THE PHARUS SYSTEM; AN OVERVIEW AND RECENT DEVELOPMENTS

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ABSTRACT

The PHARUS system is a fully polarimetric C-band SAR with an active phased array antenna. PHARUS is an experimental system. It is meant for remote sensing research in many application areas, both civil and military, maritime and on land. The system performed its first test flight in 1995. In the following years a large amount of data was acquired. In the standard mode the resolution in both range and azimuth is about 3 m. The capability of PHARUS to obtain fully polarimetric images with a high resolution is extensively used.

More advanced SAR applications require both high resolution and the flexibility that is offered only by phased array SAR systems. The PHARUS system, since it has an active array, which is fully programmable in its operating modes, allows investigations of these applications. Advanced SAR modes that are being investigated are: (sliding) spotlight SAR and interferometric SAR, both along track (Moving Target Indication) and across track (Repeat Pass Interferometry). The flight experiments are carried out in co-operation with the National Aerospace Laboratory.

In this paper the status of the different new processing techniques is reported. These new techniques include doubling of the range resolution, increasing the azimuth resolution through spotlight processing, Displaced Phase Center Antenna MTI and Repeat Pass Interferometry. Also the use of PHARUS as a test bed for the ASAR modes of the ENVISAT satellite is shown.

1 INTRODUCTION AND OVERVIEW

The PHARUS (PHased ARray Universal SAR) system is a fully polarimetric C-band Synthetic Aperture Radar (SAR) with an active phased array antenna. The system has been developed by the TNO Physics and Electronics Laboratory (TNO-FEL) in co-operation with the National Aerospace Laboratory (NLR) and the Delft University of Technology (DUT). The project is carried out with financial contributions from the Ministry of Defense and the Netherlands Remote Sensing Board (BCRS). PHARUS is an experimental system. It is meant for remote sensing research in many application areas, both civil and military, maritime and on land. It is an airborne system, flown with a Cessna Citation II aircraft. The system performed its first test flight in 1995.

In the following years a large amount of data was acquired. In the standard mode the resolution in both range and azimuth is about 3 m. In Figure 1 an example of a high resolution SAR image is shown. The colors represent the different polarimetric channels. PHARUS is a fully polarimetric system, it can alternately transmit horizontal (H) and vertical (V) polarized beams while receiving simultaneously horizontal and vertical polarized signals. The intensity of the four channels HH, HV, VH and VV (the first letter signifies the polarization of the received signals, the second the polarization of the transmitted beam) are then represented in the following way: HH by red, HV+VH by green and VV by blue.

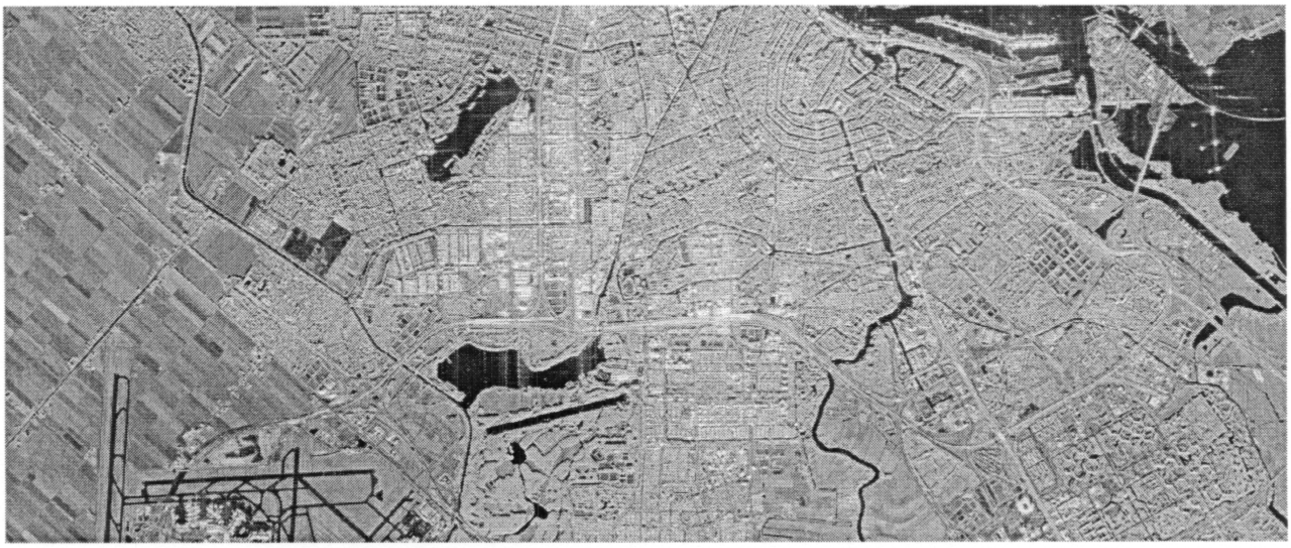

Figure 1. Example of a fully polarimetric PHARUS image of Amsterdam and Schiphol. The colors are assigned in the following way: HH channel to red, HV+VH to green and VV to blue.

The applications for which data have been acquired and analyzed are e.g. land use classification, cartography, road detection, ocean bottom topography, detection of ships and ship wakes, (moving) target detection, crop classification and forestry applications. For these applications the capability of PHARUS to obtain fully polarimetric images with a high resolution is extensively used. Overall, most applications could be carried out successfully.

For example land use could be classified into six classes: water, urban, forest, grass, bare soil and moor. Shown in Figure 2 is the Heerde test site near Enschede (the Netherlands) which has been classified in five classes (no moor has been found in this region). The river dividing the figure is the IJssel, the urban area is the village of Olst. The dominating light areas are classified as grass, the darker areas without texture are classified as bare soil, the darker areas with texture as forest. The intensity of the colors in the original image are scaled with the backscatter intensity of the SAR image, adding details to the figure which are not seen in the classified image by itself.

Another example: for road detection a PHARUS image has been compared to a road graph file. The shift between the road file and the PHARUS image could for the greatest part be attributed to the inaccuracy of the road graph file.

Figure 2. A classified image of the Heerde test area.

More advanced SAR applications require both high resolution and the flexibility that is offered only by phased array SAR systems. The PHARUS system, since it has an active array, which is fully programmable in its operating modes, allows investigations of these applications. Advanced SAR modes that are being investigated are: (sliding) spotlight SAR and interferometric SAR (both along- and across-track).. In the following sections the investigation into these advanced applications will be discussed. The use of PHARUS as an test bed for ASAR data will also be shown.

2 RESOLUTION ENHANCEMENT

2.1 Azimuth resolution

Since PHARUS is a phased array system, it is very well suited for spotlight mode operation. A Spotlight Beam Steering Control mode was implemented by the National Aerospace Laboratory (NLR. In this mode the beam is steered electronically to a point on the ground resulting in a larger synthetic aperture and consequently in a higher resolution as compared to the normal scan mode of PHARUS.

Focussing of the image proved to be difficult. The phase consistency across the synthetic aperture was investigated. During the acquisition of the synthetic aperture several beam position changes occur. These changes, with a minimum step size of 0.5°, keep the beam pointed to the designated spot. Inspection of corner and transponder signals indicated that there were no significant phase discontinuities associated with beam switching [Nijenboer, 1999].

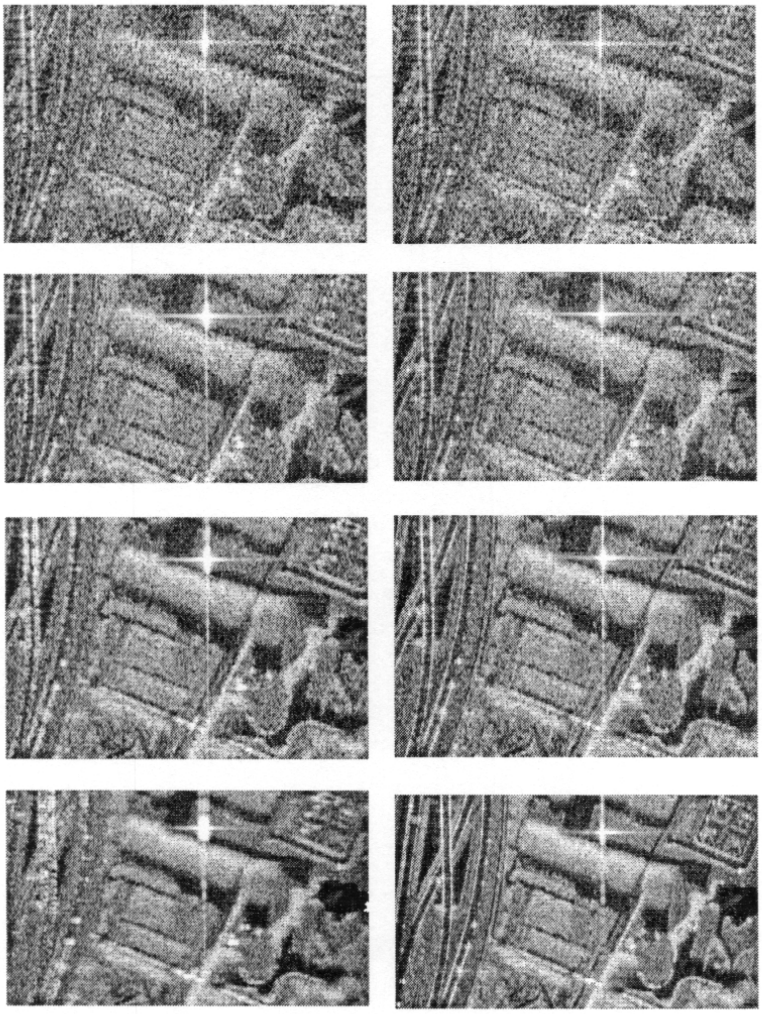

Figure 3. Extending the synthetic aperture. In the left column the motion compensation is performed using the motion data only, in the right column an extra phase estimation is performed using PGA.

The same investigation also showed that sometimes motion compensation using only the on-board recorded motion data was not sufficient. Improvement of this compensation was achieved with the use of an autofocussing technique. The technique used is the Phase Gradient Autofocus algorithm [Wahl., 1994]. In this algorithm the phase error caused by an unknown movement of the platform is estimated using the data by means of an iteration loop. In Figure 3 images obtained using the PGA algorithm are compared with the images obtained using the range-Doppler algorithm only. The azimuth resolution could be improved significantly as compared to the normal SAR mode. The PGA algorithm then further improved the resolution, e.g. from 87 cm to 37 cm in the lower two images of Figure 3.

An azimuth resolution better than 30 cm has been achieved. However, with a range resolution of 3 m, it was more sensible to perform azimuth multi-looking in order to make the azimuth and range resolution comparable than to show the full resolution in azimuth. The multi-looking accounts for the reduction in speckle in Figure 3.

2.2 Range resolution

From the previous sub-section it could be concluded that also an improvement in the range resolution is needed. The normal bandwidth of PHARUS is 45 MHz which allows for a range resolution of 3 m. The data acquisition chain has been designed for this bandwidth. However, the radar antenna hardware allows for the use of 100 MHz bandwidth. By transmitting two different chirps of 45 MHz, spanning a 90 MHz band, the effective bandwidth can be doubled without any changes to the radar or data-acquisition hardware. This doubling leads to an increase of the range resolution by a factor two, from 3 m in slant range to 1,5 m.

This approach was tested using two transponders. In Figure 4 the response of one transponder in the range direction is shown for both the original 45 MHz chirp and the response for the total 90-MHz chirp. The increase in the range resolution is clearly visible.

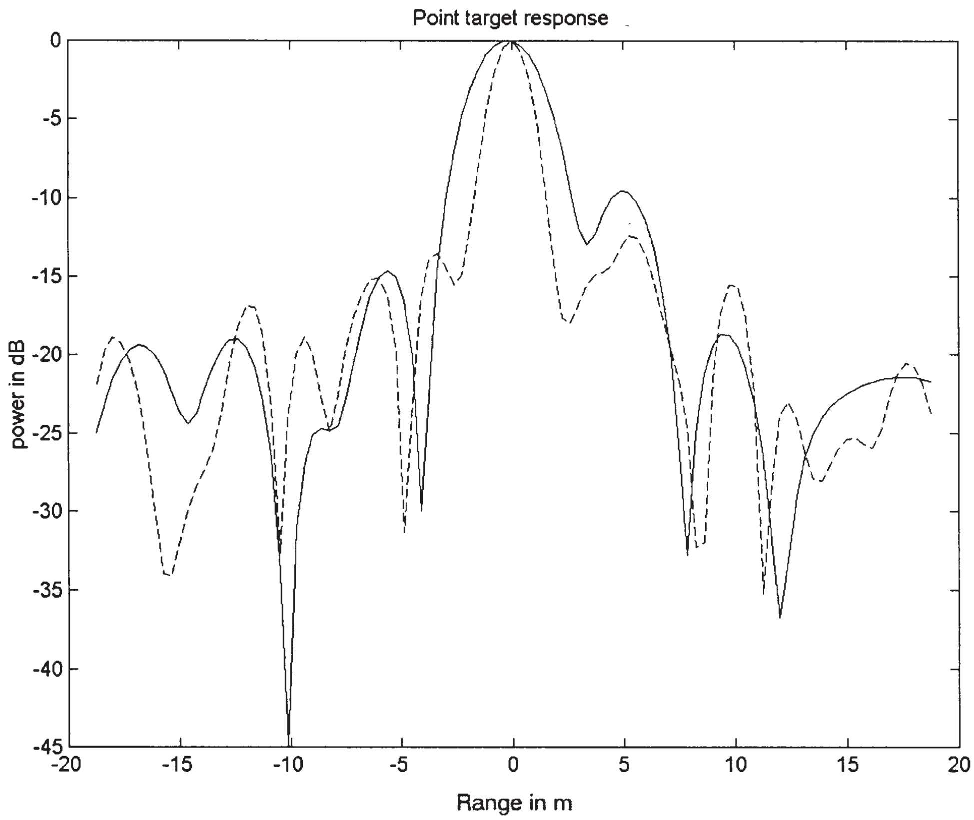

Figure 4. Increase of the resolution by doubling the bandwidth. The solid line represents the point target response of the transponder on the 45 MHz chirp giving a resolution of 3. m, the dashed line represents the response on the combined 90-MHz chirp giving a resolution of 1.5 m.

3 INTERFEROMETRY

3.1 Along-track interferometry (Moving Target Indication)

Moving target indication (MTI) with SAR technology is complicated due to the movement of the platform which results in Doppler shifts for the stationary background clutter. Single beam MTI still can be performed and was demonstrated for PHARUS some time ago [van Rossum, 1999]. By processing a part of the Doppler spectrum outside the main lobe clutter (the stationary background) moving targets with velocities above 25 km/h can be detected. This technique was applied to a highway near Zoetermeer. In this application the part of the Doppler spectrum that was investigated yielded velocities around 120 km/h (the allowed maximum velocity on that highway) with a window of about 30 km/h. The moving targets were superimposed on the normal SAR image to give Figure 5.

(less than approximately 20 m apart, so as to avoid baseline decorrelation) during passes spaced in time by several months ("repeat pass interferometry"), the subsidence of the area will be mapped..

In order to obtain coherence between the two passes, the azimuth aspect angle of the two passes must be nearly the same. In the case of PHARUS, a difference of no more than 0.6° (30 % coherence loss) is allowed. This necessitates active, real-time beam steering, to compensate for aircraft attitude. This geographically locked beam steering mode differs from the other steering modes for PHARUS; the beam is kept pointing in a specific direction, while the usual beam steering mode keeps the beam at zero Doppler and the spotlight steering mode keeps the beam directed to a specific point on the ground.

The experiments are on-going. Due to the relatively narrow antenna beam of PHARUS maintaining angular overlap between the passes proved to be difficult. For this reason a sliding spot technique is used as an alternative. In this mode the beam is pointed to an elongated spot (instead of the normal smaller spot). Thus, the effective observation angle is increased w.r.t. the normal RPI mode and thereby the chances of achieving overlap.

4 ASAR DEMONSTRATOR

4.1 ENVISAT's Advanced Synthetic Aperture Radar (ASAR)

Compared to the single-channel (VV) SAR onboard of ERS-1 and ERS-2, ENVISAT's ASAR employs a number of new developments, which have resulted in some attractive improvements. Most importantly, instead of a passive radiator array, the ASAR antenna uses an active phased array which results in a large coverage of incidence angles. Also, the possibility to switch between polarisation channels allows scenes to be imaged with a combination of horizontal and vertical polarized beams. Because of the active array and the possibility to switch between channels, the ASAR instrument can be operated in five modes, which are mutually exclusive and can be operated on request. The five modes are described in Table 7.

Table 7. ASAR operating mode parameters [ESA, 1998].

	Image	wide swath	alternating polarisation	Wave	global monitoring
Polarization	HH or VV	HH or VV	HH/HV,HH/VV or HV/VV	HH or VV	HH or VV
Spatial resolution	< 30 m (4 looks)	< 150 m (12 looks)	< 30 m (2 looks)	< 10 m (single look)	< 1000 m (7 looks)
Swath width	< 100 km	>400 km	<100 km	5 ×5 km	>400 km
Looking angle	15°-45°	17°-43°	15°-45°	15°-45°	17°-43°

Because PHARUS is fully polarimetric and has a better resolution than ASAR these five modes can be simulated using PHARUS data. Obviously, because of its resolution of 3 m together with a swath width of about 10 km, PHARUS is best suited to demonstrate ASAR applications that require medium resolution. These applications include geocoding, stereoscopy, land-use classification and the determination of directional wave spectra. Geocoding and land-use classification will be discussed in more detail.

With regard to land applications, several studies have shown that land-use classification with one single channel, e.g. the VV channel of the ERS satellites, is very restricted. Fully polarimetric SAR systems like PHARUS have been quite successful in providing detailed land-use classification results (see Figure 2). Therefore, PHARUS offers an unique opportunity to evaluate the possibilities of ASAR's dual-channel alternating polarization mode for land-use classification. Images with the characteristics of ENVISAT's ASAR operating in image mode, i.e. with a resolution of 30 m, a number of looks of 4, have been simulated using PHARUS data. An elevated area near Freiburg (Germany) and an area without elevation, the Heerde test site, were classified using a Bayes type classifier. It was concluded that in elevated areas only fully polarimetric (three channels) images could be classified. The classification using only two channels gave disappointing results. For areas without relief the extension from one to two channels is profitable and the classifier works well with only two channels.

4.2 Geocoding using simulated data

With steep looking angles like those of ENVISAT, relief displacements are a common distortion in the SAR imagery. Because of these distortions, points in the imaged scene are displaced towards the SAR platform (foreshortening) so that the images cannot be used directly for cartographic purposes, e.g. updating of geographic information systems. The procedure to correct for relief displacements, which is referred to as geocoding is basically a first-order transformation between the SAR image co-ordinate system and a selected geographic co-ordinate system, usually UTM. Implicitly contained in the transformation is that distorted ground range co-ordinates are restored to their actual positions by means of a digital terrain elevation model. The unknown parameters of the co-ordinate transformation are estimated from a number of ground control points, which are located at easy to recognize points such as crossroads or buildings in both the SAR image and an UTM map and have a known elevation. With known transformation parameters, a grid in UTM co-ordinates can be set up and for each point in the grid the corresponding point in the SAR image can be identified.

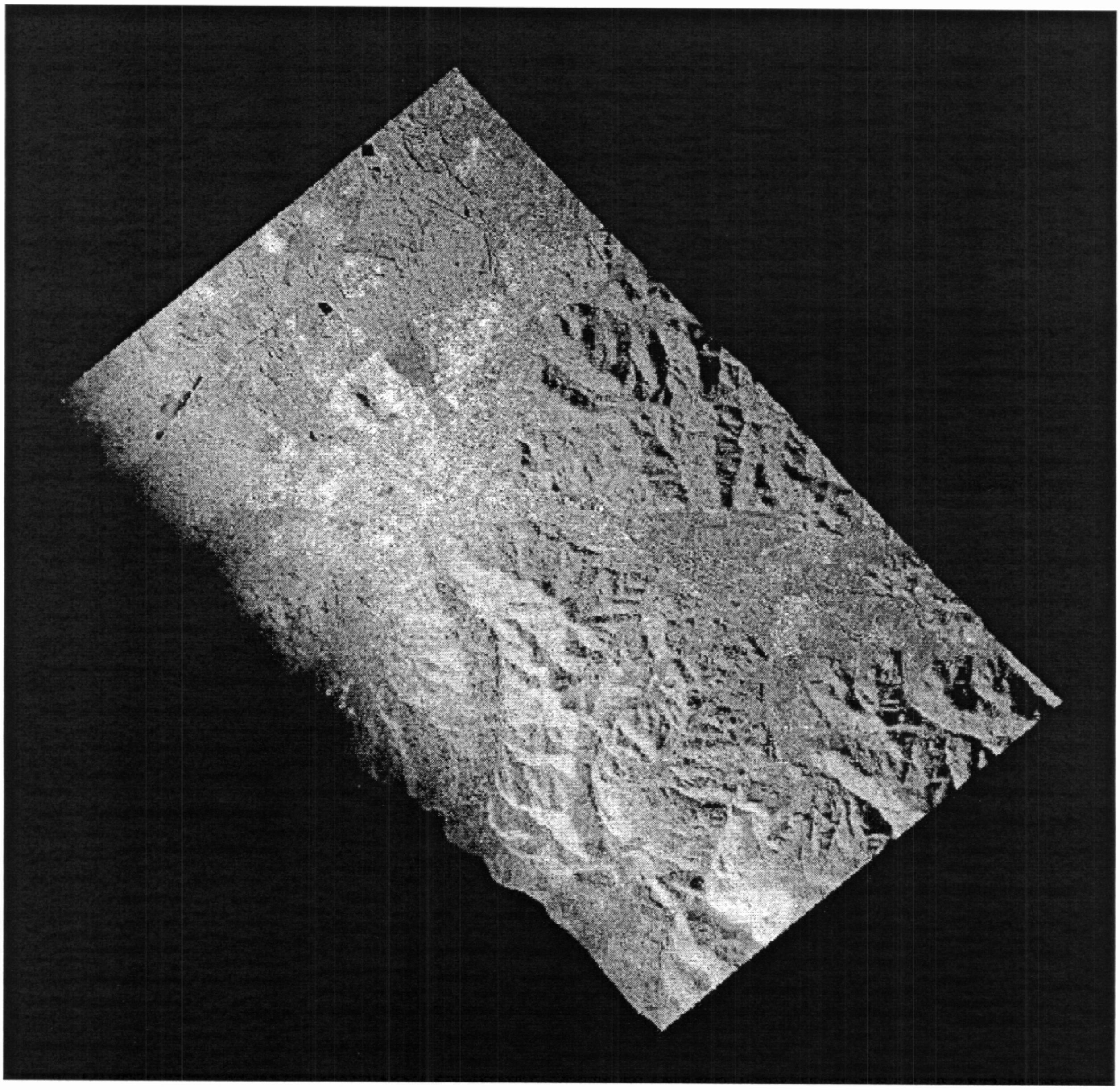

Figure 8. Geocoded SAR image of simulated ASAR data of the Black Forest in Germany.

The above procedure has been applied to a SAR image of the Black Forest, near the city of Freiburg in Germany, Figure 8. The image has the characteristics of ENVISAT's ASAR operating in image mode, it has been simulated with PHARUS. The accuracy of the geocoded image is estimated at 100 m, which demonstrates the ability of ASAR for geocoding purposes.

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