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PHARUS Market Assessment Report

Final report

M.R. Ritt-Fischer
D. van Halsema
H. Pouwels
G.J. Wensink

BELEIDSCOMMISSIE REMOTE SENSING

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M.R. Ritt-Fischer
Fokker Space
D. van Halsema
TNO-FEL
H. Pouwels
NLR
G.J. Wensink
ARGOSS

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This report describes a project, carried out in the framework of the National Remote Sensing Programme (NRSP-2), under responsibility of the Netherlands Remote Sensing Board (BCRS).

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1. Abstract

In recent years PHARUS, a phased array synthetic aperture radar airborne instrument, has been developed by a Dutch team of institutes. Now that the experimental value for PHARUS has been demonstrated, it is important to investigate the commercial potential of this instrument in an end-to-end system for operational services.
In the presented study, the PHARUS system as-is is described as well as its applications and potentials. In addition, the market and the competitors are examined.

It is concluded that:

- both bathymetry and tropical forest monitoring are valuable applications which should be investigated in more detail
- for commercial applications, improvements of today's PHARUS instrument are needed:
    - for the bathymetry, the high-resolution mode being the most relevant one, faster data processing is highly desirable
    - for tropical forest monitoring, interferometry has to be implemented in support of an operational system
- the end-to-end approach, advocated for these applications, provides a leading edge with respect to competitors
- clustering of parties, providing the required capabilities for this approach, is a condition for commercial success

The latter condition can be met by the formation of an industrial consortium, for which this study team can be viewed as a precursor.

2. Executive Summary

Several years ago three Dutch institutions (the TNO Physics and Electronics Laboratory, the National Aerospace Laboratory NLR and the Delft Technical University) developed a C-band airborne phased array synthetic aperture radar, called PHARUS. Now that the final design of the PHARUS (PHased ARray Universal SAR) has been completed already for some time, and a familiarization study is ongoing to familiarize the potential Dutch customers with the possibilities of PHARUS, time has come to investigate the potential commercial applications of PHARUS or potential future developments on PHARUS.

As PHARUS was designed for both civil and military applications, the PHARUS design is universal, i.e., a large flexibility in operation modes. The universal character of the design makes PHARUS suitable for a large number of applications, however it also implies that PHARUS was not optimized for the operational use of for any specific application yet.

Within the Netherlands, the owners of the current PHARUS (TNO-FEL, NLR) have been joined by industry (Fokker Space) and value-adders (ARGOSS) to investigate the commercial potential of PHARUS as part of a so-called end-to-end system. An end-to-end system comprises a combination of the remote sensing system, a data-processing system, an application and the data-distribution system to get the data to the users in a timely manner.

In the presented study the current PHARUS system is described. A first inventarisation of potential commercial applications of PHARUS is given and a trade-off is made to identify the most promising one.

It is concluded that:

- both bathymetry and tropical forest monitoring are valuable applications which should be investigated in more detail
- for commercial applications, improvements of today's PHARUS instrument are needed:
    - for the bathymetry, the high-resolution mode being the most relevant one, faster data processing is highly desirable
    - for tropical forest monitoring, interferometry has to be implemented in support of an operational system
- the end-to-end approach, advocated for these applications, provides a leading edge with respect to competitors
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The latter condition can be met by the formation of an industrial consortium, for which this study team can be viewed as a precursor.

3. Introduction

The development of the Netherlands polarimetric Synthetic Aperture Radar (SAR) PHARUS (PHased ARray Universal SAR) has entered a stage in which the instrument has been technically developed and the users are being familiarized with the instrument. Now the time has come to evaluate whether PHARUS should be operationalized and industrialized. To this end this first global market assessment of PHARUS market potential has been performed.

Due to budgetary constraints of the study the market assessment presented here is based on information already available with the partners, and yields insight in:

- the products/services/applications
    - ◊ which are the most viable w.r.t. operationalization/commercialization
    - ◊ how well are they developed
    - ◊ (how competitive are they)
- market volume
- cost build-up and marketprice
- technology overview:
    - ◊ what is already available
    - ◊ which technical developments are needed to make PHARUS more commercially viable (e.g., making PHARUS interferometric, platform independent)

The market assessment has been performed in close cooperation with and based on the results of the PHARUS Familiarization project. Furthermore the initiatives and results of the feasibility study of the use of PHARUS for tropical forest monitoring applications (SIRAMHUTAN: Sistem Informasi Radar untuk Menejemem Hutan; formerly: RASIMHUTAN: Radar Sistem Informasi Manajemen Hutan) have been used as input.

A trade-off, based on the answers to above questions and criteria has resulted in the choice of a launching application, for which the framework of a businessplan has been written.

For general information about the PHARUS project and system, the reader is referred to the BCRS report 96-28 ("PHARUS Executive Report")

In order to take full advantage of the commercial potential of the PHARUS system, products and services, strategic cooperation of interested parties from industry, institutes and universities is a key factor for success. Such a cooperation (possibly formalised as a consortium) could undertake the required operationalisation and commercialisation of the current experimental PHARUS system and promising SAR applications and prepare for operational services. In particular, integration of PHARUS-based data acquisition and generic SAR processing with specific applications and supporting services (providing an end-to-end system) would greatly enhance the competitive market position of such a consortium, which would unite Dutch capabilities for the complete remote sensing chain. This approach is in line with Dutch governmental policy and provides continuity for technology development, research and industrial activities.

Currently, a number of project-oriented initiatives can be viewed as precursors to a PHARUS-oriented consortium:

- the SIRAMHUTAN program, focussed on operational tropical forest management, with Fokker Space, NLR, TNO-FEL, WAU and ITC as partners
- the SIMBA project, focussed on operational Coastal Zone Management, with Fokker Space, ARGOSS, NLR, TNO-FEL and Delft Hydraulics as partners
- the ICALA platform, aiming at development and implementation of operational airborne remote sensing, with Fokker Space, NLR and Eurosense as basic partners.

For ICALA, it should be noted that the development of commercial/operational services based on PHARUS and available (pre-)operational applications has recently become a viable option. For this purpose, ICALA needs to be formally extended with TNO-FEL and value adding companies like ARGOSS.

Given these developments, the ambitions of the partners involved and present national interests to further develop and operationalise PHARUS and related applications, it seems logical that a consortium in the above sense will soon amalgamate from these and other (e.g. this very PHARUS market assessment) precursor initiatives. The kernel could well consist of TNO-FEL and NLR as owners of the current PHARUS system and providers of technology development, Fokker Space as industrial and commercial coordinator and system integrator together with value adding industries like ARGOSS, providing operational applications with commercial potential. It is in this sense that the phrase “a Dutch PHARUS consortium” is used in this report.

4. PHARUS Technical Today and tomorrow

4.1 Today

This chapter describes the PHARUS functional flow, from data-acquisition and -processing, to data distribution. This flow is depicted in Figure 4-1, Figure 4-2 and Figure 4-3.
In Figure 4-1 the Flight Operations functional flow is given. This includes the preparations of the flight(s) and the actual performance of the flight campaign with PHARUS attached to the Citation aircraft. Figure 4-2 reflects the data pre-processing functional flow. Items covered in this chart include the pre-processing of the data collected on board of the aircraft during the flight campaign and the merging of the various necessary data-flows. Finally, in Figure 4-3 the SAR data-processing functional flow is covered. As potential extra processing steps georeferencing, terrain height modeling, mosaicing and / or mapping are included.

Furthermore a global assessment of the feasibility of the market-driven requirements and their implications for the design of PHARUS, and the related necessary investments are given.

4.2 Tomorrow

The current ideas for further development of PHARUS include the inclusion of interferometry, acceleration actions for the Generic SAR Processor, development of a Quick Look Processor. However, it should be noted that the sequence of any further developments will depend specifically on the market which is to be served.

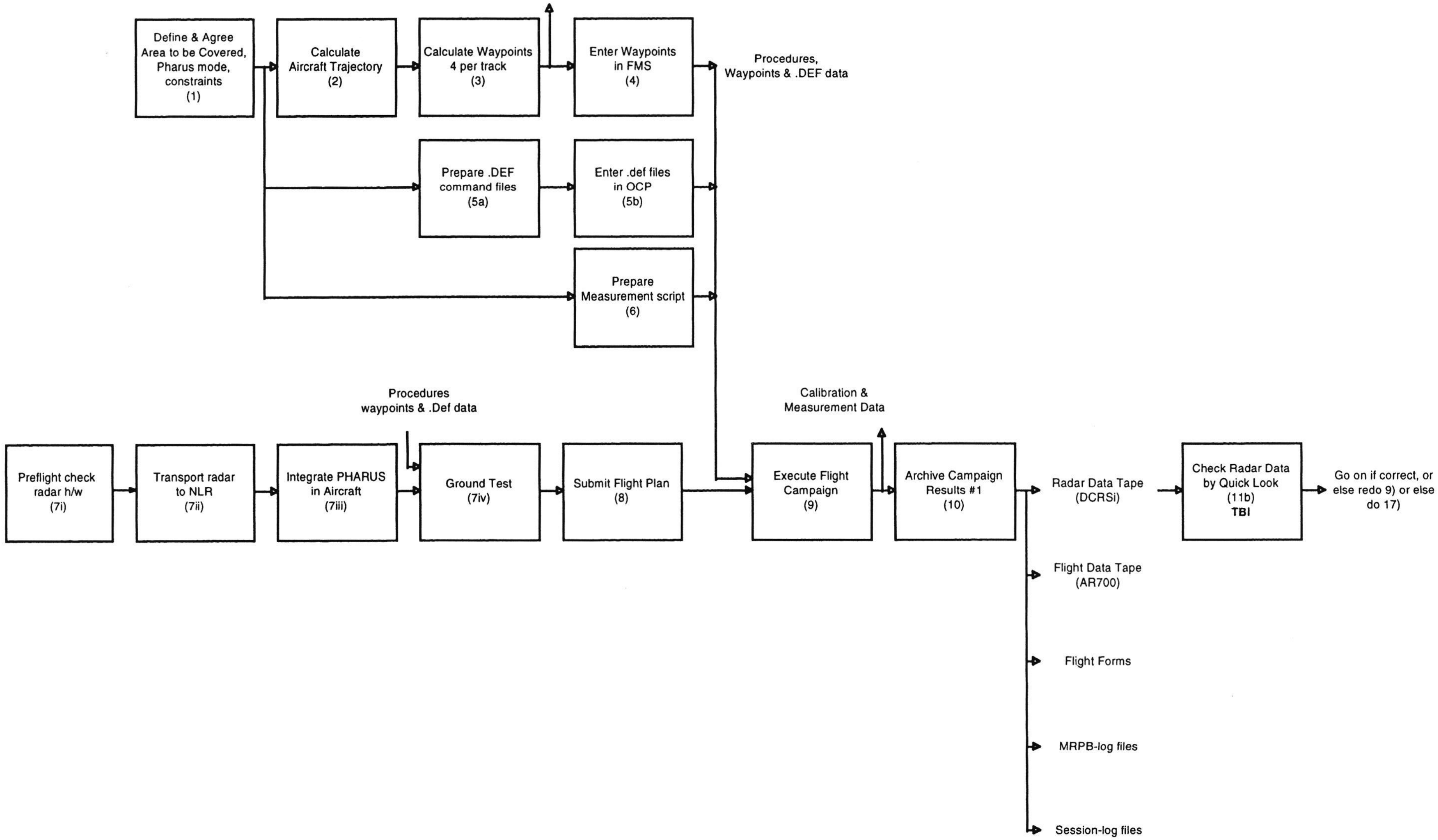

Figure 4-1: *Flight Operations functional flow block diagram.*

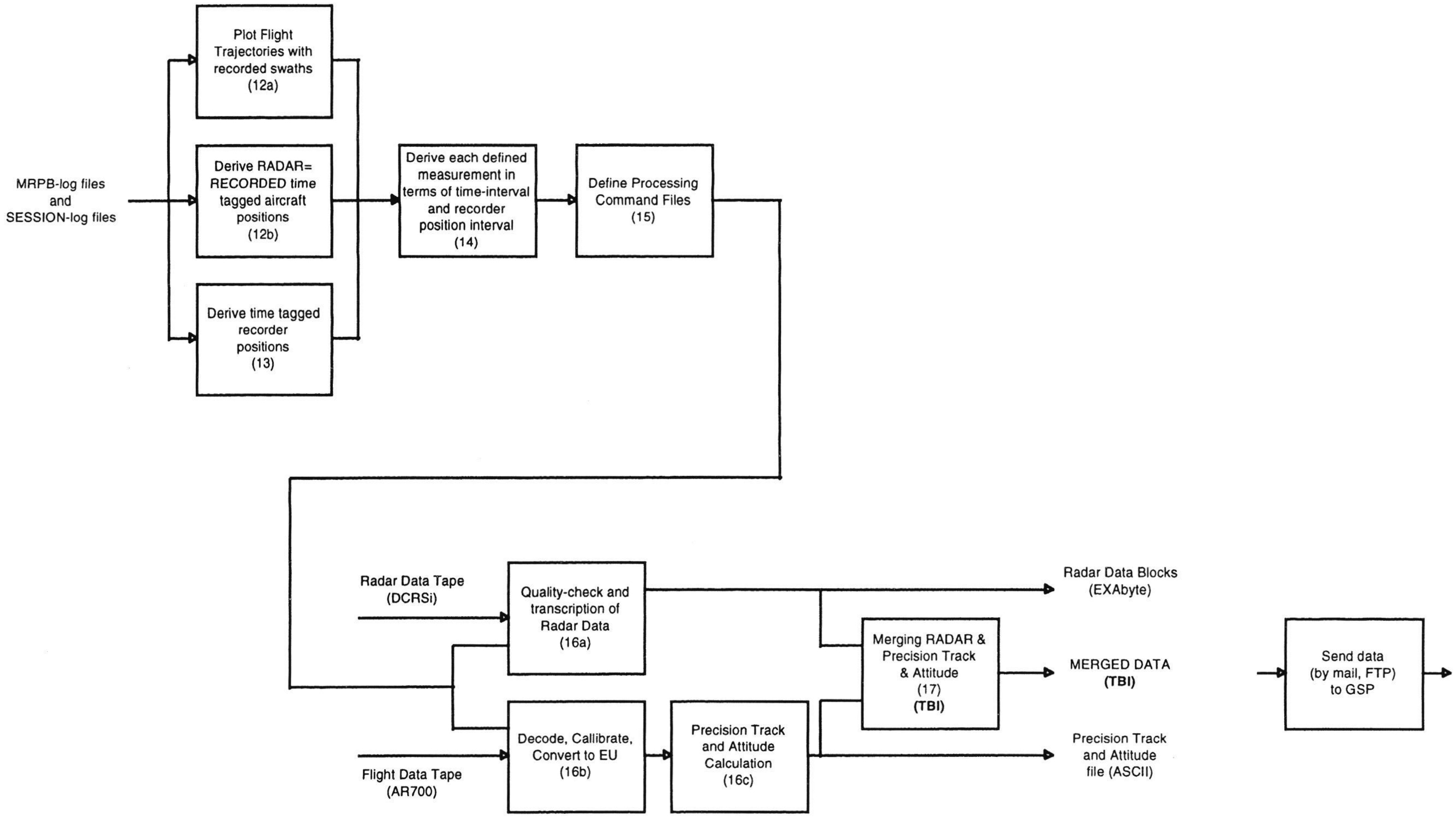

Figure 4-2: *Data Pre-processing functional flow block diagram*

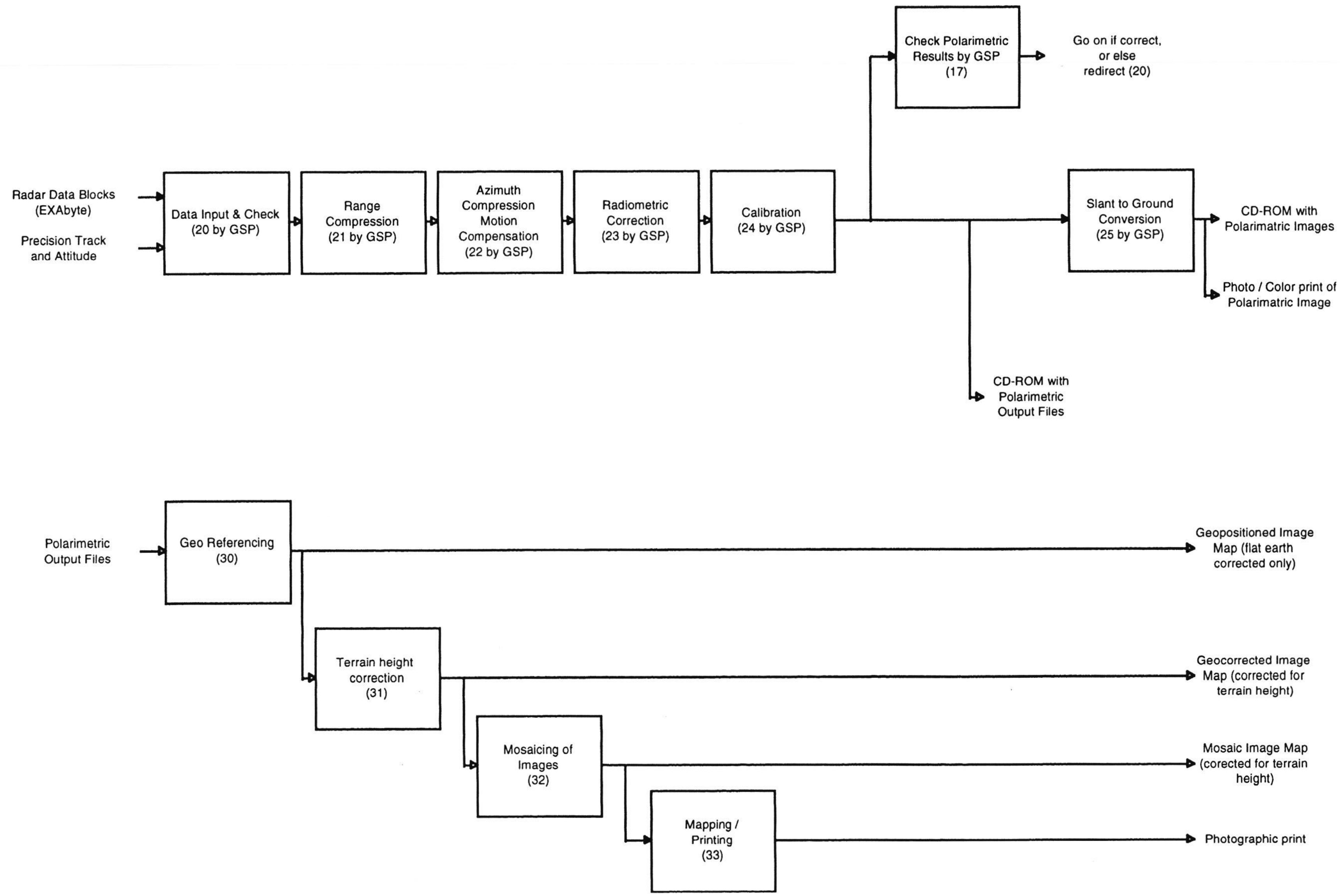

Figure 4-3: *Data Processing-2 functional flow block diagram*

PHARUS can measure long uninterrupted tracks. For processing purposes and due to computer and datastorage limitations the tracks have to be cut into smaller pieces ("scenes") of approx. 1 Gbyte. The two modes considered in this report are the High Resolution Wide Swath Mode (most commonly used) and the Bathymetry Mode. Please refer to Table 4-1for a defintion of scenes.

Table 4-1: *Scene definition per mode*

	High Res. Wide Swath Mode	**Bathymetry Mode**
flying altitude	4.5 km	6 km
swath width	8 km	11 km
distance between tracks	6 km	9 km
spatial resolution	3 x 3 m (4 looks)	6 x 6 m (16 looks)
	size per scene (length x width)	size per 'super-scene' (length x width)
1 scene raw data	10 km x 8 km	22 km x 11 km
1 scene after SAR processing	8 km x 8 km	20 km x 11 km
1 separate scene in a track	8 km x 8 km (effective size)	20 km x 11 km (effective size)
mosaiced scenes within long track	6 km x 8 km (effective size)	18 km x 11 km (effective size)
mosaiced scenes within large area	6 km x 6 km (effective size)	18 km x 8 km (effective size)

The use of the present PHARUS can be roughly divided into three different cases. In the first case, which is mostly used with PHARUS at this moment, PHARUS is being used to collect data 'here and there', a scene at a time. This case is mostly applied for scientific or demonstration purposes. In the second case being considered for PHARUS operations, the four hours of flying time will be used to measure 80 consecutive scenes. Such a case is used to cover large areas, for mapping or management purposes. For a bathymetric campaign case 3 is defined. For this case the preconditions are more stringent with respect to the tide, current, wind and waves, and a number of standby days has to be reserved in addition to the flying time.
In Table 4-2 these cases have been summarized.

Table 4-2: *Definition of cases*

	case 1 research flight	case 2 production flight	case 3 bathymetry campaign
test flight	no	no	yes
number of flights	1	1	3
standby days	0	0	3 ‡
approx. flying time	3 hrs	4 hrs	10 hrs
number of tracks	5	4	20
number of (super-)scenes	5	80	30
total processed km2	320	5120	6600
total effective km2	320	3000	5000
polarization	quad	quad	VV

‡: due to strict requirements on tide, current, wind, waves

Only limited on-ground testing takes place after the mounting and installation of the PHARUS equipment in the Citation airplane.
After the flight, the flight trajectory is plotted on an A4 map of the Netherlands, identifying the tracks along which was measured.

5. Available other Airborne SAR systems

In general it can be stated that airborne remote sensing data are more expensive than space-borne data per square kilometer due to the cost of flying the sensor. This is due to the fact that usually the cost of development and launch of a satellite are not passed on to the customers, whereas the depreciation of planes is included in the price of data. For some applications, however, a higher spatial and temporal resolution is required than presently available by spaceborne remote sensing, but which is available through airborne remote sensing. Therefore there is a market for airborne remote sensing data, and (as detailed furtheron in this document) specifically for airborne SAR data.

This study has focused on the market potential of products and services which can be provided by the use of airborne end-to-end systems based on PHARUS technology. In this section we focus on the available other airborne SAR systems, which can be potential competitors for PHARUS (for summary, ref. Table 5-1).

For a complete overview, including space-borne SAR systems, please refer to the appendix, Table 12-1.

The most serious competition is formed by instruments which can be used in an operational manner. These include the Aerosensing AeS-1, the Do-SAR and the Intermap STAR 3i, which are engaged in commercial activities. Also to be included in the list of operational airborne SAR instruments is the US-based AirSAR, which up to now, however, has only been employed for scientific campaigns, and not on the commercial market.

All these systems are interferometric, whereas PHARUS is not. PHARUS can be used in a repeat-pass interferometric mode, but this involves at least twice the number of flights necessary with respect to single-pass interferometric capabilities, and this mode has not been proven yet for height-mapping. Especially in mapping campaigns, where also Digital Terrain Models have to be created, this interferometric capability is crucial. The advantage over the competitors of the PHARUS sensor is its polarimetric capabilities.

There is however one significant difference between the competition and PHARUS. The PHARUS sensor is to be incorporated into an end-to-end system, which is specifically tailored towards the user-needs.

For most applications a combination of (several) airborne / spaceborne sensors will be most effective in meeting all the user requirements. For maximum effectiveness these sensor systems will have to be incorporated into an end-to-end system. Such an end-to-end system further consists of ground-stations for receiving the satellite data; data-processing systems to manage the large amount of data in a timely manner; applications which convert the data into the required information for the user; and a data-distribution system to send the information to the users. Furthermore such a system can only be effective if attention is given to operations planning, operations and maintenance, education and training, and to on-going supporting research.

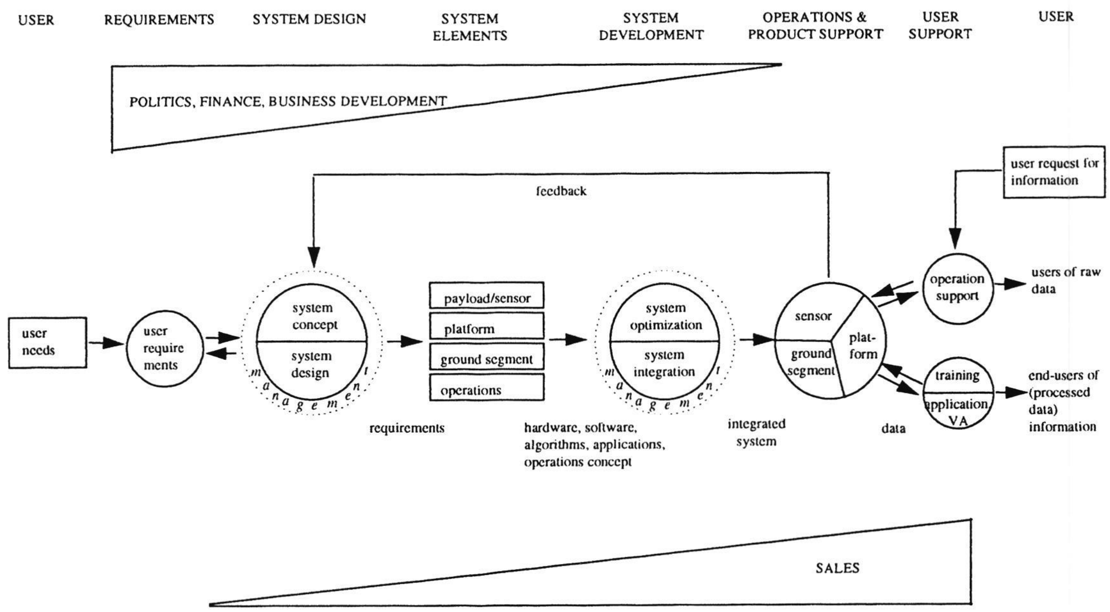

Figure 5-1: *End-to-end system*

Within the Dutch PHARUS team extensive expertise exists on all elements of the envisaged end-to-end system. This includes knowledge of applications (such as e.g. tropical forests, bathymetry); remote sensing expertise; SAR (Synthetic Aperture Radar) techniques; operational expertise with airborne (and spaceborne) SAR and optical remote sensing systems; and managerial, technical and educational skills to develop and operate complex operational systems.

Table 5-1: *A Summary of Competitive Airborne Imaging Synthetic Aperture Radar Systems (concise information)*

System (country) (platform)		freq	Range res	Azim res	looks	look incidence angle	polarimetry	altitude	Swath	interferometry	power	pro-cessing cap.	quick look
		GHz	m	m		deg.		km	km	m	kW		
Do-SAR (Germany)													
(DO-228)	**L**		3	3	8		HH,VV	10	3.6				
	C	5.3	0.4	0.4	8		quad	10	3.6	1	1	Y	Y
			3	3	8		HH,VV						Y
			2.5	3	7		VV	10000 ft	8-10	Y			
	X	9.6	3	3	8	30-89	quad	0.1-3.6	0.5-10	-	2	Y	Y
	Ka	35	1-3			30-89	HH	0.1-3.6	0.5-10	-	1	Y	Y
E-SAR (Germany)													
(Dornier DO-228)	**X**	9.6	2	2	8	25-70	HH/VV or HH/HV or VV/HV	3.6 (1.0-6.0)	3-5		2.5		
	C	5.3	2	2	8	25-70	HH/VV or HH/HV or VV/HV	3.6 (1.0-6.0)	3-5		0.05		
from 1999	**S**	3.3					HH/VV or HH/HV or VV/HV	3.6 (1.0-6.0)	3-5		2.0		
	L	1.3	2	2	4 or 8	25-70	quad	3.6 (1.0-6.0)	3-5		0.36		
	P	0.45	12	12	4	25-70	quad	3.6 (1.0-6.0)	3-5		0.18		
INSAR (Germany)	**X**		2.5	2.5	7		VV	10000 ft	7	Y			
INTERA-IRIS (Canada)	**L**		5-30	6-10									
	C		5-30	6-10									
	X		5-30	6-10									
Intermap STARMAP (Canada)	**X**	3.2	6	6	7		HH		23				
Intermap STAR 3i = ERIM IFSARE (Canada)													
(Learjet 36)	**X**		2.5	5	7		VV	12	10	3			
Hughes HISAR (USA) (Beechcraft Raytheon King Air 200)	**X**		1.8						100			Y	Y
ERIM P3												Y	
(NADC P-3)	**L**	1.25	8.4	2.2	4	11-79	quad	3-8	6-48				
	C	5.3	8.4	2.2	4	11-79	quad	3-8	6-48				
	X	9.34	8.4	2.2	4	11-79	quad	3-8	6-48				
ERIM DCS													

System (country) (platform)		freq	Range res	Azim res	looks	look incidence angle	polarimetry	altitude	Swath	interferometry	power	pro-cessing cap.	quick look
		GHz	m	m		deg.		km	km	m	kW		
	X						quad				1		
	Ku						VV				0.077		
DCRS EMISAR (Denmark)												Y	Y
(military Gulfstream G-3)	**L**	1.25	2-8	2-8			quad	17	12-48	1-2	6		
	C	5.3	2-8	2-8			quad	17	12-48	1-2	2		
PHARUS (Netherlands)												Y	
(Citation)	**C**	5.3	3.75	1	1		quad	4.5 - 12	8		1		
Aerosensing AeS-1 (Germany) (Dornier DO-228, Cessna 207A, Rockwell Aero-commander 685)	**X**	9.6	0.5-2	0.5-2	4-16			3.5	1-14.8	0.5		Y	
CCRS													
(Convair 580)	**C**	5.3	6-20	6-10	7	0-85	quad	5-6	18-63				
	X	9.25	6-20	6-10	7	0-85	quad	5-6	18-63				
PHARS (Netherlands) (Metro)	**C**		4.8	1	1		VV	7.5	12				
TOPSAR										Y			
(DC-8)	**C**		5-10	1-3									
AirSAR (USA)													
(DC-8-72)	**L**	1.25	8.4	2.2	4	11-79	quad	3-8	6-48				
1500 kg	**C**	5.3	8.4	2.2	4	11-79	quad	3-8	6-48	Y	60		
	P	9.34	8.4	2.2	4	11-79	quad	3-8	6-48		62		
AMPS (Lockheed RP-3A)		14.85	1-3	1-3		9-60	VV	1500-20000 ft	6-16		0.75		
BYU SAR/Y-SAR (360 lbs)			1.5	0.5									

6. Potential Markets and products

Over the recent years many potential applications of SAR services and products have been investigated and developed. Within the framework of the familiarisation process of end-users with the PHARUS system, a number of these applications have been selected for demonstration purposes in a BCRS funded project. These applications were:

1. sea bottom topography,
2. tide monitoring,
3. oil spill detection
4. ship- and ship wake detection,
5. crop classification
6. precision farming
7. forest monitoring
8. road detection / determination
9. military target detection
10. moving target detection

From this basic list of potential applications a selection has been made of the four most promising markets and products. The following four main products lines were distinguished:

1. Bathymetry (1)
2. Civil Cartography (2, 8)
3. Tropical Forest Monitoring and Management (7)
4. Military applications (4,9,10)

The numbers in brackets refer to the application numbers as given in the upper list. From this original list of applications, oil spill detection was at present not selected as main product line because this application is presently being served by a governmental SLAR system. Of course it might become a market for PHARUS SAR technology when the present SLAR system needs to be replaced, but this is not an issue at the moment of writing of this report. Crop classification is another important application that was not selected. The reason for this is, that although at present crop classification for selected areas is a commercial business contracted out by the European Community, the EC only funds the use of optical satellite imagery and not of airborne imagery (optical nor microwave). As such this market at present only consists of providing a back-up system in case the optical satellite systems do not provide imagery in time. Precision farming is at the moment of writing of this report not yet a proven application.

In the following paragraphs the selected four main product lines will be dealt with in more detail.

6.1 Bathymetry

6.1.1 Potential bathymetric products

In this section an overview is presented of several bathymetric products for different applications. Also, a strength-weakness analysis with respect to satellite data has been made to assess the potential of PHARUS for these applications.

6.1.1.1 Bathymetric maps for maritime charting

Maritime charting: production of Admiralty and equivalent navigational charts for the purpose of save shipping. Information in Admiralty charts is typically based traditional echo-soundings and is often out-dated. Maps based on data more than 20 to 50 years old are not exceptional. Remote sensing provides a means to obtain updates over large areas.

Market sector
Naval authorities: hydrographic department or other governmental agencies with a responsibility for mapping of national waters.

User requirements

horizontal resolution	50 m
vertical accuracy	30 cm

Market size
The market at the moment is completely covered by Hydrographic offices (except Indonesia and Malaysia). However, the market is privatizing. The turn over if this market is 1M US$ at the moment and it is expected to grow towards 1000 M US$ the coming years on an annual basis.

Product cost
16,000 US$ per square kilometer by conventional instruments

60 – 60.000 km sq.

6.1.1.2 Bathymetric maps for hydrodynamic modeling

Bathymetric maps for the purpose of hydrodynamic modeling and morphodynamics and to be used in civil engineering projects over large coastal areas.

Market sector
These surveys would usually be commissioned by consulting engineering companies or by governmental agencies.

User requirements

horizontal resolution	20 - 100 m
vertical accuracy	50 cm

500 kmsq /yR

Market size
The market at the moment is in the order of 1 M US$ but will grow up to 5 M US$ annually
Product cost 7,500 to 10,000 US$ per square kilometer

6.1.1.3 Bathymetric maps for submarine engineering projects

Bathymetric maps of long narrow areas in shallow waters to used in various stages of submarine pipeline / telecommunication engineering projects.

These submarine engineering projects are typically executed in several phases: reconnaissance, route, pre-lay, as-laid and as-built survey. During the reconnaissance phase a selection of potential routes is made taking into consideration the total length of the route and the number of obstacles (sand waves) to be expected. As the project proceeds and additional depth measurements become available the range of potential routes is reduced. For example, during the route-survey is single track sailed to look for uncharted objects and/or unexpected depth modulations. Using high resolution SAR imagery this single track information can be extrapolated to improve existing bathymetric maps in a corridor along the sailed track. Thereby the sounding effort in subsequent phases can be reduced and the selection of the route can be optimized.

Market sector
These surveys would be commissioned by consulting engineering companies or by oil / gas companies or telecommunication operators.

User requirements

horizontal resolution	5 - 50 m
vertical accuracy	20 - 100 cm

Horizontal resolution and vertical accuracy depend on stage of the project. The least accurate result is required in the reconnaissance phase whereas the highest accuracy is required in the as-laid and as-built phase. Information about the global depth range and local depth modulations is more important than absolute depth accuracy.

Market size
1 - 10 M US$ annually

Product cost*
7,500- 16,000 US$ per square kilometer

=> ± 10.000 kmsq /yR
(10 MUS$ / 10 kUS$)

6.1.1.4 Bathymetric maps for mineral and hydrocarbon exploration reconnaissance

Bathymetric maps to be used for mineral and hydrocarbon exploration reconnaissance surveys of shallow-water concessions (marine and fresh water).

Market sector
These surveys would be commissioned by oil / gas and mining companies.

User requirements

horizontal resolution	5 m
vertical accuracy	20 - 100 cm

Information about the position of flaws in the earth crest is more important than absolute depth accuracy.

Market size
5 - 10 M US$ annually

Product cost*
7,500- 16,000 US$ per square kilometer

6.1.1.5 Bathymetric maps for fishery purposes

Bathymetric maps to be used in support of fishery, for example mapping of spawning areas. These maps can best be sold in conjunction with an analysis including other environmental data important for breeding of a certain species. Relevant data might be tidal range, current direction and velocity, sea surface temperature (from thermal infrared images), turbidity maps, etc.

Market sector
These surveys would be commissioned by governmental and international agencies such as EU, WB, ADB, LAB etc.

User requirements

horizontal resolution	100 m
vertical accuracy	30 - 50 cm

Market size
.5 - 1 MUS$ annually

Product cost*
7,500- 16,000 US$ per square kilometer

6.1.2 Use of PHARUS for bathymetric purposes: strength-weakness analysis

Present SAR based bathymetric applications mainly make use of satellite-borne (ERS) imagery. To assess the market potential of PHARUS images for this purpose and select suitable product-market combinations, a strength-weakness analysis of PHARUS versus ERS imagery is relevant.

PHARUS strengths:
1. better resolution / noise level
2. deployment flexibility
3. adjustment flexibility
4. polarimetric capabilities

PHARUS weaknesses:
1. costs
2. limited experience
3. transport costs
4. limited width of image

These points will be worked out in more detail below.

6.1.2.1 Strengths

1. The most important asset of PHARUS is its resolution of 4 m (4 looks) compared to 20-30 m (3 looks) for ERS. This improved resolution opens new markets: detection of small scale under water features such as ship's wrecks or shoals near harbors or in rivers. It also makes possible an improved positioning of prominent features such as channel walls. By pixel averaging the noise level of the signal can be reduced at the cost of reducing spatial resolution at the same time. The improved noise level enables the detection of less prominent depth variations, whose signatures would otherwise be swamped in the noise. Applying high resolution PHARUS imagery to produce depth maps on a 25 m grid has the advantage that the accuracy of the mapping improves (error reduction up to a factor of six) and that remote sensing methods may be used in areas where ERS is not sensitive enough (sand waves in the North Sea).
2. In contrast to the ERS satellite, which is bound to fixed orbits, PHARUS has the flexibility to take SAR images under optimum tidal and weather conditions. If maximum mapping accuracy is required, it is possible to obtain several images of the same area under different looking and tidal direction on one day.
3. For each obtained image, the PHARUS instrument may be adjusted to the conditions at that moment for optimum performance. This will further improve the quality of the depth assessment.
4. Polarimetric capabilities of PHARUS are presently not relevant for coastal mapping as the models do not use this extra information.

6.1.2.2 Weaknesses

1. The costs of a PHARUS image is much higher than of an ERS image, whereas the ERS image covers a much wider area. The latter is not a real problem: usually only a small part of an ERS image is used for depth assessment, whereas PHARUS can take an image of exactly the required area. The costs should be compared with the (much higher) total cost of map production, which include collection of ship's soundings and processing of the images.
2. ESA is by now an experienced organization which can take orders, program ERS, process and ship data on a routine basis. For PHARUS, this experience yet has to be built up.
3. ERS, as a satellite, can operate world-wide without extra costs. The PHARUS system has to be transported physically, which may incur considerable extra costs.
4. The counterpart of the high resolution of PHARUS imagery is the smaller width of the acquired image. Widening the area by adding several strips together generally introduce strong intensity gradients at the transition between two strips. This makes further processing of the images more difficult.

6.1.3 Conclusions for the use of PHARUS vs. ERS for bathymetric applications

PHARUS can successfully compete with ERS when:

- high resolution and/or high accuracy maps are required for relatively small areas,
- time pressure prohibits waiting for collecting sufficient ERS images.

This means that the PHARUS high resolution mode is most relevant for bathymetric applications and that processing of the acquired data should be done quickly. Potential markets are:

- precision maps for offshore activities / pipe laying
- precision monitoring near harbors or in channels
- monitoring of shoals in rivers

6.2 Civil Cartography

In this section an overview of civil cartographic products and applications is presented.

In civil cartography the output product is an (updated) map of an area. Site specific information on the appearance of the terrain and the cultural elements of importance, such as roads, buildings, power plants, as well as natural information such as the vegetation and rivers, but also embankments and dikes and existing infrastructure has to be added to the maps. The details of this information depends on the scale of the map.

Generally the following list applies for the accuracy of positioning (also ref. section 6.4.1):

scale	x,y accuracy	vertical accuracy
1:10,000	2 m	2 m
1:25,000	5 m	5 m
1:50,000	10 m	10 m.

For all aerial photographic cartography in principle the global cost breakdown is applicable:

- 10 % flying cost
- 20% mosaicing (making one big picture from a number of pictures)
- 70% mapping (including the digitization of cultural elements, and adding e.g. the road numbers): this is the most labor-intensive step in the production process

Putting the data into a Geo Information System (GIS) is to be added on top of this.

6.2.1 Large scale cartographic maps

Large scale maps are maps with scales ranging from 1:500 to 1:10.000. These maps are most commonly used by (local) authorities for (underground) pipesystems (such as water, sewage, electricity, gas, urban central heat, etc.) and land register related activities. Applications include urban and road trajectory planning.
Other customers for large scale maps are the land register, governmental agencies with a responsibility for mapping of national waters, public utility companies, public works, cable-television system operating companies and telecommunication companies.
The requested resolution is 0.1 mm on mapscale.

The Topografische Dienst Nederland (TDN) produces the TOP10vector, a 1: 10.000 scale map, which is updated in a 4 yearly interval. The Netherlands is covered by 625 separate sheets of 10 x 6.25 km in a uniform manner. This database can be used for development purpose, planning of infrastructure, use of soil, hydrology.

Prices that are charged to the customer for large scale maps are in the range of the rough order of magnitude of 50 fl/km2 (1:10.000 scale) to 30.000 fl/km2 (1:500 scale).

6.2.2 Cartographic road- and streetmaps

Companies selling roadmaps, (digital) routeplanners and streetmaps are interested in data of lesser resolution. The required detail for these maps is the ability to determine the centerline of roads. Data of this resolution are abundantly available in an up-to-date form from aerial surveys.
TOP10wegen is a product of the Topografische Dienst Nederland (TDN), which already fulfills the needs in this area. An agreement has been reached between TDN and the Adviesdienst Verkeer en Vervoer of the Dutch Ministry of Transport, Public Works and Water Management for yearly revisions of the data.

6.2.3 Heightmaps

Another cartographic product is the Digital Terrain Model (DTM) or heightmap. The Netherlands is a flat country in which is of utmost importance to know the exact height of natural riverborders and dikes. A difference in the order of several centimeters can mean the flooding of an area in times of high water conditions. Therefore in the Netherlands detailed heightmaps are available already for a long time. These maps need regular updating, because the ground changes throughout the years.
In W.W.II the US army established the DETED map which is still being used for the guidance of cruise-missiles. With 1 point per 10.000 m2 this map is not only outdated, but also not very accurate. Later on these data were included in the TopHoogte MD, which yields altitude-lines with higher accuracy than DETED. The AHN (Actueel Hoogtebestand Nederland) has a height resolution of better than 15 cm. For the update of the AHN a higher number of points per area is required. For the next years budget has been allocated for this update.

Data can be acquired with aerial photography. New methods to determine digital terrain models (DTMs) include the use of laser scanners, which yield 1 point every 16 m2. This method can be used at night and fog, but not during rainy conditions. For coastal, river and water management purposes laseraltimetry with its fast data-handling is more cost effective than traditional methods of gathering the relevant information. Another advantage of digital data is the possibility of three dimensional views with image processing software.

Another method to produce DTMs is the use of interferometric SAR. This can be done both by single-pass interferometry (two receiving antennas) and by multipass interferometry (one receiving antenna). The advantages of SAR with respect to laser altimetry and traditional methods is mainly the all-weather capability.

6.2.4 Conclusions for the use of PHARUS for cartographic applications

Due to the large number of cartographic companies offering their services, competition in this field is severe. Prices for airborne data have decreased considerably the last few years. As SAR processing is more time consuming and labor intensive, and thus more expensive than the processing of aerial photographic data or laser altimetry data, this is a serious disadvantage for SAR cartographic applications.
It will be very hard to get into competition with established aerial photography. The added value of the polarimetric SAR does not justify the higher cost related to the additional processing.

In general it can be said that the less fieldwork is required to “calibrate” or support the aerial / satellite data, the more the ‘rough’ aerial / satellite data are worth. Keeping this in mind, combined with the strength of the ability to yield information on the properties of the observed items, for some specific applications the higher cost of the SAR data can be justified.

Concluding, the cartographic SAR application is most likely successful for the digital terrain modeling. However, looking at the market and the competition, in general it is not useful to identify cartography as the launching application for PHARUS operationalization. However, when campaigns deliver cartographic data as side-products of the original campaign, users may be interested in SAR data.

6.3 Tropical Forest Monitoring and Management

6.3.1 Requirements

In countries where extensive areas are covered by forests, in order to manage this effectively, a monitoring and management system is required that can map and visualize both the status of the forest and the changes as function of time and place. The need for such a system has become urgent for some countries with the commitment to the international ITTO agreements only to export timber which has been obtained from sustainable managed forests in the future.
Because optical observation techniques suffer from severe cloud cover, research into the utility of advanced radar techniques is performed.

The user needs can be categorized and for every category the sensor requirements can be summarized as follows (also ref. Seminar Tropical Forest Monitoring in Indonesia, April 1997):

- Mapping:

Depending on the mapping scales, spaceborne data (>1:100.000) or airborne data (1:10.000 - 1:50.000) can be used. Satellite optical and/or radar sensors are suitable for providing overviews at larger scales. This will support coordination and decision making activities. Airborne sensors can be used if more detailed information or a smaller scale is necessary. For mapping applications multichannel polarimetric sensors are necessary. Mapping 1:10.000 to 1:50.000 can be achieved by using the currently available PHARUS combined with the spaceborne sensors of SPOT and RADARSAT.

- Forest fire monitoring:

Forest fire monitoring includes not only the detection of fire spots and fire damage, but also the detection of dry areas for fire prevention activities. Also these user needs can be met with spaceborne and airborne remote sensing data. For fire-monitoring a combination of the spaceborne NOAA-AVHRR sensor for fire detection with an airborne single channel short wave sensor for fire damage assessment is adequate. The airborne sensor PHARS (single channel C-band radar, 5m resolution), the flying testbed of PHARUS, meets the sensor requirements. Using RADARSAT, ERS, PHARUS and PHARS and available processors, it is already possible to be compliant with many user requirements.

- Monitoring indicators for sustainable forest management:

For the operational monitoring for verifying indicators for sustainable forest management the required spatial and thematic detail is high. Moreover, the total size of the area of interest is vast. Information is needed on the position and size of trees, on the degree of canopy closure, on characteristics of skid trails/timber roads and on reforestation. This requires very high resolution radar images and fast SAR processing capabilities. For instance, for detailed mapping (up to 1: 10.000) a very high resolution interferometric airborne radar system is required. The development of an airborne short wave interferometric radar sensor (2 to 3m resolution) can be based on the PHARUS expertise. With respect to processing capabilities the existing SAR processors need to be improved both in hardware and software to reduce operational cost.

- New products/applications:

One of the main parameters of sustainable forest management includes the determination of timber volume. To date no system exists that can easily deliver information on this matter.

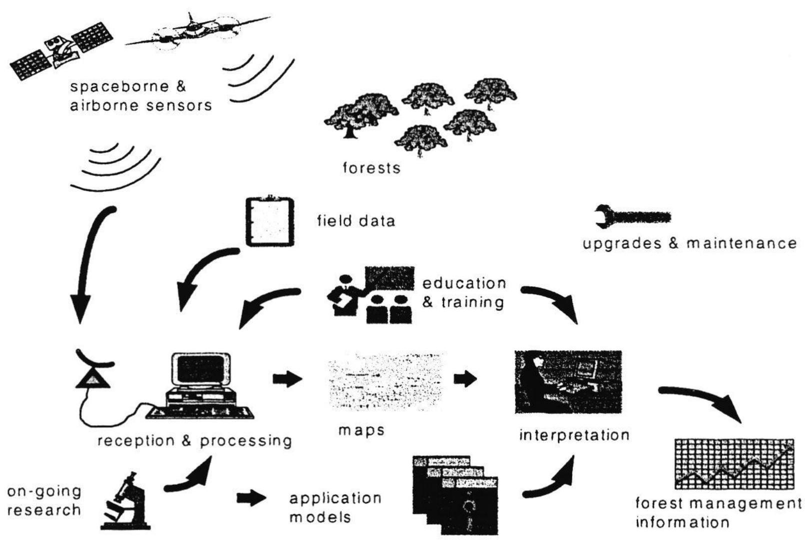

Figure 6-1: *A visualization of the tropical forest end-to-end monitoring system.*

6.3.2 Market

Based on the FAO report 1997 an estimate of the potential market for forest monitoring systems can be made. The total amount of tropical forest has been summarized per region (ref. Table 6-1), followed by a breakdown of forest production per production area. Summarizing the available information on tropical forest production, it is obvious that the largest amount of the world's forest production is used for local consumption, mainly being fuelwood and charcoal.

On the one hand it is important to look at the potential market of the private companies involved in the timber production who could use a forest monitoring system based on airborne SAR data. On the other hand the (local) governments are important players on the market for airborne SAR data. Not only did most governments of timber-exporting countries sign the ITTO treaty. These (local) governments could also be motivated (e.g. by external funding from World Banks etc.) to stimulate the sustainable use of tropical forests by supplying other means of energy for the main users of fuelwood and charcoal. Other means of motivation include the adhering to the ITTO treaty of timber importing countries by only buying sustainably produced tropical wood.

All together it is concluded that the market for these systems is mainly politically influenced. Therefore it is difficult to give a prediction of the market for forest monitoring systems based on SAR technology. At best predictions can be given with high uncertainty factors.

A system based on the currently available PHARUS can provide data on a rough order of magnitude of 60 Mha tropical forest area annually, based on a velocity of 100 m/sec, swathwidth of 8 km, overlap of 25% between tracks, 1.5 hrs effective measurement time per flight, 2 flights a day and 90 flying days a year.

Table 6-1: *Forest Production per region (source: FAO Report 1997, ref.44)*

region (tropical only)	total tropical forest (1995) M ha	forest production (1994): fuelwood and charcoal production (1000 m3)	export	(%)	industrial roundwood production (1000 m3)	export	(%)	sawnwood and sleepers production (1000 m3)	export	(%)
Africa	504	483,933	162	0.0	45,425	4,853	10.7	6,222	1,387	22.3
Asia	280	648,448	2,003	0.3	117,845	11,038	9.4	38,963	6,278	16.1
Oceania	42	5,802	0	0.0	3,345	4,019	# 120.1	276	45	16.3
N.- and Central America	79	62,028	79	0.1	10,108	235	2.3	4,680	909	19.4
S.-America	827	239,354	92	0.0	90,512	1,754	1.9	21,396	1,709	8.0
total (sub)tropical regions	1732	1,439,565	2,336	0.1	267,235	21,899	6.1	71,537	10,328	16.4

region (tropical only)	forest production (1994): wood based panels production (1000 m3)	export	(%)	pulp for paper production (1000 ton's)	export	(%)	paper and paperboard production (1000 ton's)	export	(%)
Africa	934	244	26.1	211	5	2.4	367	1	0.3
Asia	17,627	13,116	74.4	4,351	221	5.1	9,283	1,322	14.2
Oceania	62	17	27.4	0	0		0	0	
N.- and Central America	903	51	5.6	339	4	1.2	2,663	168	6.3
S.-America	3,590	1,358	37.8	6,311	2,170	34.4	7,531	1,370	18.2
total (sub)tropical regions	23,116	14,786	34.3	11,212	2,400	10.8	19,844	2,861	9.8

fuelwood and charcoal	wood harvested for fuel; charcoal is converted to equivalent volume
industrial roundwood	includes sawlogs or veneer logs
sawn wood and sleepers	wood processed in a sawmill
wood based panels	includes veneer sheets, plywood, particle board and fiberboard
pulp for paper	includes wood and non-wood pulp, does not include recovered paper
paper and paperboard	includes newsprint, printing/writing paper, other paper and paper-board

due to production in temperate Oceania

Assuming that in the long term approximately one quarter of the total tropical forest will be monitored, a conservatively estimate of 20 to 30 systems could be operated simultaneously globally. Taking into account that the lifecycle time of such a system is approximately 5 years, and that it should be possible to capture one quarter of the total market with a system based on SAR technology, one to two systems could be produced and sold annually.

Much more money than in the development and production is involved in the operation of these systems. Assuming that a realistic market price per ha of processed data would be 1 US$ (i.e., 100 US$/km2) , and assuming that the tropical forest needs to be monitored at least once every year, an annual turnover of at least 400 M US$ will be achieved in the operations part.
This is still a conservative estimate of the turnover. According to our information higher market prices of processed data are currently common. Moreover, for tropical forest monitoring, fire detecting, etc. more frequent coverage than annual is needed.

6.3.3 Initiatives

The Dutch PHARUS team has started an initiative to identify and supply a tropical forest monitoring and management system for Indonesia, referred to as SIRAMHUTAN (Sistem Informasi Radar untuk Menejemem Hutan; formerly: RASIMHUTAN: Radar Sistem Informasi Manajemen Hutan). In view of the necessary developments a phased approach of the end-to-end system is proposed, based on the available PHARUS technology.
The Dutch SIRAMHUTAN team presently consists of Fokker Space, TNO-Physics and Electronics Laboratory (TNO-FEL), National Aerospace Laboratory (NLR), the Wageningen Agricultural University (WAU) and the International Institute for Aerospace Survey and Earth Sciences (ITC). It is expected that the SIRAMHUTAN team will involve more partners both in Indonesia and in the Netherlands when the project advances.

6.3.4 Conclusions on the use of PHARUS for tropical forest management applications

The PHARUS end-to-end system has a high potential of providing the necessary services to the user in need of a tropical forest management and monitoring system. As a launching customer for this application discussions with Indonesia are ongoing. Interferometric capabilities are essential for such an end-to-end system. This capability can either be incorporated into an updated PHARUS design, or it could be included into the end-to-end system by an additional interferometric sensor. Furthermore, fast SAR processing capabilities and development of the necessary data fusion techniques need specific attention in the near future.

6.4 Military applications

The military application of a SAR sensor like PHARUS can be distinguished in two major application areas being: military cartography and surveillance or reconnaissance. Paragraph 6.4.1 will deal with the cartography whereas paragraph 6.4.2. deals with the surveillance.

6.4.1 Stand off military cartography.

Military cartography is similar to civil cartography in the sense that the eventual output product should be an (updated) map of an area. The scale of the map determines the amount of detail that is necessary to include. The map should show cultural elements like roads, buildings, power plants etc. as well as natural information as the vegetation, rivers etc. The details with which this information should be known depends, similar to civil cartography on the scale of the map.
Generally the following list applies for the accuracy of positioning:

	scale	x,y accuracy	vertical accuracy
1.	1:10,000	2 m	2 m
2.	1:25,000	5 m	5 m
3.	1:50,000	10 m	10 m.

Military cartography can differ from national civil cartography in the sense that the area can be anywhere in the world and that overflying the area with aircraft might be a sensitive political and sometimes military issue. Another difference with civil map production is that there is only limited time allowed between the first request for maps and the time when these maps should be ready for reproduction. This throughput time can be as little as a few days to a few weeks.

6.4.1.1 Market sector

Within the Netherlands Defense Organization the department "MilGeo" is responsible for the information acquisition and the production of maps for as well the Navy, the Army as the Airforce. The maps are produced by the "Topografische Dienst Nederland (TDN)".

6.4.1.2 Market size.

It is very difficult to predict the market size. In general one can say that the Netherlands Defense Organization operates on average in one or two external areas. Sometimes it is responsible for its own information gathering, other times this task might be performed within an international framework. The market volume is as such roughly estimated at a map area of 50x50 km once per two years.

6.4.1.3 PHARUS

The conventional way of updating maps is first of all to gather as much information as possible from existing maps. Experience learns however, that many of these maps are outdated for many areas in the world. Therefore a second step is usually to acquire high resolution optical satellite imagery and update the maps using these images. However, these optical images are not always available and sometimes they do not show the details and objects which are necessary for map-updating.
The *strengths* of PHARUS are that it is an all weather, day and night sensor, thus not restricted by light and weather conditions. Furthermore it can be used as a stand-off sensor and thus it is not necessary to overfly over the area to be imaged. The polarimetric features of PHARUS permit fast and reliable discrimination of various types of vegetation and the relatively large swath (when compared with airborne optical sensor) allows effective and fast surveying.
Weaknesses are the transfer time and cost associated with transfer (depending on the area of interest of course), but this applies to all airborne sensors. Another weakness is that PHARUS is at present bound to a civil aircraft, which will not be permitted to fly in areas where military threats occur. Also the recognition of objects in radar imagery is more difficult than in optical imagery. Finally no information can be obtained at present about the height of the terrain and object in the terrain. This latter problem can be solved by adding an interferometric mode to PHARUS. This way height information can be acquired with resolutions good enough for 1:10,000 maps.

6.4.1.4 Conclusion on PHARUS for military cartographic applications

PHARUS might contribute in situations where updates of maps are required, especially where time constrains are strong and when it is difficult to obtain high resolution optical data (e.g. because of cloud cover or because of political reasons).

6.4.2 Surveillance and reconnaissance

Surveillance is a military application in which a terrain is monitored regularly to detect changes, troop movements as well as enemy assets. The intention is to obtain information about the (intended) actions of the enemy. A secondary goal is to efficiently direct other sensors with higher resolution and consequently smaller swath widths to certain areas of interest. *Reconnaissance* is aimed getting more specific information about enemy objects units and activities within a certain area. The goal of reconnaissance is to obtain detailed information in the present status of the enemy, to identify targets and to perform damage assessment.
In general the area to be imaged is quite large for surveillance and small for reconnaissance. The amount of detail (read: the sensor resolution) is consequently larger for reconnaissance than for surveillance.
At present the reconnaissance tasks are performed using a suite of sensors both groundbased and airborne. The airborne sensors work primarily in the optical and Thermal Infrared (TIR) windows. Recent developments in SAR technology, especially the improved resolution, moving target indication and polarimetry, make SAR a promising sensor for surveillance and perhaps reconnaissance. Especially the all-weather, day and night capabilities of SAR are a valuable addition to the optical and TIR sensors.

6.4.2.1 Market sector

Within the Netherlands Defense Organization the tasks of surveillance and reconnaissance are divided between the army, navy and airforce. The army has its own responsibilities with respect to the acquisition. Within the next few years small remotely piloted vehicles equipped with most probable optical and TIR cameras will become available to the army for this purpose. Within the airforce, the 306

Squadron is responsible for the reconnaissance tasks. For this purpose they have optical and TIR cameras available on F-16 aircraft.

6.4.2.2 Market size

The market for surveillance and reconnaissance is not so much in the field of SAR imagery as well in SAR systems. Since it is the responsibility of commanders in the field to obtain intelligence of the area for which they are responsible, they also need to have the assets to get these. This means, that a SAR system flying on a civil aircraft will be of very limited importance to them. They need to have access and control over a complete sensor/platform system. At a number of places in the army and airforce studies are being performed at present aimed at the usefulness and specifications of radar systems for surveillance and reconnaissance. Some of these studies are conducted within the framework of NATO. Others are aimed at smaller scale applications of SAR. PHARUS fits best within this latter category. Depending on the outcome of these studies there might be a market for a number of dedicated military SAR systems.

6.4.2.3 PHARUS

The strength of PHARUS for this military application is the flexibility of its configuration and its concept using phased array technology. By employment of the electronic beam steering PHARUS can be used to map large areas (strip-map mode), small areas (spot-light mode by steering the antenna to illuminate an area as long as possible), or even moving target indication (although this latter mode still has to be implemented). Another advantage is the moderate demand on the platform is the sense that no mechanically steerable mounting is required.
The major disadvantage of PHARUS is its limited resolution. At present this resolution is 3x3 meter. With some adjustments, which are presently being implemented, this resolution can be improved to 0,5 x 1,5 m for small areas ("spot light mode") and to 1,5 x 1,5 m. for strip imagery. For target recognition resolutions in the order of 0,3-0,5 meter are preferable.

6.4.2.4 Conclusion on PHARUS for military surveillance and reconnaissance applications

For the purpose of surveillance and reconnaissance the market is for SAR hardware rather than for SAR products. There might be a military market for a military version of PHARUS. One of the major differences with the present civil PHARUS system specifications would be an improved resolution (preferably better than 0,5 m.).

6.4.3 Research / Other Applications

SAR hardware and software are developing rapidly. For the Netherlands Defense Organization it is of importance to be kept informed on the capabilities of SAR first of all to act as a "smart buyer", secondly to be informed about possible capabilities of enemies which have access to SAR sensors. Areas of research are:

1. high resolution SAR processing (< 0,8 m), as well hardware as software, including spot-light mode SAR processing,
2. moving target indication,
3. SAR polarimetry,
4. cartographic applications of polarimetric SAR,
5. target detection and recognition using SAR (including polarimetry),
6. real-time SAR processing,
7. SAR jamming (and contra-SAR jamming),
8. SAR image interpretation,
9. SAR miniaturization,
10. phased array antenna technology.

6.4.3.1 Market sector

The market sector for military research of SAR technology is divided between the Army, the Airforce, the central office and the Navy. Because of the sensitive nature of this research, this type of work is performed in the Netherlands by a few institutions (TNO, NLR) which have the capability to work on classified projects. Part of the work is performed in cooperation with research institutions from other NATO countries, organized in NATO RSG's..

6.4.3.2 PHARUS

PHARUS is based on a very flexible design and as such it is a near ideal platform for of military SAR and SAR processing research. The phased array technology allows rapid antenna steering, necessary for e.g. spot-light mode processing and for some types of contra SAR jamming techniques. The programmable pulse modes provide MTI capabilities. With some relatively small hardware adjustments PHARUS can be transformed to an advanced MTI radar.
The major disadvantage of PHARUS is its limited resolution. At present this resolution is 3 x 3 meter. With some adjustments, which are presently being implemented, this resolution can be improved to 0.5 x 1.5 m for small areas ("spot light mode") and to 1.5 x 1.5 m for strip imagery. For target recognition resolutions in the order of 0.3 - 0.5 meter are preferable.

6.4.3.3 Conclusion on PHARUS for military research applications

For the purpose of surveillance and reconnaissance the market is for SAR hardware rather than for SAR products. There might be a military market for a military version of PHARUS. One of the major differences with the present civil PHARUS system specifications would be an improved resolution (preferably better than 0.5 m).

7. Most Promising PHARUS Product/service

7.1 Trade-Off

There are two different groups of customers with respect to PHARUS. The first group (mainly the military, research related customers) is not so much interested in the processed SAR data, but much more in the SAR sensor and the SAR technology. This group can be served by a Dutch PHARUS consortium. However, this is not a commercial activity, but more a development activity, and possibly a production activity.

The other group of customers is more interested in SAR data, and possibly even only in processed SAR data, without wishing to understand or know the technology or all of the activities leading to this end-product. This is exactly the winning edge of a Dutch PHARUS consortium over competitors: due to the end-to-end approach as described in section 5, such customers can be served. It is commercially much more attractive to serve this group, as the turnover (and thus the revenues) will be much bigger here.

In the latter area the most promising applications for end-to-end systems are the following. On the one hand the bathymetric application seems feasible, for which no major technology development is needed. Moreover, an application already exists and implementation of an end-to-end system seems near at hand. The commercial potential is clear, and competition due to the existing, unique application is negligible.

On the other hand the tropical forest management and monitoring application is promising. For first campaigns it is envisioned that PHARUS can be used, and the end-to-end system to be developed can be based on existing PHARUS technology. There are several competitors who are already engaged in flying tropical forest mapping campaigns (ref. section 5). However, from the ongoing SIRAMHUTAN activities (ref. section 6.3.3) it can be concluded that potential customers are particularly interested in the end-to-end approach, for which the Dutch SIRAMHUTAN program is unique. A major disadvantage is the political dependency of the market, on which relatively little influence can be exerted and the limited operational experience gained so far.

7.2 Conclusion

The ultimate synergy of activities would be the combination of the development of the end-to-end system for those customers only interested in SAR data products, together with paid research and technology development for customers only interested in technology.

The most promising product/services for a launching application in the opinion of the partners are the tropical forest monitoring and the bathymetry applications. Initiatives in the field of tropical forest management are already ongoing by the SIRAMHUTAN team.

8. Conclusions

The study team has assessed the PHARUS products/services and their related markets, based on already available information. The conclusion from this is that both bathymetry as tropical forest monitoring are valuable applications which should be investigated in more detail.

For commercial applications today's PHARUS instrument is a valuable asset, albeit that technical improvements could increase this value. For the bathymetry application, the high-resolution mode being the most relevant one, faster data processing is highly desirable. For tropical forest monitoring also interferometry has to be implemented for an operational system. The major difference between the competition and a Dutch PHARUS consortium, however, is that the PHARUS sensor is to be incorporated into en end-to-end system, which is tailored towards the user-needs. Such an end-to-end system consists of (a combination of) sensors; ground-stations for receiving the satellite data; data-processing systems to manage the large amount of data in a timely manner; applications which convert the data into the required information for the user; and a data-distribution system to send the information to the users. Furthermore such a system can only be effective if attention is given to operations planning, operations and maintenance, education and training, and to on-going supporting research.

Within a Dutch PHARUS consortium extensive expertise exists on all elements of the envisaged end-to-end system. This includes knowledge of applications (such as e.g. tropical forests, bathymetry); remote sensing expertise; SAR (Synthetic Aperture Radar) techniques; operational expertise with airborne (and spaceborne) SAR and optical remote sensing systems; and managerial, technical and educational skills to develop and operate complex operational systems. Without this clustering, the leading edge with respect to the competitive SAR systems is lost.

9. Acknowledgment

We are grateful to F. Hagman, former general manager of Eurosense BV, who supplied us with the information on aerial photography and cartography.

10. Appendix A: Index of Tables and Figures

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11. Appendix B: Abbreviations

ARGOSS	Advisory and Research Group on Geo Observation Systems and Services
BCRS	Beleidscommissie Remote Sensing, Netherlands Remote Sensing Board
DTM	Digital Terrain Model
ERS	European Remote sensing Satellite
FAO	Food and Agriculture Organization of the United Nations
FS	Fokker Space
GBKN	Grootschalige Basiskaart Nederland
ICALA	Industrial Centre for Airborne Land, water and Atmosphere observation
ITC	International Institute for Aerospace Survey and Earth Sciences
ITTO	International Timber Trade Organization
NLR	Nationaal Lucht-en Ruimtevaartlaboratorium, National Aerospace Laboratory
PHARUS	PHased ARray Universal Synthetic Aperture Radar
RASIMHUTAN	Radar Sistem Informasi Manajem Hutan
SAR	Synthetic Aperture Radar
SIRAMHUTAN	Sistem Informasi Radar untuk Menejemem Hutan; formerly: RASIMHUTAN
TNO-FEL	TNO Physics and Electronics Laboratory
WAU	Wageningen Agricultural University

12. Appendix C: Overview of Synthetic Aperture Radar Systems

In Table 12-1 an overview of the synthetic aperture radar systems is given, both for airborne and space borne platforms.
Obviously the airborne systems are the direct competition of PHARUS, and therefore in section Table 5-1 attention is focused on these sensors. Nevertheless it has to be taken into account that if spatial and temporal resolution of spaceborne sensors is sufficient for some specific applications, these sensors generally yield data at a lower cost, and therefore are competing as well.

In this section all available information has been summarized. This information is complied from various sources, as given in the reference column.

Table 12-1: *Overview of Imaging Synthetic Aperture Radar Systems*

System (country) (platform)		freq	Range res	Azim res	looks	look incidence angle	polarimetry	altitude	Swath	interferometry	power	pro-cessing cap.	quick look	cost/km2	ref
		GHz	m	m		deg.		km	km	m	kW				
AIRBORNE															
Do-SAR (Germany) (DO-228)	**L**							10	3.6						38
			3	3	8		HH,VV								39
	C	5.3	1-3			30-89	quad	0.1-3.6	0.5-10	Y: VV polarization	1	Y	Y		25
			0.4	0.4	8		quad	10	3.6	1	1	Y	Y		38
			3	3	8		HH,VV								39
			2.5	3	7		VV	10000 ft	8-10	Y					49
	X	9.6	1-3			30-89	quad	0.1-3.6	0.5-10	-	2	Y	Y		25
							quad	10	3.6		2	Y	Y		38
			3	3	8		HH,VV								39
	Ka	35	1-3			30-89	HH	0.1-3.6	0.5-10	-	1	Y	Y		25
							HH	10	3.6		1	Y	Y		38
E-SAR (Germany) (Dornier DO-228)	**X**	9.6	2	2	8	25-70	HH/VV or HH/HV or VV/HV	3.6 (1.0-6.0)	3-5		2.5				22, 23
	C	5.3	2	2	8	25-70	HH/VV or HH/HV or VV/HV	3.6 (1.0-6.0)	3-5		0.05				22,23
from 1999	**S**	3.3					HH/VV or HH/HV or VV/HV	3.6 (1.0-6.0)	3-5		2.0				22, 23
	L	1.3	2	2	4 or 8	25-70	quad	3.6 (1.0-6.0)	3-5		0.36				22, 23
	P	0.45	12	12	4	25-70	quad	3.6 (1.0-6.0)	3-5		0.18				22, 23
INSAR (Germany)	**X**		2.5	2.5	7		VV	10000 ft	7	Y					49
INTERA-IRIS (Canada)	**L**		5-30	6-10											39
	C		5-30	6-10											39
	X		5-30	6-10											39
Intermap STARMAP (Canada)	**X**	3.2	6	6	7		HH		23						49

System (country) (platform)		freq	Range res	Azim res	looks	look incidence angle	polarimetry	altitude	Swath	interferometry	power	pro-cessing cap.	quick look	cost/km2	ref
		GHz	m	m		deg.		km	km	m	kW				
Intermap STAR 3i = ERIM IFSARE (Canada)															
(Learjet 36)	**X**		2.5					12	10	3				50-100 $ 73 $ (15 M km2) 39 $ (90 M km2)	56 1
			2.5					12.2	10	2					53
			2.5	5	7		VV	20000 ft	8-10	Y					49
Hughes HISAR (USA) (Beechcraft Raytheon King Air 200)	**X**		1.8						100			Y	Y		56
ERIM P3 (NADC P-3)	**L**		1.5	1.5								Y			38
	L	1.25	8.4	2.2	4	11-79	quad	3-8	6-48						38
	C		1.5	1.5											39
	C	5.3	8.4	2.2	4	11-79	quad	3-8	6-48						38
	X		1.5	1.5											39
	X	9.34	8.4	2.2	4	11-79	quad	3-8	6-48						38
															39
ERIM DCS	**X**						quad				1				38
	Ku						VV				0.077				38
DCRS EMISAR (Denmark)												Y	Y		38
(military Gulfstream G-3)	**L**	1.25	2-8	2-8			quad	17	12-48	1-2	6				38
		1.25	2,4 or 8	2,4 or 8			quad	41.000 ft	12, 24 or 48		6				2
	C	5.3	2-8	2-8			quad	17	12-48	1-2	2				38
		5.3	2,4 or 8	2,4 or 8			quad	41.000 ft	12, 24 or 48		2				2
PHARUS (Netherlands) (Citation)	**C**	5.3	3.75	1	1		quad	4.5	8		1		Y		38
Aerosensing AeS-1 (Germany) (Dornier DO-228, Cessna 207A, Rockwell Aero-commander 685)	**P** **L** **X** **C**		0.5-2	0.5-2	4-16				1-14.8						53
	X	9.6	0.5-2	0.5-2	4-16				1-14.8	0.5					54
	X		0.5	0.5				3.5	15	0.5		Y			

System (country) (platform)	band	freq	Range res	Azim res	looks	look incidence angle	polarimetry	altitude	Swath	interferometry	power	pro-cessing cap.	quick look	cost/km2	ref
		GHz	m	m		deg.		km	km	m	kW				
CCRS															
(Convair 580)	**C**	5.3	6-20	6-10	7	0-85	quad	5-6	18-63						39
	X	9.25	6-20	6-10	7	0-85	quad	5-6	18-63						39
PHARS (Netherlands) (Metro)	**C**		4.8	1	1		VV	7.5	12						
TOPSAR										Y					
(DC-8)	**C**		5-10	1-3											
AirSAR (USA)															
(DC-8-72)	**L**	1.25	8.4	2.2	4	11-79	quad	3-8	6-48						39
1500 kg			10	1				8	10-15	Y	67				46c
	C	5.3	8.4	2.2	4	11-79	quad	3-8	6-48						39
			10	1				8	10-15	Y	60				46c
	P	9.34	8.4	2.2	4	11-79	quad	3-8	6-48						39
			10	1				8	10-15		62				46c
AMPS															
(Lockheed RP-3A)		14.85	1-3	1-3		9-60	VV	1500-20000 ft	6-16		0.75				32
BYU SAR/Y-SAR (360 lbs)			1.5	0.5											43
SPACESHUTTLE															
SIR-A	**L**	1.278	40	40	6	47	HH		50						39
SIR-B	**L**	1.282	17-58	25	4	15-60	HH		10-60						39
SIR-C/X-SAR	**L**	1.25	10-60	25	4	15-55	quad		15-90						39
						17-63		225	15-90						50
11.000 kg	**C**	5.3	10-60	25	4	15-55	quad		15-90						39
						17-63		225	15-90						50
	X	9.6	10-60	25	4	15-55	VV		15-90						39
						17-63		225	15-40						50
SPACEBORNE															
ERS1/2	**C**	5.25	20	30	4	20	VV		100						39
JERS1	**L**	1.275	18	18	3	32-38	HH		75						39
ALMAZ	**S**	3	15-30	15		30-60	HH		20-45						39

System (country) (platform)		freq	Range res	Azim res	looks	look incidence angle	polarimetry	altitude	Swath	interferometry	power	pro-cessing cap.	quick look	cost/km2	ref
		GHz	m	m		deg.		km	km	m	kW				
RADARSAT	**C**	5.3	10-100	10-100	1-16	20-59	HH		45-500						39
										10-15				1.6 $ (fine mode) 0.014 $ (wide mode))	52
			10	10			HH		50						49
SEASAT	**L**	1.275	25	25	4	20	HH		100						39
KOSMOS 1870															39
EOS SAR (1999)	**L**	1.25	8-250	20-250	4	15-45	quad		30-360						39
	C	5.3	8-250	20-250	4	15-45	VV, HH		30-360						39
	X	9.6	8-250	20-250	4	15-45	VV, HH		30-360						39
LightSAR (>1999) 100 kg	**L**										0.5				42
TOPSAT (2001)															
SIDUSS															

13. Appendix D: references

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ref.nr	reference	system	remarks
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Netherlands Remote Sensing Board (BCRS)
Programme Bureau
Rijkswaterstaat Survey Department

P.O. Box 5023
2600 GA Delft
The Netherlands
Tel.: + 31 15 2691111
Fax: 2618962