Detection and recognition of vehicles in high-resolution SAR imagery

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ABSTRACT

Designing SAR sensors is an extremely complex process. Thereby it is very important to keep in mind the goal for which the SAR sensor has to be built. For military purpose the detection and recognition of vehicles is essential. To give recommendations for design and use of SAR sensors we carried out interpreter experiments. To assess the interpreter performance we measured performance parameters like detection rate, false alarm rate etc. The following topics were of interest:

- How do the SAR sensor parameters bandwidth and incidence angle influence the interpreter performance?
- Could the length, width and orientation of vehicles be measured in SAR-images?
- Which information (size, signature ...) will be used by the interpreters for vehicle recognition?

Using our *SaLVe* evaluation testbed we prepared lots of images from the experimental SAR-system DOSAR (EADS Dornier) and defined several military interpretation tasks for the trials. In a 4 weeks experiment 30 German military photo interpreters had to detect and classify tanks and trucks in X-Band images with different resolutions. To accustom the interpreters to SAR image interpretation they carried out a computer based SAR tutorial. To complete the investigations also subjective assessment of image quality was done by the interpreters.

Keywords: SAR image interpretation, sensor evaluation, image quality, interpreter experiments

1 INTRODUCTION

Over the past years remote sensing by airborne and spaceborne sensors is booming intensively. Scenarios like ice monitoring, agriculture inspection and flood analysis are extended by new ones, last but not least in the military field.
With new sensors, powerful lenses and enhanced image processing imagery with high resolution and image quality are available. Due to the use of multispectral, optical, infrared and SAR sensors, imagery independent of daytime and weather conditions can be obtained. Additionally most of the sensors deliver digital image data nowadays, which have to be inspected and evaluated by human beings using computer-based tools. For this tasks image interpretation components from simple viewers up to sophisticated image interpretation with integrated image archives, GIS functionality and ATR are available.[1]
Only if imagery and image interpretation components are well adapted to the interpretation tasks an effective and efficient interpretation could be ensured. The interpretation process "sensor - image interpretation system – human being" (image chain) has to be optimized. For supporting the selection of image interpretation components evaluation procedures are necessary. For this purpose the Fraunhofer Institute for Information and Data Processing (IITB) has developed the experimental system *SaLBa+* [2] which allows to evaluate

- imagery of different sensors with different sensor parameter settings,
- interactive image interpretation components and
- ATR-algorithms for interactive image interpretation [3]

by performing interpreter experiments. The goal of our investigations was to give recommendations for SAR sensor design especially for the range of sensor parameters like incidence angle, bandwidth and resolution. In the following we describe our research concerning the influence of incidence angle and bandwidth on image quality for detection and recognition of vehicles.

2 METHODOLOGY

To assess image quality in dependence of sensor parameters we carried out interpreter experiments with 30 military interpreters. Performance parameters like detection rate, false alarm rate, recognition rate and false recognition rate were defined and measured in several trials. The imagery we used was recorded by the experimental airborne SAR system DOSAR (operated by EADS Dornier) with different incidence angles and bandwidths. High attention was paid to the training of the image interpreters. The training was done in two steps:

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1. Training with the training system *Tutor*.[4]
   With help of *Tutor* the interpreter got
   - a training in SAR techniques,
   - information about the experimental goals, sequences and set up and
   - a training with the kind of images used later in the experiments.

2. Training with the experimental set up.
   The image interpreter had to exploit images which he had been trained during his work with *Tutor.* Each interpreter got only the training images with these parameters he had later to exploit during the test phase. Within this training phase the interpreter got familiar with
   - the interaction with the exploitation system *SaLBa+*,
   - the interaction with the help system *OSHelp* and
   - the interactive exploitation of high resolution SAR images.

2.1 Training system *Tutor*

This system was developed at the IITB to teach the image interpreter in SAR techniques. Therefore both the creation of SAR images and the influence of SAR parameters onto the SAR image is explained. Also *Tutor* is used to inform the image interpreter about the experimental goals, sequences and set up.

During the experiments the image interpreter had the possibility to choose between different filtered SAR images. These kind of images were also presented during the *Tutor* training. *Tutor* works with text, animation and different image visualization techniques. Figure 1 shows screen dumps of the training system displaying an animation of SAR principles.

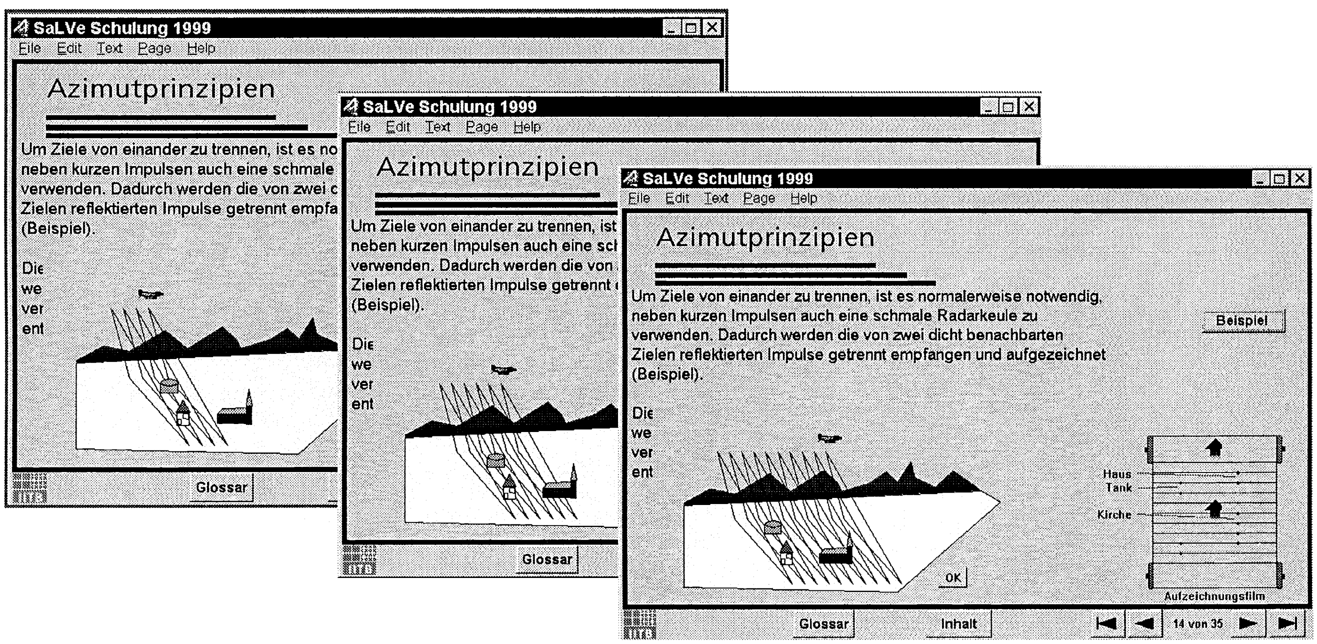

Figure 1: Demonstration of SAR principles within the system *Tutor* done by an animation.

2.2 Experimental set up

To perform the experiments an experimental set up was created (see Figure 2). The platform is a personal computer (PC) with two monitors. The software components (trial guide, *OSHelp*, *SaLBa+*) are running on PC.

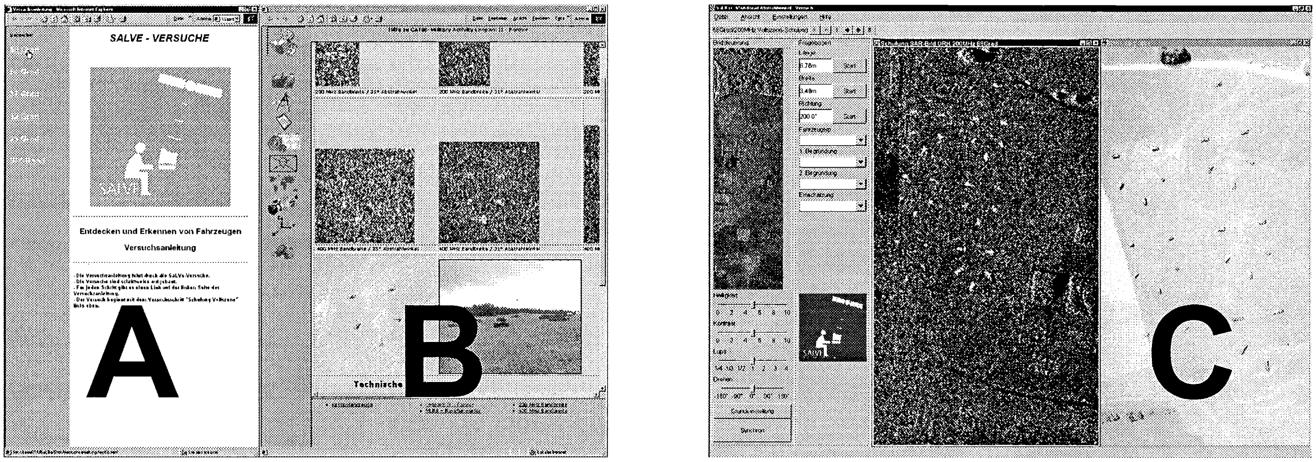

Figure 2: Screen dump of the experimental set up.

(A) The trial guide leads the image interpreter through the experiment.
(B) *OSHelp* supplies the image interpreter with SAR images and technical data from the searched vehicles.
(C) *SaLBa+* is the experimental exploitation system used for the experiments.

2.3 Experimental system *SaLBa+*

SaLBa+ is an experimental exploitation system which offers the possibility to build up, execute and analyze objective and subjective interpreter experiments in a flexible way. Figure 2 (C) and Figure 3 show the two kinds of *SaLBa+* user interfaces which were used in the described experiments. Figure 2 (C) shows a screen dump with complete images (SAR and optical), Figure 3 a screen dump with a composed image.

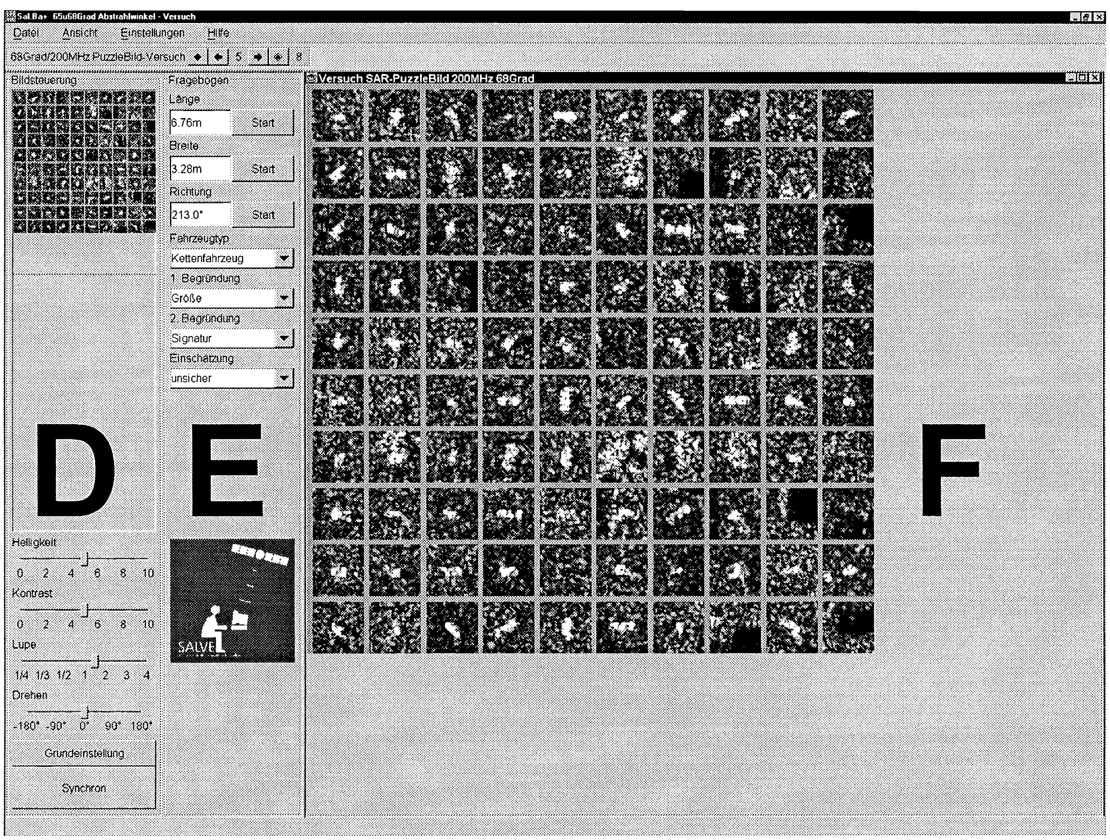

Figure 3: *SaLBa+* user interface, showing a composed image, was used for both training and test phase.

The *SaLBa+* display set up used in these experiments was structured as follows:

(D) Panel:
This panel shows an overview image of the active image in the image viewer and the image manipulation tools *brightness, contrast*, *zoom* (1/4 – 4 times) and *image rotation*. Image manipulations can be done on the active image.

(E) Questionnaire:
The questionnaire includes different functions which are applied to a detected vehicle.
- Measurement of length, width and orientation of a vehicle,
- Classification menu with the alternatives *wheeled vehicle, tracked vehicle, Leo 2, MARS, ARV*, *truck 10 to, truck 5 to, truck 2 to* and *truck 0.9 to*.
- Menus for evaluating the motivation for the exploitation decision by the interpreter, offering the following possibilities: *object size, signature, contrast* and *context*.
- A menu for rating the decision certainty by the interpreter including the items *very good, good, satisfyingly, poor, very poor*.

(F) Image viewer:
In the image viewer several images can be displayed simultaneously in different views. In these experiments each view comprised a set of 5 different images (except the view with the optical reference image!). These images were different presentations of the examined 16/32 bit deep original SAR image.

2.4 Exploitation tasks and interaction
During the experiments two kinds of tasks were formulated:

Images with 100 MHz bandwidth:
Detection of vehicles in the image. In that case only a mark had to be set on that place where a vehicle is assumed.

Images with 200 and 400 MHz bandwidth:
Measurements of the length, width and orientation of detected vehicles. Providing a value for the menu "second motivation" was optional. The answers in the questionnaire are related to the highest recognition depth.

After detecting a vehicle in an image the interpreter had to set a mark on it. Now the questionnaire was switched active and could be filled out. Marks could be set, moved, deleted and selected. The answers of the questionnaire were always related to the selected mark.

2.5 Examination of the parameters bandwidth and incidence angle
For the examination of the SAR parameters bandwidth and incidence angle five different trials were built up at the *SaLBa+* system (see Figure 4). Each trial comprised of images with nearly the same incidence angle. The trials consisted of five to seven trial steps.

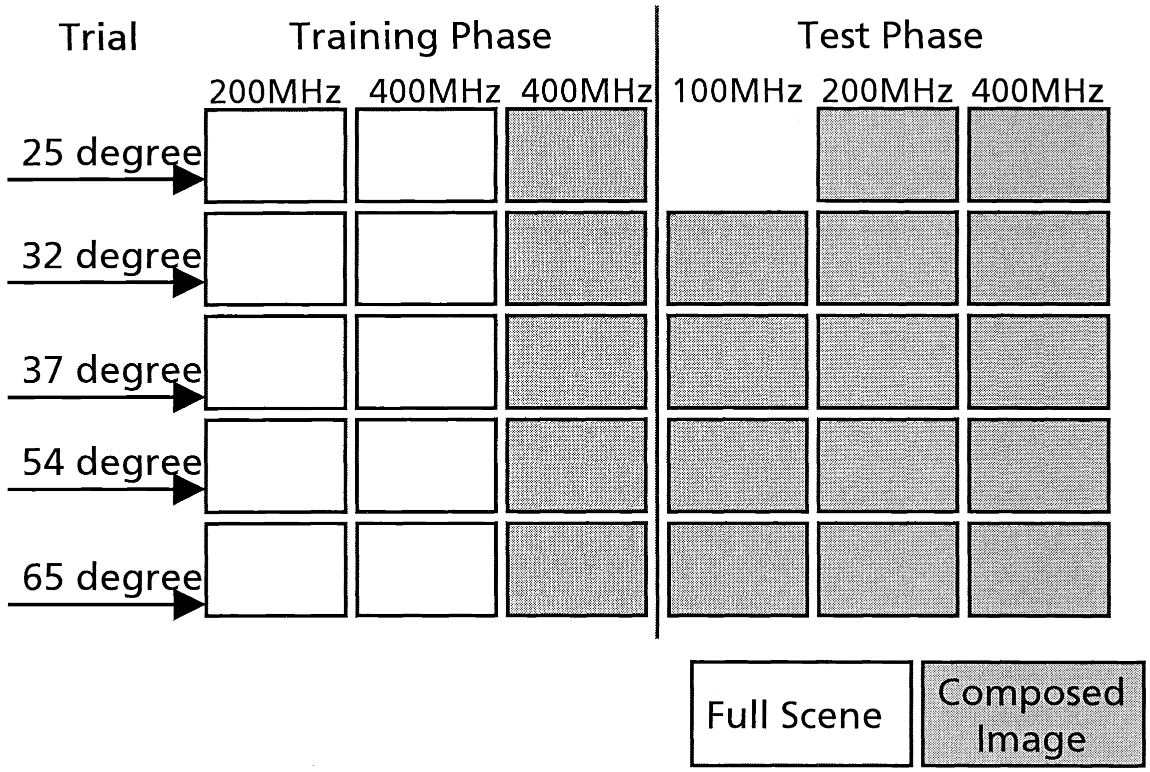

Figure 4: Trial sequences for the investigation of bandwidth and incidence angle.

Each image interpreter had to perform exact one trial. Each trial was carried out by a group of 6 image interpreters. During the first two trial steps the image interpreter had to get familiar with the SAR parameters of the current trial and the whole experimental exploitation system. Therefore he got the full scene in SAR and optical (see Figure 2 (C)). Before starting with the test phase the image interpreter had to complete a training. He got a composed image with 30 small images containing vehicles and 20 small empty images. After the exploitation of this image the interpreter could compare his results with the Ground Truth to get an imagination of his own performance.

3 IMAGE DATA SET

3.1 Image preparation

For each SAR parameter combination images from three different exactly defined scenes were available. Each scene comprised 5 or 6 groups of vehicles (see Figure 6). Each vehicle group included 5 vehicles of same type but with different orientation to the sensor (0°, 45°, 90°, 135° and 180°). One scene was used for the training, the two other were used for the test phase. Small images with a size of 100 x 100 pixels were clipped from these scenes and arranged in a composed image (see Figure 3). If a small image included a vehicle, the vehicle lied in the center of the small image.

The small images without vehicle were created as follows: 20 significant landscape positions were defined in the images of the whole scene. The requirement was that these significant landscape points appear in all images with different sensor parameters. Figure 5 shows an example of a SAR image were these landscape points are marked.

Usually the composed images included 80 small images with a vehicle inside and 20 small images without a vehicle. The composed image for the training phase included 30 images with vehicles and 20 images without a vehicle.

The arrangement of the composed image was randomized. A list of the available small images was read by a *Perl* program, the list entries were mixed and used as basis for the composed image. The random function was applied for each composed image separately, that means that each composed image was built differently.

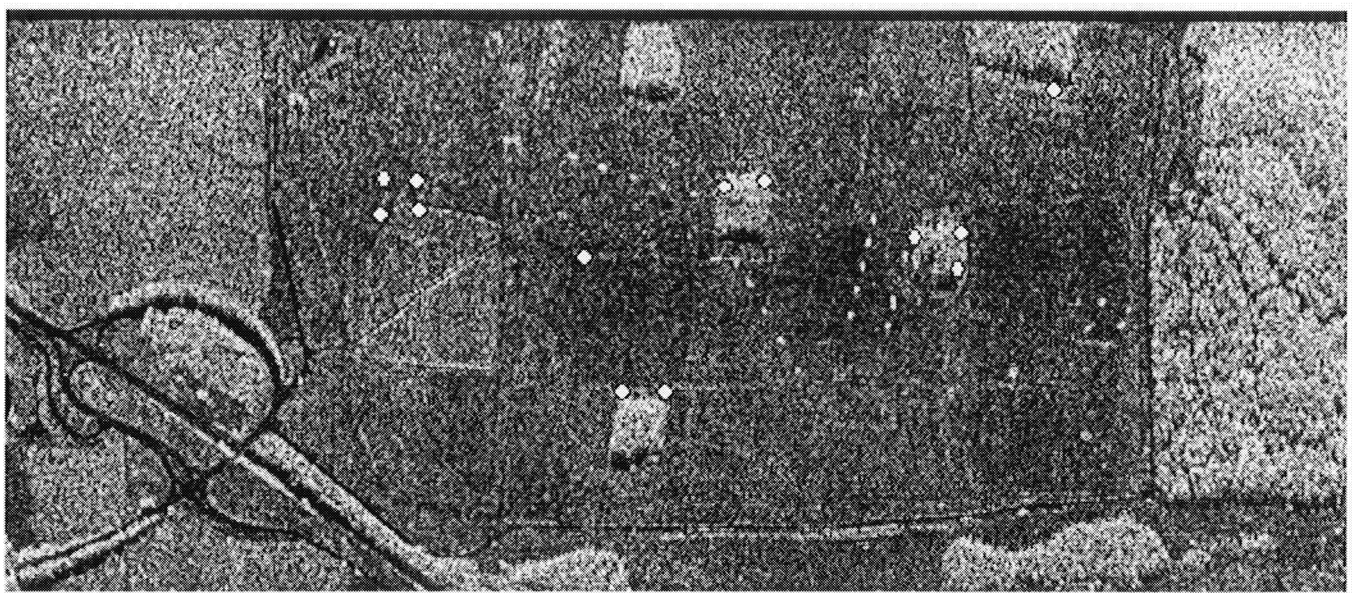

Figure 5: Whole vehicle scene with marks of the landscape points.

3.2 Image presentation : 16 to 8 bit transformations and speckle filters

The original DOSAR images have a pixel depth of 16 bit. To present images with the viewer of *SaLBa+* the images had to be reduced to 8 bit depth.

<u>16 to 8 bit transformation:</u> A logarithmic transformation was done (gamma correction). In all cases 1% of the upper values were leaded to the saturation. In the first case 0.05%, in the second case 0.5% and in the third case 1.6% of the lower values were leaded to the saturation. To simplify the notation of these different kind of transformations for the image interpreter in the experiments the gamma corrections were called bright, normal and dark filter. Figure 6 shows an image prepared with the three different transformations.

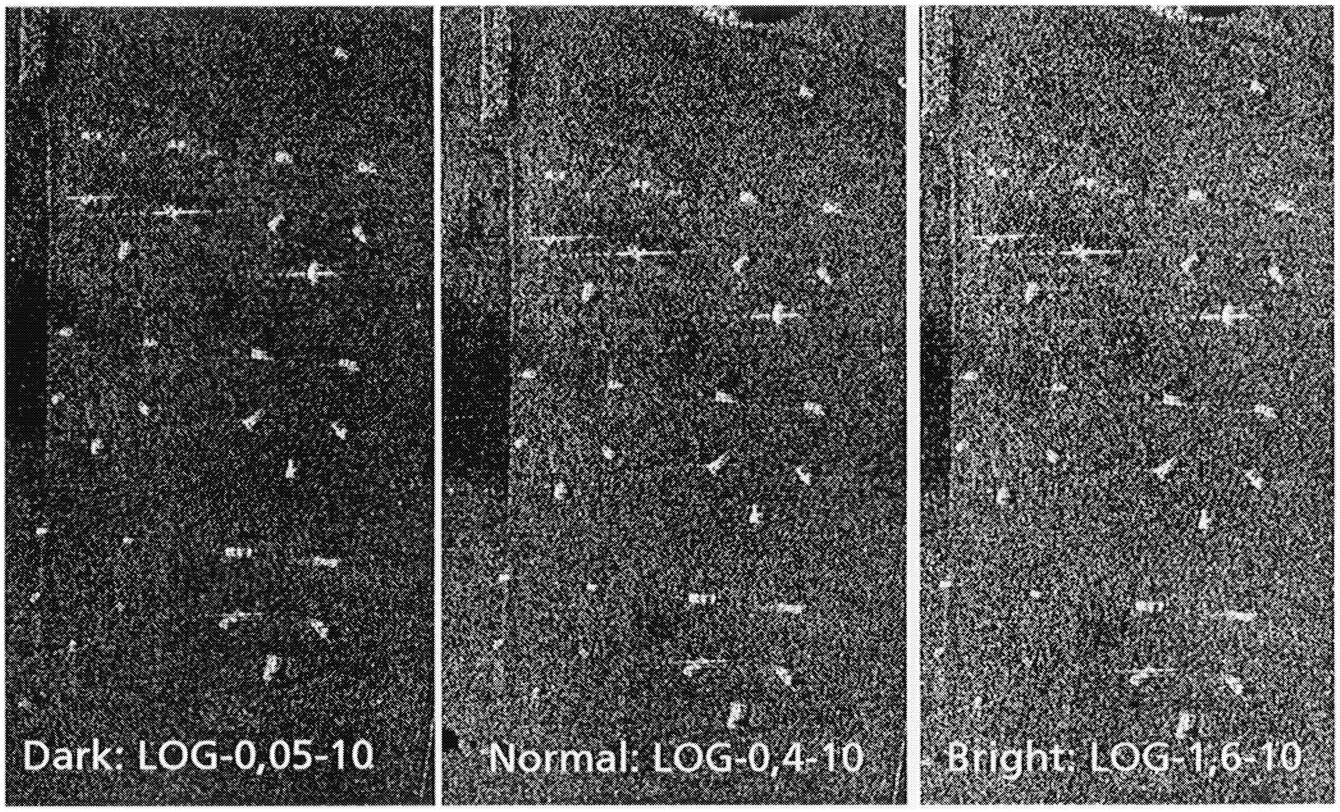

Figure 6: Vehicle scene prepared with three different Gamma corrections for the experiments. In the experiments these filters were called (from left to right) dark, normal and bright filter.

Speckle filter: Two kinds of speckle filters were applied. One filter is the well known *LEE filter* [5, 6], the other one is called *RSIGMA filter* and was developed at the IITB. Figure 7 shows an image prepared with these two speckle filters.

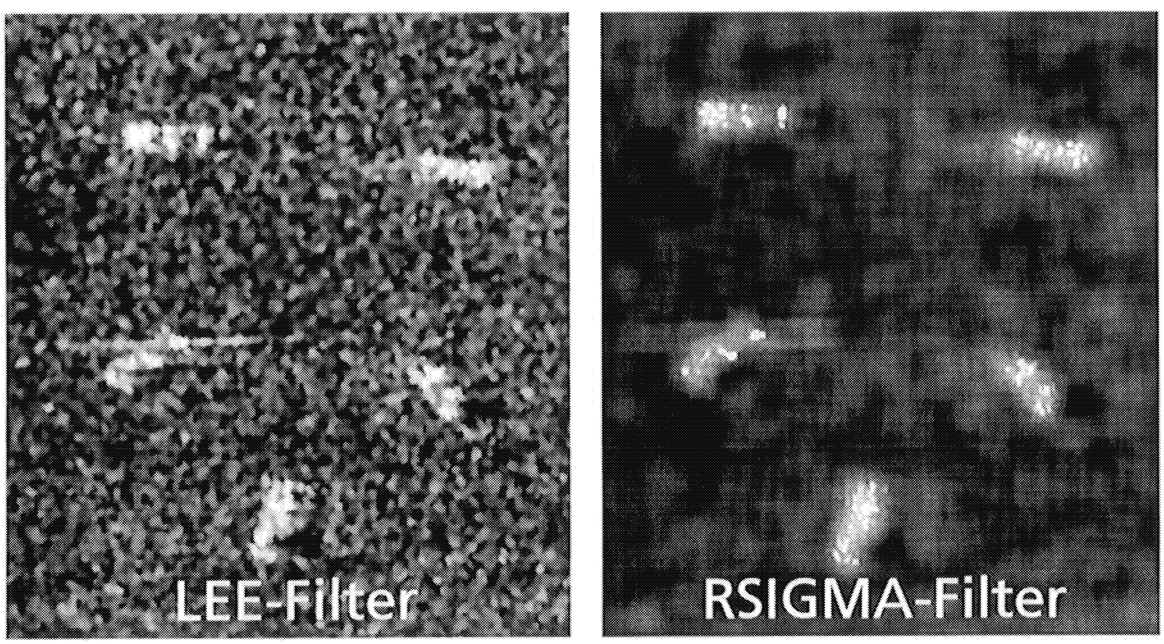

Figure 7: Vehicle group prepared with two different speckle filters for the experiments.

4 RESULTS

The following diagrams show the reliability factor for detection and recognition of trucks and tanks. The reliability factor is the difference between detection rate and false alarm rate respectively the recognition rate and the false recognition rate.

4.1 Detection results

Figure 8 shows the reliable factor for detection in dependence of bandwidth and for several incidence angles. For a steep incidence angle of 25° the reliability factor is at least 25% less than for the others. For incidence angles bigger than 37° the reliability factor is nearly constant between 60% and 80%, whereas for 32° the increase of bandwidth causes an increase of reliability factor.

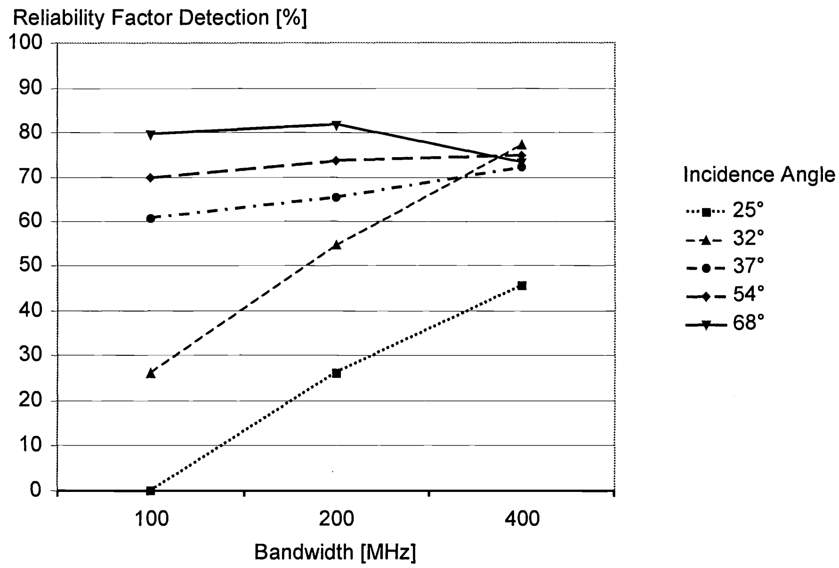

Figure 8: Reliability factor for detection in dependence of incidence angle and bandwidth.

4.2 Recognition results

On the left side of Figure 9 the reliability factor for the distinction between wheeled and tracked vehicles (recognition level 1) is shown. There is a gap of 15% to 20% between 37° and 54° incidence angle. You can also see that for all incidence angles the reliability factor slightly increases with increasing bandwidth. On the right side the reliability factor for vehicle type distinction (recognition level 2) is displayed. For all parameter combinations the reliability factor is nearby zero that means that the recognition rate equals the false recognition rate. Therefore type recognition was not possible.

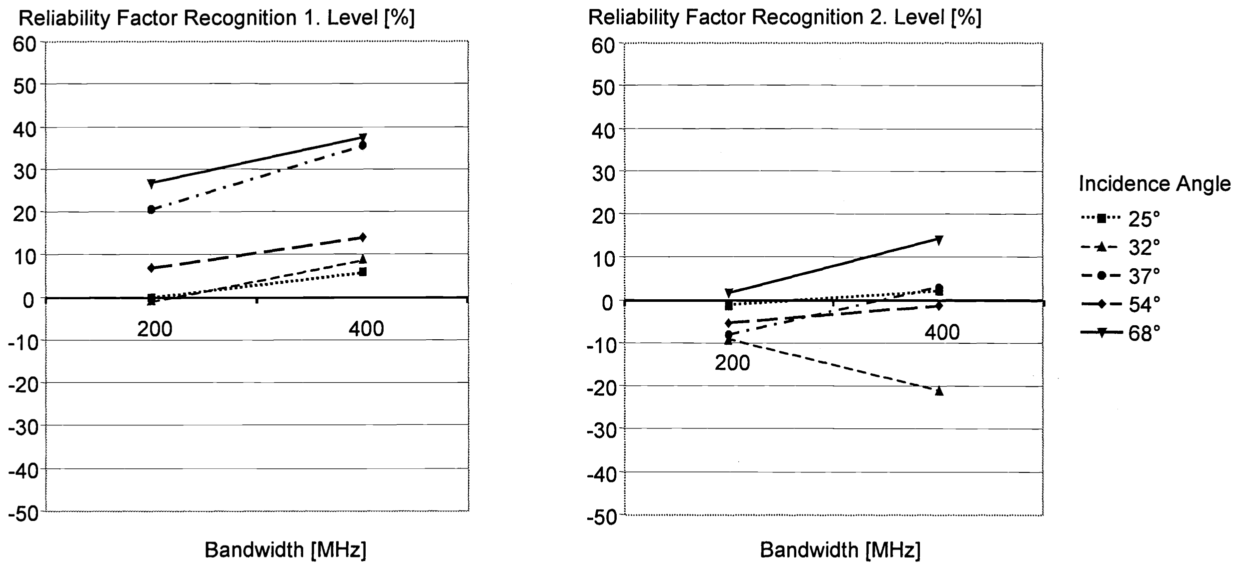

Figure 9: Reliability factor for recognition in dependence of incidence angle and bandwidth.

In Figure 10 the reliability factor for recognition level 1 is drawn against the resolution. We find out that the interpreters started recognition at 1.4 m resolution. Then the performance increases with higher resolution. For comparison the resolution intervals for NIIRS 5 and NIIRS 6 are displayed. NIIRS [7, 8] stands for National Imagery Interpretation Rating Scales. Developed in the U.S. it serves for subjective assessment of image quality due to resolution. It seems that the distinction between wheeled and tracked vehicles fits in the resolution range of NIIRS 6.

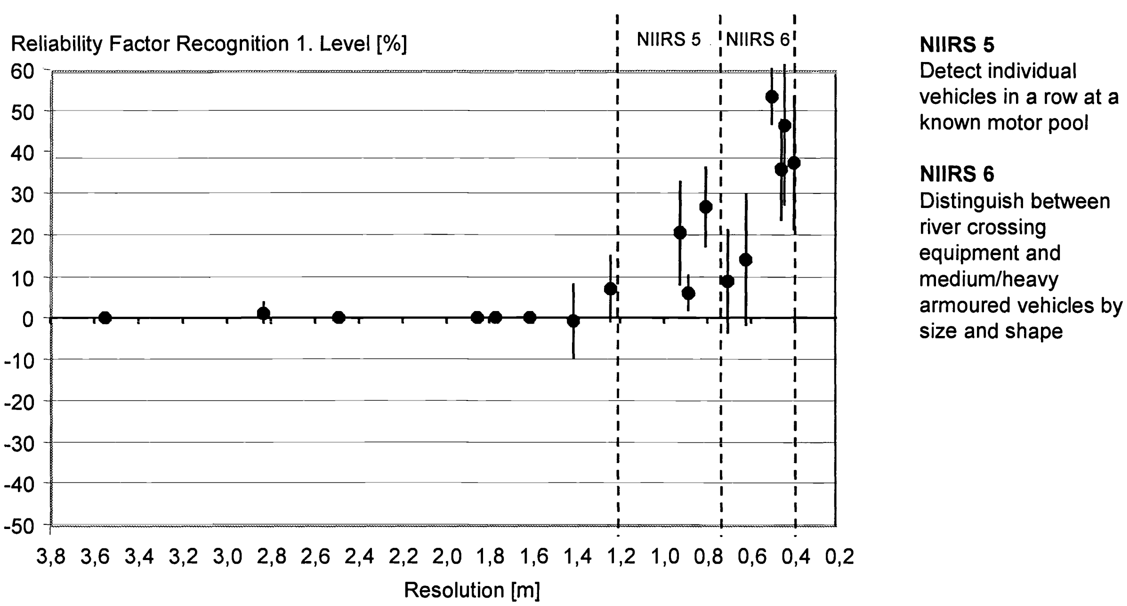

Figure 10: Reliability factor for recognition level 1 in dependence of resolution.

The left diagram in Figure 11 shows the detection reliability factor over the bandwidth for all 5 vehicle types and 54° incidence angle. There is a big gap between the 0.9 to and the other vehicles, which vanishes for 400 MHz bandwidth. For the other vehicles the detection performance changes only slightly with increasing bandwidth.
Once a 0.9 to truck is detected it can be distinguished form the others very well (see right diagram). The best results are obtained for the 10 to truck due to its big length to width ratio. The other vehicle types could not be separated from each other.

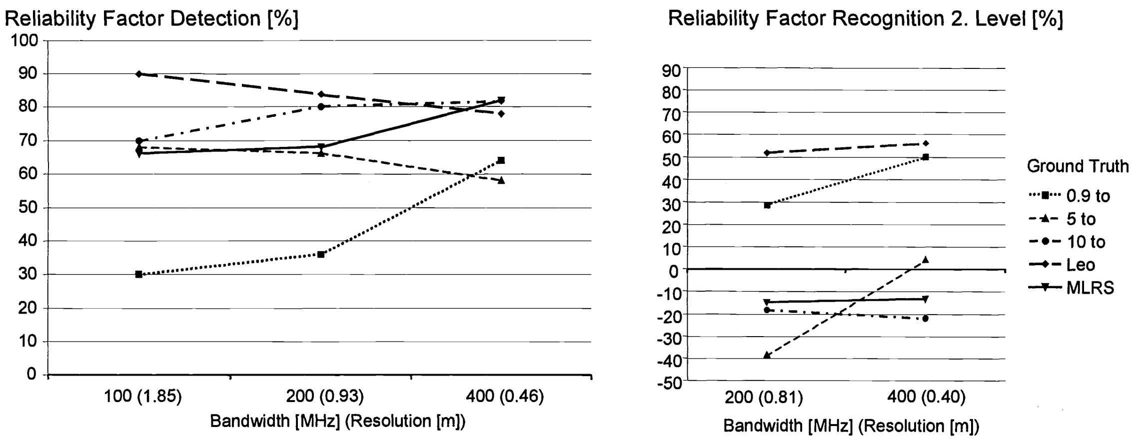

Figure 11: Reliability factor for detection and recognition in dependence of bandwidth and vehicle type.

5 CONCLUSIONS

The experiments showed that the training of the interpreters is very important to customize with the system and especially with the interpretation of SAR image interpretation. Furthermore, to get reliable results it is necessary to simplify the experimental set up as much as possible though the interpreters have no problems to perform the tests.

The detection results of vehicles in SAR images showed that for 100 MHz bandwidth the incidence angle must be larger than 37°. For 200 MHz bandwidth and higher also lower incidence angles (32°) are sufficient to achieve a reliability better than 50%. For incidence angles lower than 30° the detection performance is not acceptable for the investigated parameter combinations.
For distinction between wheeled and tracked vehicles (recognition level 1) the incidence angle should be more than 54°. According to the NIIRS our results showed, that a reasonable recognition of vehicles couldn't be achieved until the resolution is better than 0.8 m.
The discrimination of different vehicle types was done mainly by comparing the size and the length to width ratio of the vehicles. The signature of the vehicles wasn't used so often to distinguish between vehicle types.
For type distinction (recognition level 2) no parameter combination was suitable.

6 ACKNOWLEDGEMENTS

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