The PHARUS Familiarisation Programme*

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ABSTRACT

After the completion of the PHARUS polarimetric phased array SAR, an extensive programme of data acquisition was carried out under the PHARUS Familiarisation Programme, a project for the National Remote Sensing Board (BCRS). The Familiarisation Programme has been aimed at the acquisition of PHARUS data to demonstrate the potential of the PHARUS polarimetric SAR for a number of selected applications to potential users. In order to demonstrate the value of the system for each application, and to familiarise users with PHARUS data, interpretation of the data acquired has been carried out by the users involved in this project. The selected applications were land use classification, cartography in tidal areas, road detection, ocean bottom topography, detection of ships and ship wakes, (moving) target detection, crop classification, forestry applications and precision agriculture. For all these applications data were acquired. The main results are presented. Overall, most applications could be carried out successfully. For some applications, it is clear that more image material is required for a sufficient assessment of the utility of SAR polarimetric data. This is the case for tidal mapping and precision farming, where multi-temporal data is needed. Also, much insight has been gained into the characteristics of the PHARUS system in various modes of operation. Existing calibration procedures needed to be modified in order to calibrate the polarimetric data acquired with the phased array antenna.

1.0 INTRODUCTION

The PHARUS polarimetric SAR is an airborne synthetic aperture radar system, developed by TNO Physics and Electronics Laboratory (TNO-FEL), in co-operation with the National Aerospace Laboratory (NLR) and the Delft University of Technology (DUT). PHARUS stands for Phased Array Universal SAR. PHARUS is a fully polarimetric radar. This gives good tools for discrimination of targets/surfaces and provides information on the polarimetric backscattering properties of the objects in the swath.

The most important features are:

- Polarimetry; with the backscatter signal matrix S_{ij}, with $j = v$ or h is respectively horizontal or vertical polarisation of the transmitted signal and $i = v$ or h is the polarisation of the received signal. The two polarisations can be transmitted in turns and can be received simultaneously.

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Polarimetry is an important system property for applications like crop classification, reducing jammer effectiveness and many other applications.

- Phased array antenna with active Transmit/Receive modules. The phased array antenna allows fast beam steering for unwanted aircraft movements, spotlight mode, Moving Target Identification (MTI) and Scan SAR capabilities.

The familiarisation programme consisted out of seven flights. During these flights data were obtained for nine different applications. Each of these applications and their results (Rijckenberg, 1998) will be discussed. The slant range and azimuth resolution were about 3 m for all applications.

2.0 CARTOGRAPHIC APPLICATION DEMONSTRATION

The purpose of this group of demonstrations was to highlight the potential of PHARUS for cartographic applications. An important issue is the geometrical integrity of the SAR imaging process, as well as the positioning of the image in a reference co-ordinate system.

2.1 LAND USE CLASSIFICATION

For the demonstration on general land use classification a PHARUS image of an area near Assen has been supervised classified into the following types: forest, grass, bare soil, moor, urban and water. No in-situ data was available, so foreknowledge was required of the signatures of these land use classes (with the use of some learning pixels which were manually selected). The data is averaged over 5 by 5 pixels and 5 looks in order to reduce the effect of speckle and to obtain sufficient statistics. The main conclusions were:

1. Good classification results of three test sites were found for the six classes.
2. A small number of bare soil fields are grown with heather or grass and were erroneously classified as moor or grass.
3. Spillover of radar reflection to neighbouring pixels (caused by the manner in which the data is processed) causes the lake outskirts to get confused with the classes grass and moor.
4. Areas with no radar signal, due to shadowing, are wrongly classified as water or, as discussed above as grass or moor due to spillover.

Figure 1 shows the Heerde test site near Enschede 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 colours 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.

2.2 CARTOGRAPHY IN TIDAL AREAS

In order to manage and monitor fast-changing intertidal regions it is necessary to survey their conditions regularly. This is currently performed by ships using acoustic systems, and for places that are inaccessible for shipping it is performed manually. The difficulties and long time scale impose that the measurements are only carried out every three to five years. With a SAR system, the measurements can be performed on a more regular basis.

A single polarisation (VV) PHARUS image of the 'Groote Plaat' near the island of Terschelling was acquired. The image is first classified, then edge detection is applied. Three classification methods have been applied to this image, two based on manual classification and one with automatic classification. The results were:

1. The water line can well be determined by properly selecting the colours which are assigned to the classes.
2. Equal grey values have been given to various phenomena, because the reflection characteristics are the same. Current in a channel is given the same grey value as low sandflat.
3. It is not easy to automatically extract a digital tidal map from the PHARUS images.

3.0 CHANGE DETECTION FOR ROADS

In the Netherlands databases exist on traffic and infrastructure on land and water. One of these, the road database, has to be updated regularly. This is realised using information received from the road maintenance authorities. The changes in infrastructure are not given in a systematic or effective manner, leading to 'holes' in the road database. Remote Sensing is a possible solution to this problem. A PHARUS image of Amersfoort and a road graph file have been compared in this demonstration.

1. A clear shift between the two files can for the greatest part be attributed to the inaccuracy of the road graph file.
2. Within the urban areas roads are in many cases not directly recognisable, but can be deduced from the structure of the buildings surrounding the road.
3. Main roads can mostly be clearly indicated, but street patterns in residential districts often allow for multiple interpretations.

The PHARUS image contains a lot of information about buildings and consequently also about road patterns. Direct collection of road information will be possible in areas with sparse building, but in areas with complex building structures this proves to be difficult or even impossible. Here, more experience in human interpretation of PHARUS images is needed.

4.0 MARITIME APPLICATIONS

Maritime applications like the detection of oil spills have been operational in the Netherlands for many years. Also an advanced application like the mapping of the sea bottom topography with SAR has been developed in the Netherlands.

4.1 BOTTEM TOPOGRAPHY

The imaging mechanism of mapping sea bottom topography by imaging radar consists of three stages:

1. Interaction between (tidal) flow and bottom topography results in modulations in the (surface) flow velocity.
2. Modulations in surface flow velocity cause variations in the surface wave spectrum.
3. Variations in the surface wave spectrum cause modulations in the radar backscatter.

The image of the 'Groote Plaat' was used again. This image was geometrically corrected using suitable landmarks and the most recent topographic map of the area. Depth maps were constructed of the PHARUS image (spatial resolution of 3.0 m) and of ERS images (resolution of 12.5 m) using the acoustic data for calibration and hydrological and meteorological data for the modelling. The depth accuracy of the maps based on the PHARUS image (about 4 cm) is considerably better than the accuracy based on the ERS images (about 8 cm). Three reasons can be given:

1. The speckle level of the PHARUS data is lower, enabling better calibration.
2. The spatial resolution is better, which implies a better position of the radar data.
3. The better resolution allows for more detailed calculations which may improve the results.

4.2 DETECTION OF SHIPS AND SHIP WAKES

One of the oldest radar applications is the detection of ships at sea. An area of approximately 22 by 16 km was imaged in two adjacent east-west strips near Hoek van Holland.

1. Visual analysis of one strip yielded a total count of 12 targets (assumed to be ships) within a 180 km^2 processed area, one of the targets had a wake signature. In the other strip, 22 targets and 4 wakes were found in a 140 km^2 area.
2. Due to the lack of in-situ data, it can not be verified whether all targets were indeed ships or not, for instance they might have been large waves.
3. Based on visual analysis of the HH, VV and HV channels, it can be concluded that that ships are easily detected. Also ship wakes are readily imaged. The ships appear to have the highest contrast with respect to the sea clutter in the HV channel (although this signal is weaker than the HH and VV channels), indicating that the cross-polarised channels are best suited for this purpose, as long as there is sufficient signal to noise ratio.

5.0 TARGET DETECTION

This demonstration, mainly for military purposes, involved two applications.

5.1 MOVING TARGET IDENTIFICATION (MTI)

In normal imaging modes, on-board Doppler filtering is applied for the purpose of data rate reduction. This filtering also removes moving targets. Consequently, an imaging mode without pre-filtering had to be defined. Due to the higher data rate this was a single polarisation mode.

A SAR image of the A12 near Zoetermeer was analysed, see figure 2.

1. The raw data was processed with a shifted Doppler centroid. Resulting in a image with all reflections from static objects strongly suppressed, leaving only moving targets.
2. With the velocity approximately known from the azimut shift, the position of the targets on the A12 was calculated.
3. A composite image was made using the SAR image, processed in the normal imaging mode, on which the detected targets are superimposed with their velocities.
4. The minimal detectable velocity is about 20 km/h. Detection of slower targets requires more sophisticated MTI techniques, which in turn require modifications of the PHARUS system.

5.2 JAMMING (DISTORTION) OF AN IMAGE

A PHARUS image was distorted with a simple jamming device and model calculations were performed. It was tried to remove the effects of jamming by appropriate filtering.

1. With the jamming ground features were hidden in a small region of the image.
2. The results were in accordance with the model predictions; the model could partially be verified in this way.
3. With the aid of range-frequency filtering technique, the part of the image that was initially screened was revealed, which gave a slightly distorted image.
4. Only two out of four polarimetric channels were affected, as expected.

A very simple jammer has limited effectiveness against the PHARUS system. The jamming signal could be detected and removed. The latter will become more difficult when the jamming power is increased and the signal is randomised is some way, giving it a wider spectrum.

6.0 AGRICULTURE AND FORESTRY

It is known that in agriculture and forestry the use of polarimetric SAR has many advantages over single polarised data. Three applications are aimed at demonstrating the advantages of polarimetry in these fields.

6.1 CROP CLASSIFICATION

A supervised crop classification was performed on an image obtained at the Buitenland test area. Of this area ground truth data existed. The selected classes were: onion, beet, cabbage, bare soil, grass, barley, potato and wheat.

1. All pixels inside a field (field size and shape are taken from a database) were used to construct a feature vector for the crop type classification. The constructed vector comprised all relevant elements of the polarimetric covariance matrix.
2. From all fields in a class, a class mean and class covariance matrix were constructed, which are needed for the discriminant or Bayes classifier function.
3. Cabbage fields in which the plants have recently sprouted were confused with bare soil in 50 % of the cases.
4. Out of the 194 fields, 139 were correctly classified.

6.3 FORESTRY

Two images of the Reichswald were acquired, which is a mixed deciduous and coniferous plantation forest. A database with 150 samples (stands) was constructed covering seven forest classes. This database was used to asses classification possibilities using a maximum likelihood procedure.

1. For the seven selected forest types the mean backscatter values for the HH, VV and HV polarisation do not correspond to values expected for C-band radar. This is due to the fact that these radar data were not absolutely calibrated.
2. A classification result of 81.3 % for a multitemporal observation is found, which is not very high. This is due to the small dynamic range in backscatter of trees at C-band.

6.4 PRECISION AGRICULTURE

Precision farming considers differences in soil and crop conditions within the field before and during the growing season and uses these differences to fine tune and vary management within the field. A PHARUS image was taken of the van Bergeijk farm at Zuidland on may 29, 1997. For the use in precision farming PHARUS (C-band) seems not very promising. Lack of spatial resolution may be one reason. Not detecting the appropriate crop characteristics seems the most important reason. Later in the growing season when drought effects are generally more significant, PHARUS images will probably show more detail. However, precision farming is mainly dealing with the detection of differences in an early phase of the growing season to allow management adaptations.

7.0 CONCLUSIONS

The following conclusions about the familiarisation programme were drawn:

1. Despite some technical problems, data has been collected for nine different applications.
2. Seven applications, from land use to cartography to MTI, have successfully been demonstrated.
3. The results for tidal areas and precision agriculture were not satisfactory. It is expected that the results will improve if a temporal analysis is used.
4. The logistics involved with the PHARUS flights are complicated due to limited availability of the platform.
5. There is a clear need for more images, conclusions drawn for some applications are weakened due to the low number of images used.

8.0 FUTURE PERSPECTIVES

1. Interferometry is being developed for monitoring the Dutch dikes and land subsidence due to gas extraction. This requires beam steering within 0.5° and precision flying of the aircraft (within a 10 m corridor).
2. ASAR modes are being tested with PHARUS for both land and sea usage.
3. High resolution modes are investigated, extended bandwidth (resolution of about 1.5 m) and spotlight (resolution increase of an order of magnitude).
4. Improved MTI modes are investigated with the antenna split in two receiving halves (lower bound for velocity of about 5 km/h).

9.0 REFERENCE

G.J.Rijckenberg, A.J.E.Smith, A.C.van den Broek, H.Greidanus, R.J.Dekker, J.Kogels, M.P.G.Otten, H.Landa, G.H.F.M.Hesselmans, O.Pietersen, H.W.G.Booltink, D.H.Hoekman, M.A.M.Vissers,"The PHARUS Familiarization Programme", NRSP Report, No. 98-18, pp.1-137, November 1998.

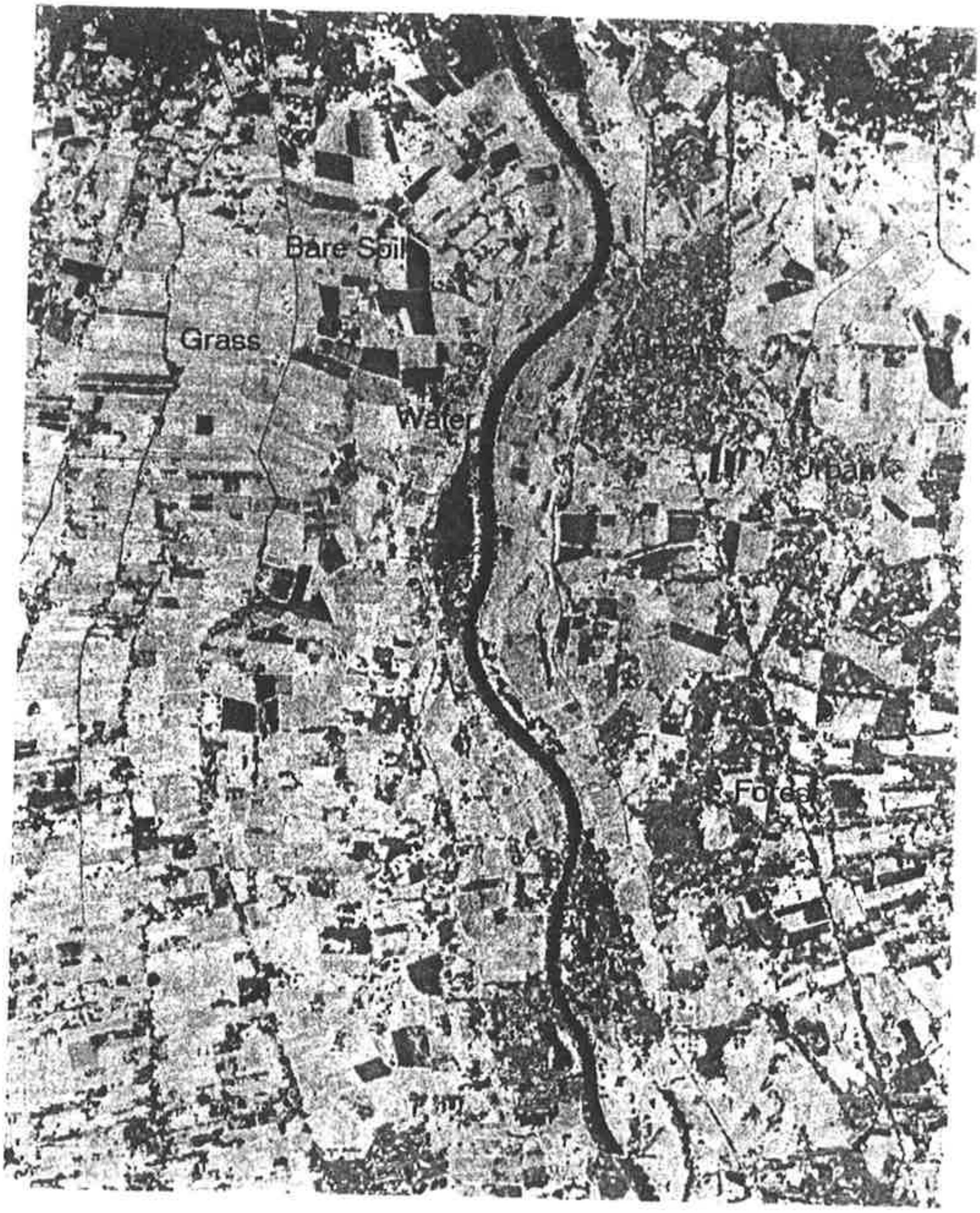

Figure 1.Land Use Classification of the Heerde Test Site into Water, Urban, Forest, Grass and Bare Soil (Examples are indicated in the Figure).

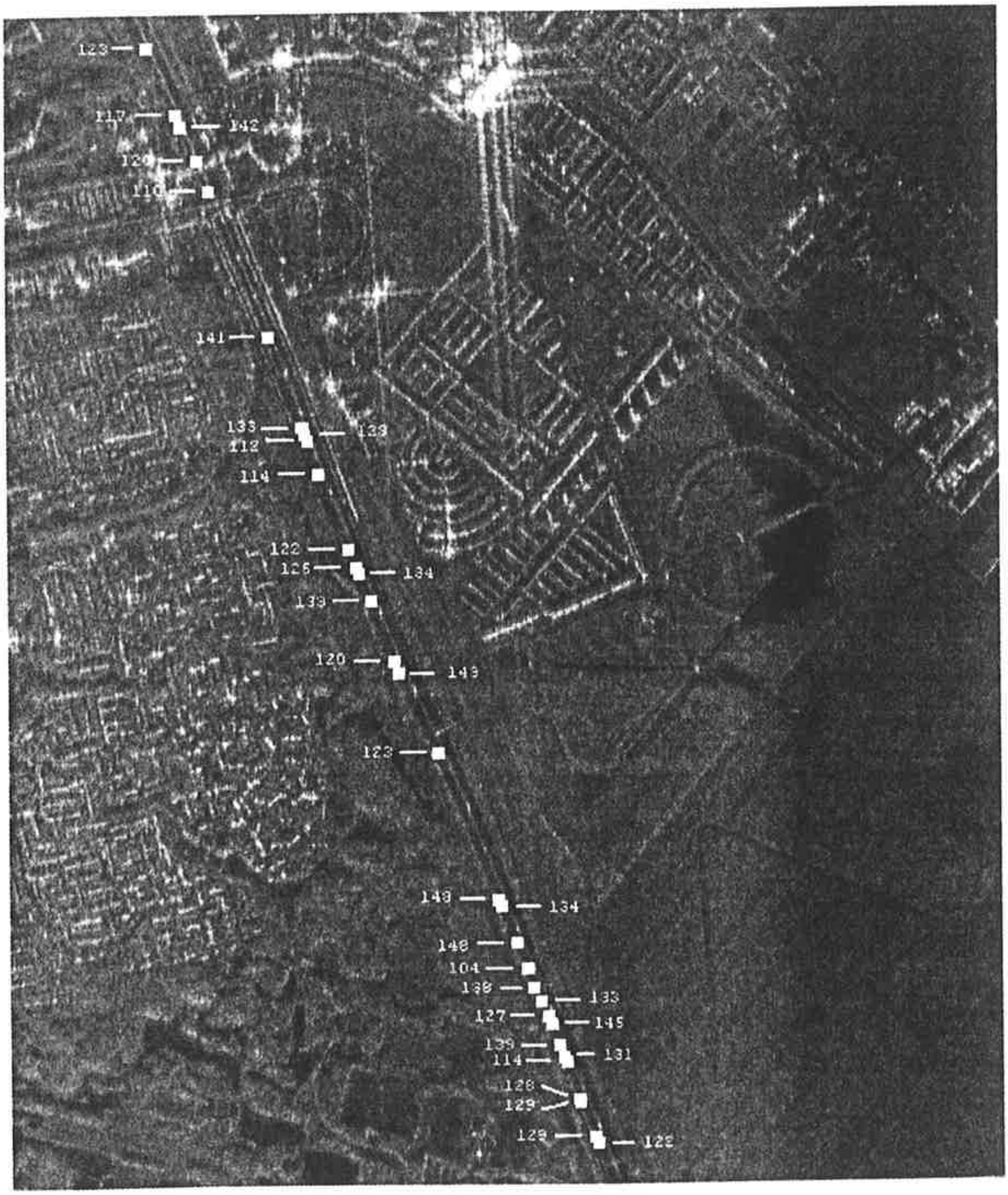

Figure 2. SAR Image with the Speed (km/h) of the Moving Targets superimposed. Only Targets travelling on the Left Lane (driving from Top to Botttom) are shown. (Note that the Legal Maximum Speed on Dutch Highways is 120 km/h.)