IMPLICATIONS OF RESOLUTION ENHANCEMENT IN RADAR IMAGES ON KNOWLEDGE-BASED ATR-ALGORITHMS

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ABSTRACT

Remote sensing by imaging radar sensors is a highly important task for civilian applications but also during peace keeping missions of the armed forces. In both applications often the task arises to recognize defined structures of ensembles of buildings or traffic ways. Military applications nowadays have to take into account that under civil war conditions a mix-up of weapon systems within sensitive urban terrain may appear, where countermeasures against these hostile weapons must not do intolerable harm to the surrounding. These tasks typically have to be fulfilled also under adverse weather conditions, which mainly can be served by airborne imaging radar sensors. Advanced radar sensors are able to deliver high resolution images with a high information content as polarimetry, 3-D-features and demonstrate robustness against changing environmental and operational conditions.

For a considerable time, ATR-algorithms for knowledge based analysis of characteristic geometric structures in visual and IR-Images have been maturing. With the improvement of resolution in radar images these algorithms can be adopted for their evaluation. The performance of the results with these existing algorithms, however, is related to the resolution cell size of the images. This is mainly dependent on the radar method used. Simple forward looking radar sensors typically are employing real aperture (RAR) scanning beam geometries. The resolution cell size in this case is determined by the illuminating beam and the range resolution of the radar. To improve the cross-range resolution under squint angles different from zero, Doppler beam sharpening (DBS) can be employed. The best image quality, however, is provided by SAR.

During various campaigns, radar data have been gathered under different geometries, thus enabling to compare image qualities for the RAR, DBS and SAR approaches. For these data, advanced image based ATR-algorithms have been validated and the characteristics of each approach with respect to the ability to detect distinct objects have been studied.

The contribution describes the different sensor approaches and gives an overview over the image material for the sample scene. The methods of image discrimination using knowledge based methods are discussed.

1 EXPERIMENTAL SYSTEM

For the work described in the following, the airborne experimental Radar MEMPHIS (Millimeterwave Experimental Multifrequency Polarimetric High resolution Imaging System) was used, employing radar front-ends at 35 GHz and 94 GHz. The system was described already in detail [1]. For Doppler processing additional information is retrieved from the inertial navigation system of the aircraft. Technical data of the system are tabulated in Tab. 1.

	35 GHz	94 GHz
Transmitter		
Output-Power	500 Watt	700 Watt
PRF	2 kHz	
Pulse-Width	400 / 800 ns	
Spectral Purity	> -70 dB/Hz	
Phasestability	10° RMS	
Polarisation	linear (H/V) or circular (R/L)	
Waveform	100 / 200 MHz Chirp + stepped Frequency 800 MHz	
Receiver		
Dynamic Range	60 dB	
System Noisefigure	15 dB (SSB)	
Polarisation	Simultaneous co- and crosspolarisation	
Bandwidth	100 / 200 MHz	
Antenna (SAR)		
Type	Monopulse, dielectric lens	
Diameter	30 cm	
3 dB Beamwidth		
Azimuth	3°	1°
Elevation	13°	13°
Gain	27 dB	29 dB
Data-Acquisition		
Type	AMPEX DCRSi	
Datarate	25 / 33 Mbyte/s	
Channels	8 Channels + Inertial Data + Timecode	
Capacity	48 GByte	

Table 1: Performance Data of MEMPHIS

The radiometric calibration is based on pre- and post-flight measurements against trihedral and dihedral precision corner reflectors.

The airborne measurements were conducted with real aperture, employing a scanning beam antenna of 1' diameter. Fig. 1 demonstrates the geometry. The lateral image resolution in this case is determined by the footprint of the real aperture. Subsequent processing with a Doppler Beam Sharpening algorithm allows to improve the lateral resolution. Subsequent flights were conducted with the radar mounted in side-looking geometry, thus allowing SAR signal processing with optimum image resolution.

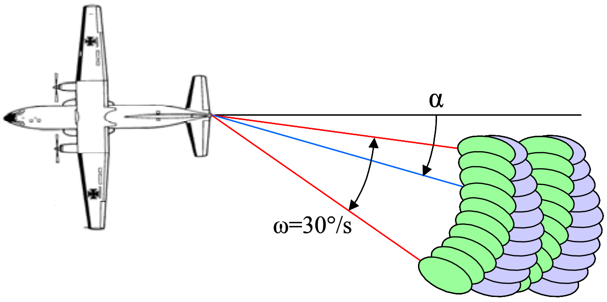

Figure 1: *Geometry of real aperture flights,*
α = -10°..+10°, 0°..20°, 10°..30°, 20°..40°

2 REFERENCE SCENE

Several measurement scenes were evaluated for the investigations. One typical containing urban terrain, a river with bridges and locks and rural environment is discussed here in detail. Figure 2 shows a photo of the scene “Bad Abbach”.

Figure 2: *Aerial View of Reference Scene*

3 DATA PROCESSING AND RESULTS

In a first step the data undergo off-line preprocessing which includes interpolation of the data from the INS platform of the aircraft as well as calibration and reformatting procedures. Afterwards the specific processing for the different approaches is applied. Based upon the extracted images the image based feature extraction algorithms are applied.

3.1 REAL APERTURE IMAGES

The easiest approach is to restrict to the geometrical resolution of the scanning beam antenna. This approach is frequently used for seeker applications at mm-waves and due to the high primary resolution, especially at the higher mm-wave-band of 94 GHz leads to images which can be used to extract simple structures, as i.e. high value targets as bridges and major roads and also point targets.

Fig. 3 shows a real aperture image of the reference scene.

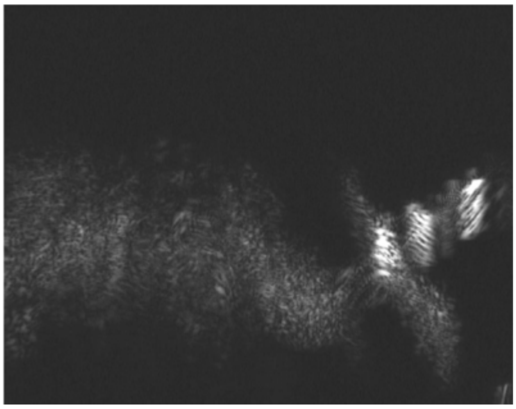

Figure 3: *RAR Image, Single-scan, 1´Antenna*

Using a radar capable to be used for high range resolution processing, i.e. by employing a chirp wave form, it is possible to improve the range resolution accordingly. Doing this, however, a non square resolution cell is obtained. Figure 4 shows the result of respective processing.

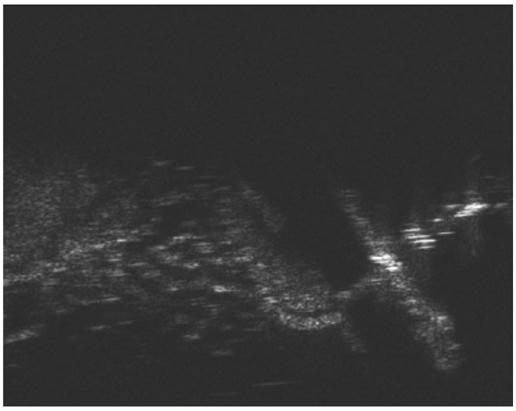

Figure 4: *RAR Image, Single Scan range-compressed*

In all directions different from boresight it is possible to use the inherent Doppler-information to improve the resolution of the sensor. One of the well known algorithms is the Doppler-Beam-Sharpening (DBS) method [2]. The capabilities of the DBS is dependent on the beam-width of the real aperture. The wider the real beam, the narrower is the gap around boresight, where the Doppler processing does not improve the cross range resolution. Fig. 5 demonstrates the resolution improvement in comparison to real aperture. The angular resolution gained by DBS is given by:

$$\Delta\varphi_{DBS} \approx \frac{c_0 \cdot \omega}{2 \cdot v \cdot \alpha_{3dB} \cdot f_C \cdot \sin(\varphi)} \cdot \frac{180}{\pi}$$

Where the parameters are given by:
Squint angle = φ , Frequency = f_c , Speed = v ,
circular velocity = ω , 3-dB-Beam = α_{3dB}

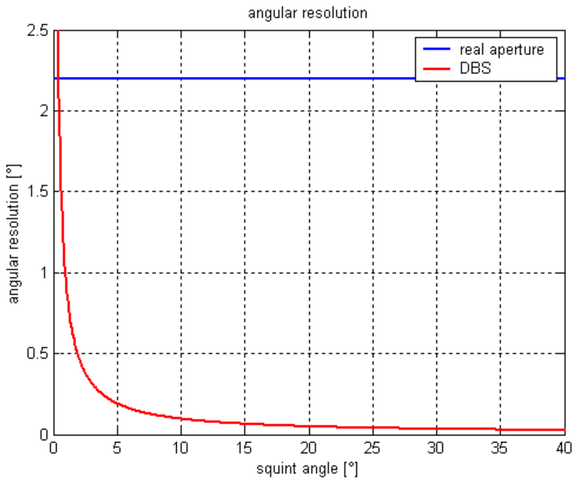

Figure 5: *Cross-Range Resolution Enhancement by DBS for a 10 cm Antenna at 94 GHz*

Fig. 6 shows the result of Doppler beam sharpening as multilook-Image.

Figure 6: *DBS-Image at 94 GHz*

3.2 SYNTHETIC APERTURE RADAR

As already mentioned above, SAR-processing at millimeter wavelengths requires a considerably lower amount of sophistication in comparison with algorithms applied at lower radar- frequencies [3]. This can mainly be attributed to the short aperture length at mm-wave frequencies. Taking this into account, the SAR-algorithm used here is relatively simple although fully automatic autofocussing is applied. The INS information is used to introduce values like drift angle and speed and especially the roll-angle correction, but the fine-tuning is done by autofocussing.

Under the parameters used here, a swath width of about 1600 m at a depression angle of 22.5° was achieved. Fig. 7 shows the respective SAR image for the reference scene.

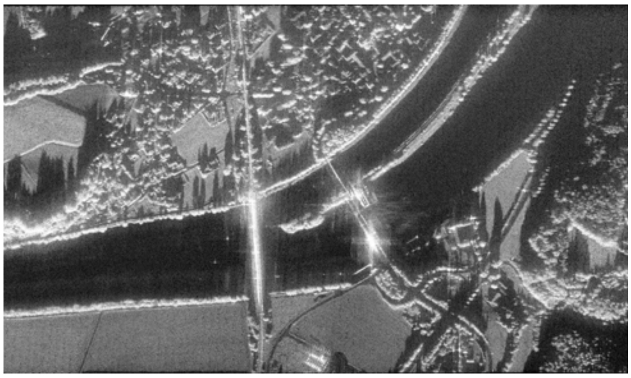

Figure 7: *SAR-Image of Sample Scene at 94 GHz*

It is obvious that the image quality is optimum for the SAR-image with a range independent geometrical resolution of 0.75 m x 0.75 m. DBS exhibits the same range resolution, only determined by the chirp-bandwidth of the radar, but the cross-range resolution is an angular resolution thus range dependent. Consequently only for short range applications DBS can deliver a resolution comparable to SAR. Forward-looking sensors, however, are typical for seeker applications, which are normally short range.

4 KNOWLEDGE-BASED ATR-ALGORITHM

4.1 IMAGE PROCESSING ARCHITECTURE

For the detection and interpretation of selected areas, a method is used, combining contour-based structure analysis and area-based texture analysis. The method is implemented by a blackboard-system using the rules of a production network for building up complex structures from primitive structures [4].

Fig. 8 shows the production net for the model URBAN AREA, as example, with the two branches representing the modules for contour-based and area-based processing [5].

The area-based analysis starts with the extraction of object primitives TEXEL (texture elements). Using proper classification algorithms and production rules, texture elements will be merged to objects T-CLUSTER (cluster of texture elements) to be combined to objects T-AREA. T-AREAs represent the image segments resulting in the definition and selection of **R**egions **o**f **I**nterest (ROI) like structured regions indicating object classes of high priority like settlement.

The screening of the image data is used for more detailed analysis by the structural approach. For the recognition of characteristic structures like roads and road networks, object primitives LINE are combined by applying rules of the inference process. In doing so, parameter values of the algorithm are determined by interpreting geometric and generic information of a city model, for example. Finally, objects URBAN AREA are generated by roads leading from outside towards the structured regions.

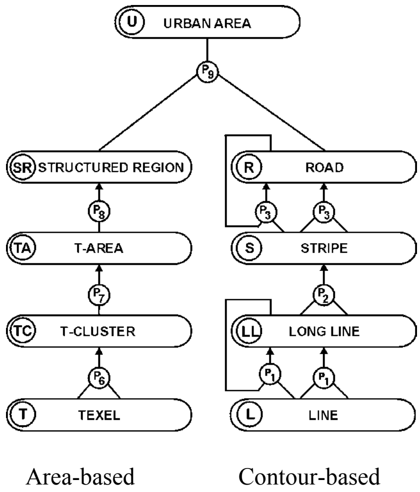

Figure 8: Production net for the model URBAN AREA

4.2 RESULTS

A result of the ATR-Algorithm for the recognition of urban areas from real aperture data as described in chapter 3 is shown in Fig. 9. Textured urban regions are displayed by yellow elements and detected roads are drawn in red stripes. It is obvious that the quality of the RAR image is already sufficient to allow the image processing algorithms to detect larger structures as bridges or urban areas. But to be able to identify smaller features within defined areas it is necessary to have a higher resolution as supplied by DBS [7].

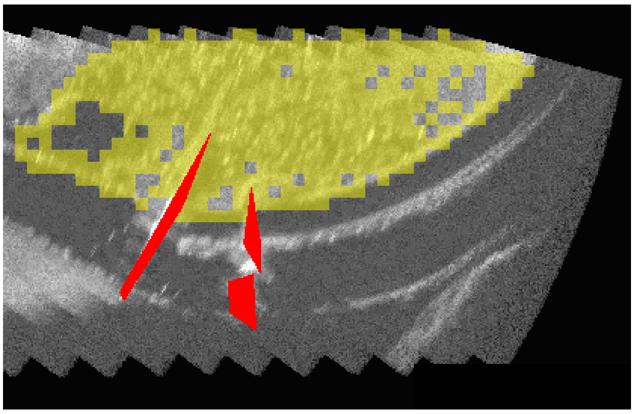

Figure 9: *Detection of urban areas in RAR data*

5 CONCLUSIONS

The investigations show, that the methods of texture and structure analysis which have matured considerably using IR-data, can be adopted to radar imagery. The data obtained with the DBS method are of such quality that those methods give good results. This gives the considerable advantage of adverse weather capability under longer range. Especially for short range applications IR and Laser systems provide an inherently high angular resolution. To be able to identify fine grain structures within prerecognized areas of interest, height information may be a necessary feature. This can be done by SAR-interferometry [6] but for short range, with very high precision with Laser scanning systems.

The data material sampled during the work discussed here, offers the unique possibility to do further investigations on multi-sensor data fusion. This is currently under investigation.

6 REFERENCES

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