Short Range mm-Wave SAR for Surveillance and Security Applications.

Peter Feil, Thomas Kraus, Wolfgang Menzel
Institute of Microwave Techniques, University of Ulm, Albert-Einstein-Allee 41, 89081 Ulm, Germany

Abstract

Recent advances in the area of automotive radar led to the development and availability of integrated components (MMICs) in the millimeter-wave range. Besides the automotive sensors also industrial and security applications can take benefit from these components. For example a distributed system for runway surveillance consisting of several mechanically steered broadband sensors has been proposed recently . To evaluate SAR as another interesting candidate for this kind of applications, a broadband demonstrator has been developed at 77 GHz. Combined with monostatic or digital beam forming (DBF) sensors, the basic SAR modes such as Stripmap SAR and Spotlight SAR have been implemented successfully. Additionally azimuth SAR processing was combined with DBF in elevation. This configuration allows the three dimensional imaging of scenarios.

1 Introduction

In the last few years the detection of so called Foreign Object Debris (FOD) on airport runways has become of growing interest. Especially the accident of a Concorde aircraft in 2000 forced the development of FOD detection systems. Current approaches typically combine a high power mechanically steered mm-Wave radar and an optical camera [3]. These systems are rather expensive and hardly scalable. Hence smaller airports cannot afford such installations. An alternative approach is a setup consisting of a number of low cost mm-wave sensors situated along the runway [2] which was shown to be a possible candidate.

Due to the fact that for mechanically steered radars the crossrange resolution degrades with increasing distance, it is necessary to place sensors an *both* sides of the runway. This is the motivation to investigate SAR based systems for this kind of applications. Of course the installation costs will be higher due to the need of moving platforms. The sensor costs however can be reduced significantly, because a onesided installation is sufficient. Additionally, the actual number of sensors depends on the speed of the sensor platforms and the desired acquisition time.

This paper describes the initial setup of a broadband mm-wave SAR demonstrator. First the mechanical setup and the sensors used to implement the different SAR modes are briefly introduced. After that the operating modes and the respective signal processing are depicted together with measurement results.

2 Demonstrator system

The whole system as shown in **Figure 1** consists of a linear actuator which accomplishes the motion of the radar sensors and an interface box controlling the sensor and providing the connection to the signal processing implemented on a laptop computer. Configurations with two different types of sensors are examined. Both employ the FMCW-principle (Frequency Modulated Continuous Wave). The first one is a monostatic sensor at 77 GHz together with a high gain folded reflectarray antenna [5]. It was originally designed for industrial, security [2] and general purpose applications. The second radar is a digital beamforming sensor at 24 GHz with 25 switchable transmitting antennas and two receiving antennas forming an equivalent aperture of 50 antennas spaced by half a wavelength [4]. It was intended for automotive applications, but other applications like industrial safety [1] have also been proposed. The key parameters of both sensors are summarized in **Table 1**.

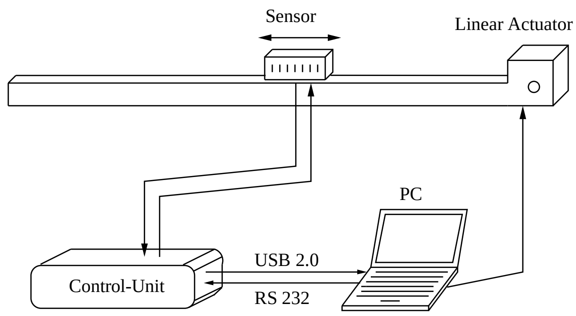

Figure 1: SAR demonstrator setup.

Table 1: Parameters of the two radar sensors used with the SAR demonstrator.

	77 GHz sensor	24 GHz sensor
Bandwidth	4.8 GHz	0.8 GHz
Range Resolution	7 cm	20 cm
(equ.) Aperture size	13 cm	30 cm
3dB beam width	2.5°	3°(typ.)

3 SAR and DBF processing

The first step in the signal processing chain is to extract the range information by calculating a fast Fourier transform (with appropriate windowing). The following step depends on the type of sensor and the SAR mode, respectively. In the monostatic case just one range profile per azimuth sampling point is available. Due to the architecture, stripmap SAR is the only possible mode.

For the imaging sensor, 50 range profiles have to be processed to extract the desired information. This can be either a virtual beam pointing to a scene of interest for spotlight operation or a complete elevation scan for the 3D mode.

Due to the use of a linear actuator and its accuracy, there was no need to take into account any errors in the trajectory. Further on, it is possible to do stop-and-go measurements. Hence the data acquisition time is not a limiting factor for the azimuth sampling rate.

3.1 Stripmap Operation

The stripmap mode was tested in conjunction with the 77 GHz radar. A picture of the overall setup is shown in **Figure 2**.

Figure 2: Photograph of the overall setup for evaluating stripmap SAR at 77 GHz.

Azimuth focussing is performed in the range Doppler domain because of the lower computational complexity and the ability of range cell migration correction (RCMC) [6]. Although RCMC is not needed for the narrow beam antenna used in this configuration, the correction has been implemented to be able to use antennas with different aperture sizes. In **Figure 3** the result of an outdoor measurement is depicted. The theoretical limit of the azimuthal resolution is about 4.5 cm. Therefore two small corner reflectors separated by 7 cm have been placed at a distance of 30 m. The measurement shows that the theoretical limit is nearly met. The range resolution is at the same scale due to the large sweep bandwidth of the FMCW frontend.

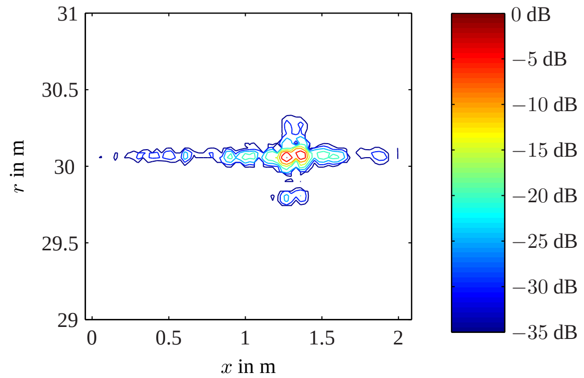

Figure 3: Measurement results obtained with the 77 GHz sensor in stripmap mode.

The following discussion will only concern the 24 GHz sensor. Of course it can be operated in stripmap mode as well, but due to the switched array antenna additional modes are possible.

3.2 Spotlight Operation

In the spotlight mode the beam steering capability of the 24 GHz imaging sensor was used to point the synthesized beam to the center of the scene of interest. Again azimuth compression and RCMC were performed in the range Doppler domain. **Figure 4** shows the measurement result of two small reflector separated by 4.5 cm at a distance of 6.5 m.

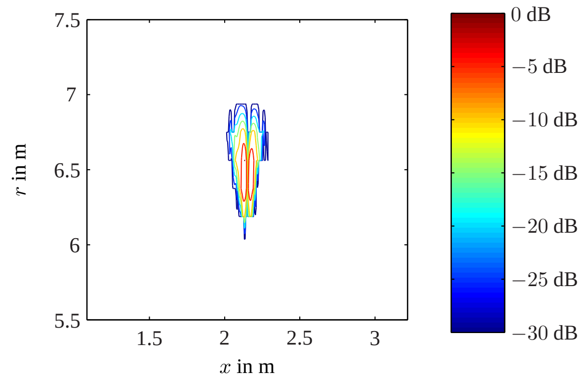

Figure 4: Measurement results obtained with the 24 GHz sensor in spotlight mode

The reflectors can be resolved clearly. Due to the limited sweep bandwidth of the 24 GHz radar the azimuthal resolution is much better than the range resolution. However both values match the simulated and theoretically expected results.

3.3 Combined SAR and DBF

A three dimensional image of the environment can be acquired by turning the imaging plane of the DBF radar perpendicular to the SAR trajectory. The respective resolution cell is depicted in **Figure 5**. The dimensions δ_r, δ_Θ and δ_{ac} depend on the sweep bandwith, the size of the equivalent aperture in elevation and the azimuth beamwidth of the switched antenna elements.

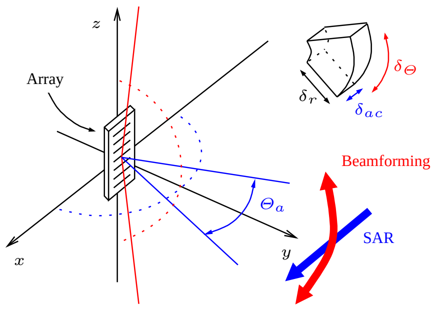

Figure 5: Geometry and resolution cell of the 3D imaging mode.

A barrier on the university campus consisting of three metal posts served as scenario for the evaluation of the 3D mode. The results are shown in **Figure 6**.

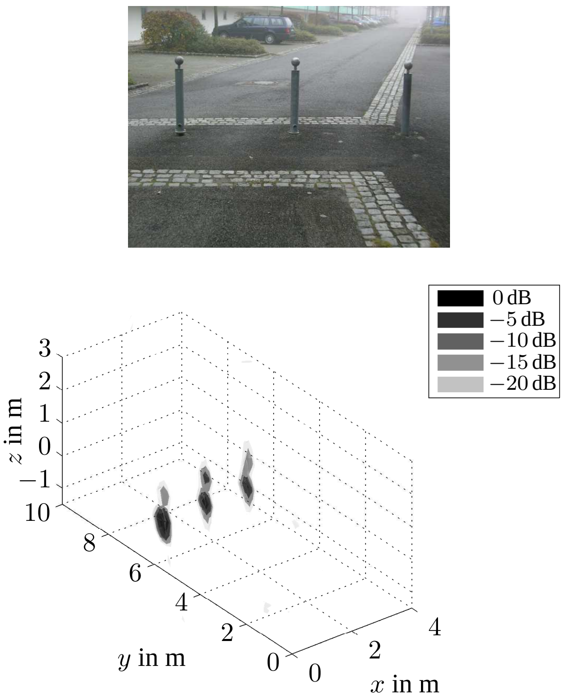

Figure 6: Three metal posts and respective 3D SAR DBF image.

The position as well as the vertical extents of the posts can be obtained by the measurement. Of course there cannot be a photo-realistic image, because the elevation radar image of these kind of posts contains the superposition of three major reflections. One caused by the sphere on top of the posts, one obtained for perpendicular incidence and a twofold reflection between post and ground. However such a measurement can help distinguishing objects lying on the ground and upright objects such as persons.

4 SAR Measurements

Due the bad weather conditions during spring 2010, no further outdoor measurements could be performed until the submission of this paper. Instead, an indoor scenario was acquired using the described setup in stripmap mode. The monostatic 77 GHz sensor was used together with a folded reflectarray antenna. The azimuthal beamwidth of the antenna is 2.5°. A photograph of the scenario and a section of the measurement results are shown in **Figure 7**.

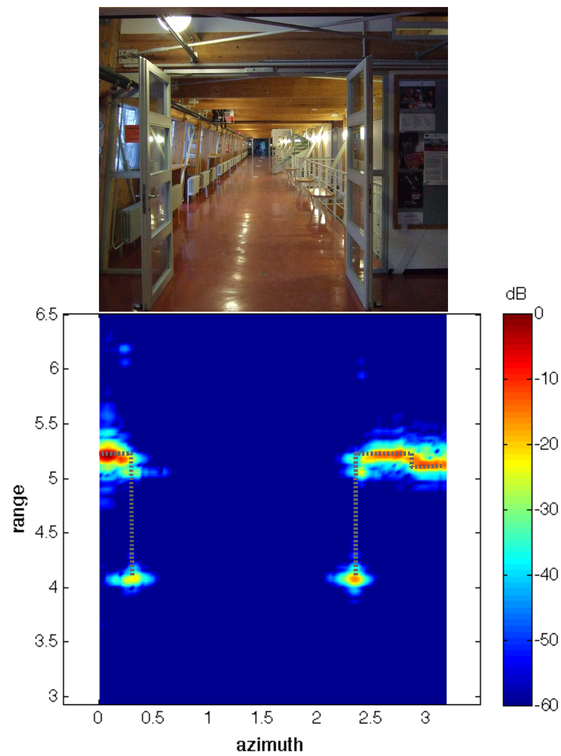

Figure 7: Photograph of the indoor scenario and SAR image of the double wing door in the foreground.

The open double wing door in the foreground is clearly visible in the SAR image with the expected resolution. The results are similar for the next doorway at 55 m, which is not shown in the viewgraph.
As the antenna was pointing towards a point on the ground at a distance of 80 m, it was possible to detect objects on

the floor. An aluminum sphere with a diameter of 40 mm was placed at a distance of 40 m. A cell averaging CFAR algorithm (constant false alarm rate) [7] was used for target detection. For each cell of interest the clutter level was estimated by averaging a region of 51 x 51 surrounding cells. The level within the cell of interest was normalized by the estimated clutter level. Hence **Figure 8** shows the relative level with respect to the estimated clutter background.

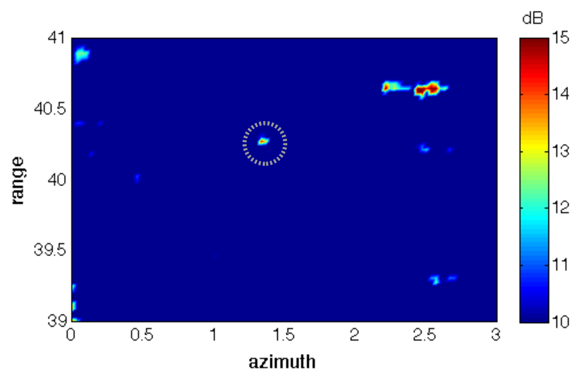

Figure 8: SAR image of a 40 mm sphere after CFAR processing.

The lower threshold was chosen as 10 dB. That means only targets with a signal to clutter ration of more than 10 dB are visible in Figure 8. Even under these constraints, the sphere can be detected reliably.

5 Conclusion and Outlook

In this paper a SAR demonstrator operating at mm-wave frequencies is presented. So far it acts still as a proof of concept. But such a system can be a candidate for security and surveillance applications such as runway protection on airfields.

During the conference presentation, FOD measurements in comparison with [2] will be shown in addition to the present results.

References

[1] Nienhaus, K.; Winkler, R.; Mayer, W.; Gronau, A.; Menzel, W.: *An Experimental Study on Using Electronically Scanning Microwave Radar Systems on Surface Mining Machines*, Proc. IEEE Radar Conference, 2007

[2] Feil, P.; Menzel, W.; Nguyen, T. P.; Pichot, C.; Migliaccio, C.: *Foreign Objects Debris Detection (FOD) on Airport Runways Using a Broadband 78 GHz Sensor*, Proc. European Radar Conference EuRAD, 2008

[3] QinetiC: *Tarsier - Automatic Runway Debris Detection*, http://www.qinetiq.com/home/products/tarsier.html

[4] Mayer, W.; Gronau, A.; Menzel, W.; Leier, H.: *A Compact 24 GHz Sensor for Beam-Forming and Imaging*, Proc. 9th International Conference on Control, Automation, Robotics and Vision ICARCV, 2006

[5] Menzel, W.; Pilz, D.; Al-Tikriti, M.: *Millimeter-Wave Folded Reflector Antennas with High Gain, Low Loss, and Low Profile*, IEEE antennas and propagation magazine, Vol. 44, Nr. 3, pp. 24–29, 2002

[6] Cumming, I. G.; Wong, F. H.: *Digital Processing Of Synthetic Aperture Radar Data: Algorithms and Implementation*, Artech House Publishers, Jan. 2005

[7] Rohling, H.: *Radar CFAR Thresholding in Clutter and Multiple Target Situations*, IEEE Transactions on Aerospace and Electronic Systems, Vol. 19, Nr. 4, pp. 608–621, 1983