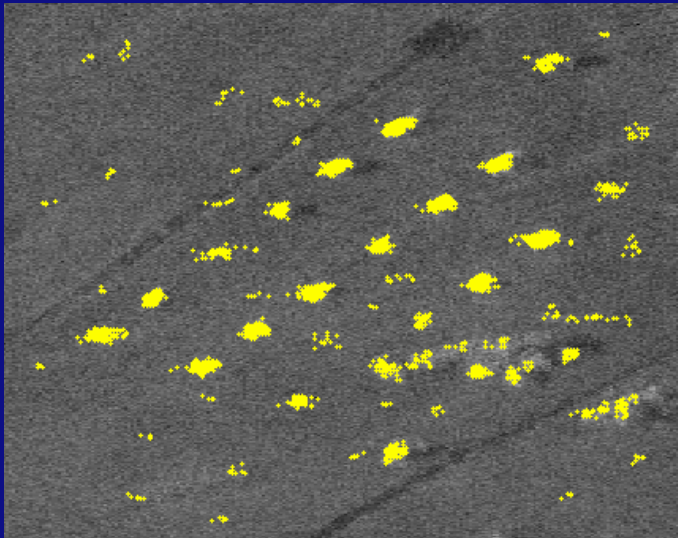
Image Clips
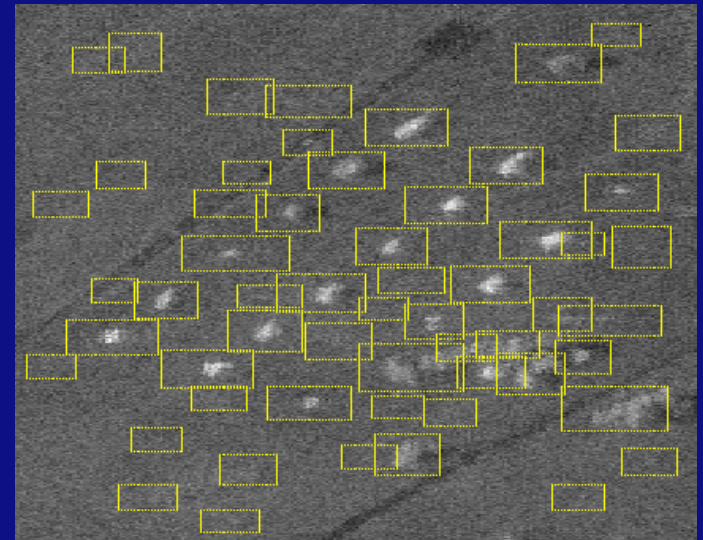
- Clusters < 3 pixels are discarded

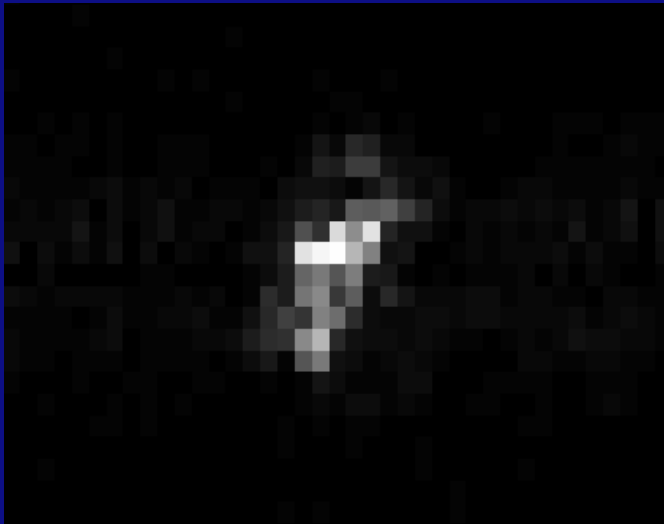# Classifier Processing Chain

Targets

Feature extraction
Classification

- False alarm reduction,
- based on *neighbor number* and
  HH/HV ratio features

ISAR Database Overview

- Tower/turntable ISAR data
- T-72, BMP, and ZSU-23-4

- FGAN-FHR Ka-band MEMPHIS radar system
- VV and VH channels
- Depression angle 17°

ISAR Image Reconstruction

ISAR Image T-72

⟹ Feature extraction
Classification

- Resolution matched to SAR image (75 cm)
- Aspect angle estimated from SAR image (40°)
- I and Q imbalances removed
- 2D Hamming window
- 2D IFFT

Classification

- Feature-based
- Nine features were investigated
- Four relevant features used:
  - Area
  - Coefficient of variation
  - Weighted-rank fill ratio
  - VV/VH ratio
- Not used:
  - Mean power (cross calibration)
  - Neighbor number (resolution)
  - Lacunarity index (resolution)
  - Percent even and odd (not fully polarimetric)

- ISAR images every 2° in an interval of 40° around estimated aspect angle
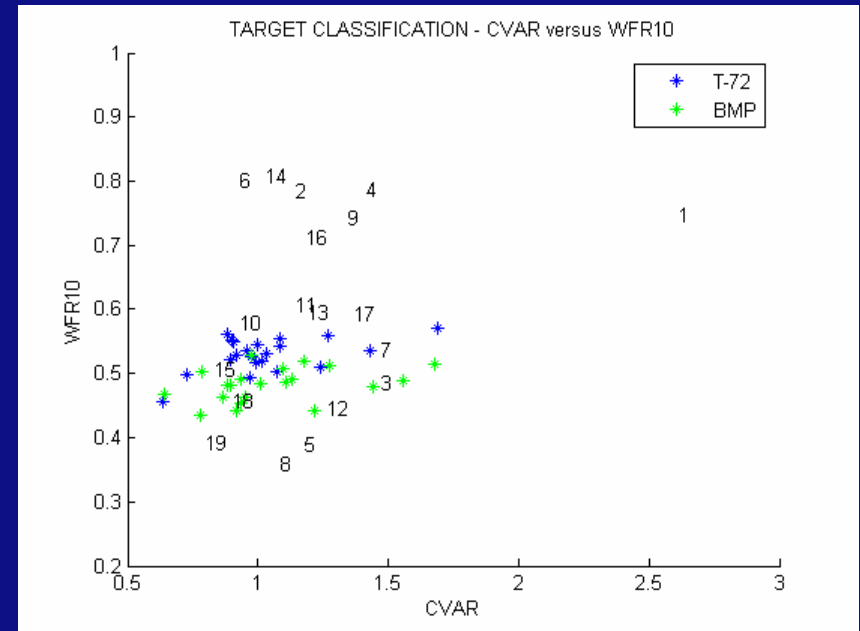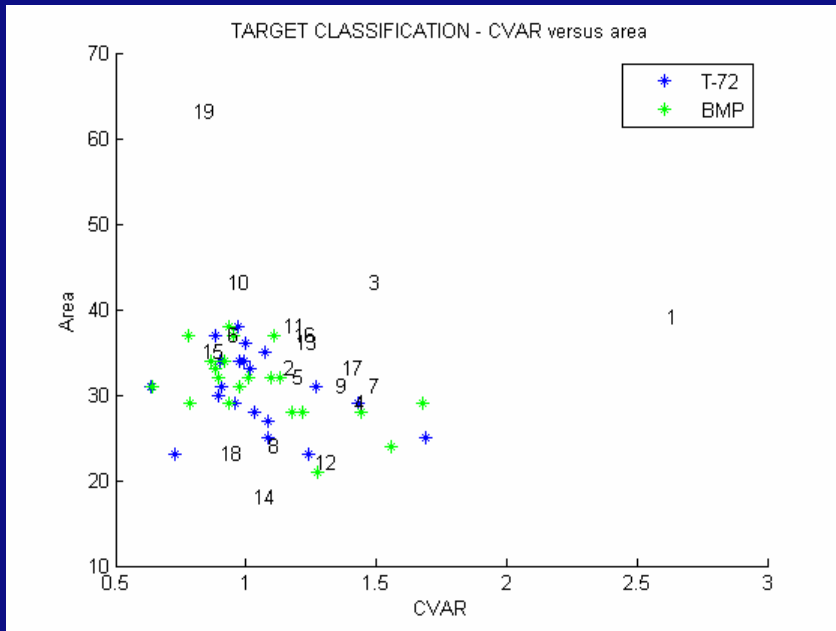- Numbers refer to targets

Scatter Diagrams (1)

Classification of Targets in SAR Images Using ISAR Data

Oberammergau, 10 May 2005
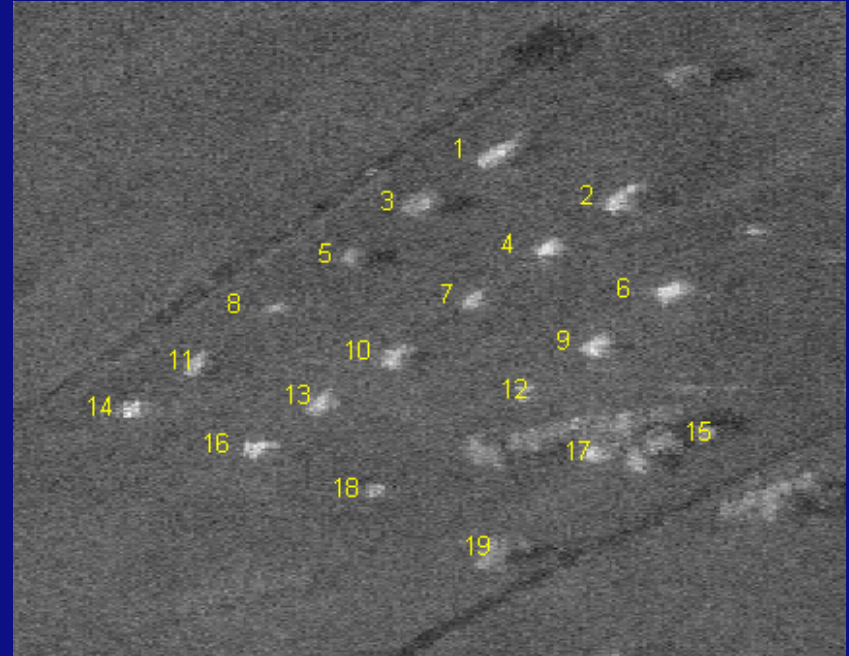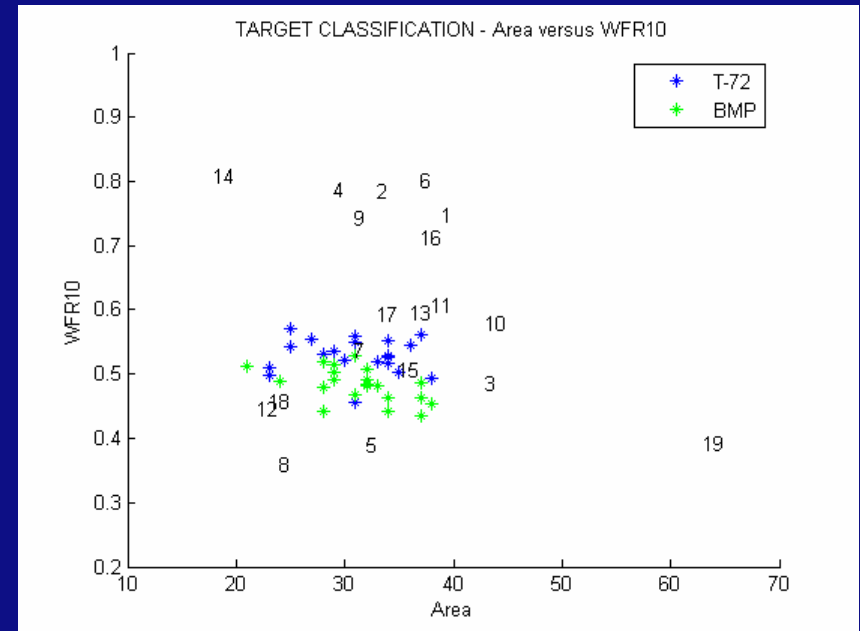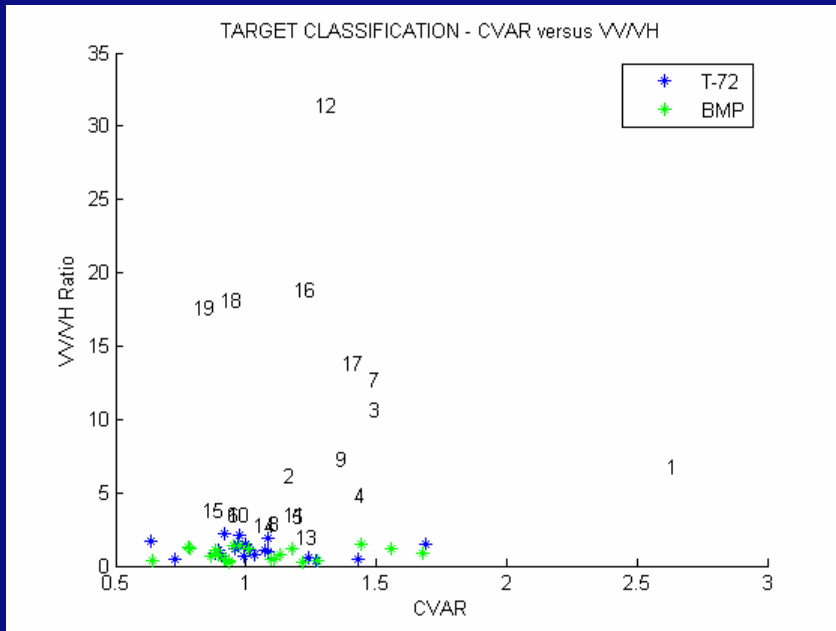
Scatter Diagrams (2)

Summary and conclusions

- Classification of targets in SAR imagery using ISAR training data
- Based on 75 cm resolution MEMPHIS data (FGAN-FHR)

- False alarm reduction successful
    - based on neighbor number, HH/HV ratio

- Nine features were investigated, four relevant features used
    - area, CVAR, WFR10, VV/VH ratio

- Only WFR10 resulted in certain separability
- However, classification based on single feature unreliable