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EUROMAR–SEASTARS
A MODULAR MULTI–SENSOR SYSTEM FOR AIRBORNE REMOTE SENSING OF THE SEA

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ABSTRACT

Airborne remote sensing systems have proved to be very useful for monitoring coastal regions, rapid assessment in response to environmental disasters and demonstration of new sensor concepts. In a joint effort involving Universities and industrial companies from Germany, Italy and other nations, the airborne remote sensing system EUROMAR–SEASTARS is currently being developed under the EUREKA programme, Italy being responsible for the requirements of the Mediterranean Sea and Germany for the North and Baltic Seas. The sensor package considered comprises active and passive, optical and microwave, imaging and profiling instruments. This set of instruments is designed to be modular and therefore an optimal subset can be chosen depending on the scientific task of the mission. All instruments are connected through a common bus and real–time images or data displays show the state of the surrounding sea. Sensor and housekeeping data, recorded on–board on standardized storage media, will be distributed among interested users.

Keywords: Remote sensing, environmental monitoring, EUREKA, EUROMAR

INTRODUCTION

Remote sensing of the oceans is usually seen in a global context and permanent monitoring of the sea surface is desired. However, the observation and analysis of the coastal zones is important, as they are in some cases the receiver and in other cases the origin of natural and manmade pollution. Rivers carry tons of poisonous chemical waste and biological substances into coastal waters. Oil spills are generated through ships and oil derricks. It is therefore important to monitor the sea surface on a regular basis in order to detect intentional pollution and prosecute criminal behavior. Observation of natural disasters like extensive growth of algae may help to limit the losses of fishing industry and tourism through an early warning. Coastal zones are therefore important regions for oceanographic remote sensing.

From a scientific point of view they represent an ambitious field for research. Compared to the open oceans, hydrological and biological features appear on a much smaller scale and therefore much finer resolutions of the remote sensing instruments are required.

Continuous monitoring of oceanographic phenomena on a global scale requires use of spaceborne sensor systems. For monitoring particular coastal regions, rapid assessment in response to environmental disasters as well as for demonstrating new sensor concepts and for supporting the scientific community by providing experiment platforms, airborne remote sensing systems have proved to be extremely useful. In addition to their rapid deployment capability, airborne platforms (both 2 engined aircraft and helicopters) have the advantage that they can operate in most weather conditions (including cloud cover) and that the sensor complement can be adapted to suit the immediate requirements.

In the EUROMAR–SEASTARS project an airborne remote sensing system is considered which comprises active and passive, optical and microwave, imaging and profiling instruments. The project is divided into two phases, the definition phase which is currently being finished and the implementation phase which is hoped to start later this year. In a joint effort involving Universities and industrial companies from Germany, Italy and other nations a modular sensor package has been designed where Italy is responsible for the requirements of the Mediterranean Sea and Germany for the North Sea and Baltic Sea.

THE AIRBORNE REMOTE SENSING SYSTEM

In line with the philosophy of EUROMAR–SEASTARS, a modular set of instruments has been designed from which a subset can be implemented at any particular time on board an aircraft. The possible sensors are listed below. The active microwave sensors are a Synthetic Aperture Radar (SAR) for the detection of sea surface phenomena and a Forward Looking Radar (FLAR) for navigating the aircraft over the area of interest. A passive microwave radiometer measures the sea surface temperature and the salt contentat a low frequencies (1.4 and 5.6 GHz), whereas higher frequencies (18, 36 and 90 GHz) are used for mapping oil spills or large ice patches. The laser fluorosensor (LFS) measures plankton and gelbstoff as well as turbidity of the water through fluoroscence and Raman spectroscopy. The imaging spectrometer produces 2–dimensional images of the sea surface with up to 256 channels in the optical part of the spectrum. Passive optical and infrared instruments may be added for e.g. identifying ships causing pollution. The laser bathymeter is a profiling instrument which measures important parameters in the water column as well as the bottom topography.

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DETAILED INSTRUMENT DESCRIPTIONS

Synthetic Aperture Radar (SAR) – Radar sensors are very useful instruments for detecting sea surface anomalies which may be due to natural phenomena or man-made pollutions. A SAR is therefore used for observing large areas in coastal waters, whilst the aircraft flies up and down in a meander type pattern. Depending on the selected imaging mode, the SAR covers swath widths between 3 km and 30 km at ground resolutions between 2 m and 30 m. In order to keep the real-time range processing simple, the number of digitized (complex) range samples has been kept constant at 1024.

C-band was chosen as transmitter frequency as this has proven to be a good compromise for imaging area targets, and a large user community will build up once the ERS-1 C-band SAR begins to deliver regular products. Due to the low altitude, the moderate swath width and the low resolution requirement, the transmitter power requirement is moderate and therefore a solid state amplifier design has been selected.

In order to minimize the processing load an Inertial Navigation System (INS) will measure the aircraft motion and deviations from a straight path will be compensated in real-time in the radar receiver. An adaptive pulse repetition frequency (PRF) is used for compensating a variable forward velocity of the aircraft and a variable pulse and A/D-conversion timing will compensate for variations in the line of sight.

A real-time SAR processor will be implemented using standard computer hardware. Time domain unfocused azimuth compression is used in the low resolution mode and frequency domain focused processing in the high resolution mode.

Two main operational radar modes are identified :

- mode 1 :
  high altitude / low resolution / wide swath ;
  this mode is used for large area observation and detection of surface phenomena

- mode 2 :
  high altitude / high resolution / narrow swath ;
  this mode is used for high quality small scale images

The specific parameters are as follows :

		mode 1	mode 2
altitude	km	3.0	3.0
max.ground range	km	30.0	5.0
bandwidth	MHz	8.0	80.0
ADC sampling rate	MHz	9.6	96.0
pulse length	μs	30.0	3.0
peak transm.power	W	200	100
antenna height	m	0.4	0.2
antenna length	m	0.5	
sl.range resolut.	m	16.6	1.66
swath width	km	16.1	2.0
azimuth resolution	m	17.7	2.0
minimum SNR	dB	28.7	24.1
noise equival. σ^0	dB	< -48.0	< -44.0

The minimum signal-to-noise ratio (SNR) is kept extremely high (i.e. the noise equivalent σ^0 is very low), as the system is designed to give excellent image quality over calm sea water at far swath. If the sea is rough and shows a higher radar return, the maximum slant range can be increased. On the other hand, the altitude can be decreased to as low as 300m in order to be compliant with the requirements of other sensors.

Forward Looking Radar (FLAR) – Once the sidelooking SAR has discovered a surface effect requiring closer investigation, the aircraft turns back and approaches the target area again. This time the aircraft flies directly over the target using the FLAR as a navigational aid. The FLAR images the sea surface about 5 km ahead with a swath width of approximately 1.5 km on either side of the nadir track and a resolution between 10 m and 50 m. Close inspection of the target area is then conducted using the on-board instrumentation package.

The FLAR design is based on a new concept for which patents have recently been awarded [1]. A concept with one transmitter, one receiver, one A/D-converter, connected to N horn antennas via switching matrix, was selected from several other possibilities mainly for cost reasons. In this case an antenna is placed at the nose of the aircraft consisting of a row of N horns perpendicular to the flight direction. A single transmitter emits a radar signal, which is received through the same horn, amplified and then digitized. This cycle is repeated N times until all horns have been switched through and acted as transmitter and receiver once. The N signals are stored in a 2-dimensional matrix of N pulses times M digitized samples. A real-time processor correlates across all pulses to obtain a finer resolution in the cross-track direction. The correlation is done in a similar way as for SAR processing. The aircraft motion from pulse to pulse has to be taken into consideration and compensated for. The main system parameters are given in the table below :

altitude	m	3000	300
radar frequency	GHz	10.0	
antenna length	m	2.0	
maximum range	m	5000	2000
worst case resolution	m	66.5	26.6
cross-track resol.cells	number	32	
cross-tr. swath width	m	2000	800
slant range resolution	m	15	
average transm.power	W	1	

Imaging Microwave Radiometer – The configuration for the EUROMAR imaging microwave radiometer consists of two independent modules, called medium resolution module (MRM) and high resolution module (HRM), covering different tasks, frequencies and technologies.

The MRM works with low frequencies and measures the basic physical parameters of salt content and sea surface temperature. It can also be used to detect biogenic films. The highest sensitivity for salinity measurements can be found around 1.4 GHz, as the measured effect depends on the resonance-behavior of water molecules. The rather low frequency causes a very large antenna for an acceptable footprint size. Since a mechanical scanner is too difficult to accommodate, an electronic multibeam system with a simple off-nadir line scan scheme has been adopted. As no deadtime for calibration is available in a multibeam system, the continously self-calibrating Dicke receiver with two reference sources is the prime choice for the MRM radiometer. To obtain the maximum sensitivity of the microwave emission for sea surface temperature measurements without a significant dependence on salinity 5.6 GHz is the most convenient frequency choice. The antenna dimensions are scaled properly to obtain coincident footprints with the lower frequency channel.

The HRM measures in three atmospheric windows at 18.7 GHz, 36.5 GHz and 90 GHz. The main application is the determination of thickness and volume of thin layers which float completely on the sea surface. This is done by analyzing and and evaluating the increase in temperature compared to the layer-free sea surface. Another application is the mapping and analysis of sea ice. A mechanical scanner using the conical scan principle and an antenna concept which enables nearly coincident footprints for all three frequencies have been selected. The total power radiometer type was chosen because it gives the highest possible sensitivity for the rather short integration time available. The following table shows the main system parameters :

frequency	GHz	1.4/5.6	18.7/36.5/90
flight altitude	m	300	3000
ground resolution	m	250	25–100
swath width	m	500–700	2000
radiometer type		Dicke	total power
receiver bandwidth	MHz	27/100	200/1000/4000
incidence angle	deg	50–58	50
polarization		vertical	hor./vert.
sensitivity	K	< 0.5	< 1.0
accuracy	K	< 1.5	1.5

Laser Fluorosensor (LFS) – The laser fluorosensor allows a measurement of the volume of films on the sea surface, and a classification of the substance type. Moreover, parameters which are relevant for the evaluation of ecological conditions such as, for example, the occurrence of plankton blooms, can be obtained. Particular emphasis has been put on the capability for 2–dimensional mapping of the sea surface [2] to allow an optical probing on small geometric scales. This is achieved by use of a XeCl laser with 200 Hz peak repetition rate, triggered by the scan position. This laser is used for the analysis of oil spills, and for mapping of natural dissolved organic matter (gelbstoff) in sea water. A dye laser with 5 Hz repetition rate, tuned to an emission at 385 nm, enables an efficient excitation of chlorophyll fluorescence. Spectra of fluorescence and water Raman scatter are obtained at 12 emission wavelengths. Calibration of the spectral sensitivity of the detector channels is done in–flight. The main system parameters are summarized in the following table :

operating altitude	300m (day)		900m (night)	
electrical power	1.0kVA		(stand by)	
	3.4kVA		(100 Hz pulse rate)	
lasers	XeCl		dye	
emission wavelength	308	nm	382	nm
pulse energy	150	mJ	15	mJ
pulse length	20	ns	15	ns
repetition rate	<200 Hz		<30	Hz
receiver telescope	reflective, Schmitt–Cassegrain			
entrance aperture	20 cm			
scanner	conical type			
full scan angle	28 degree			
scan frequency	<20 Hz			
swath width	150 m		(1000 ft altitude)	
pixel–to–pixel dist.	10 m average, 1000 ft altitude			
	110 Hz average laser rep. rate			
spectrograph	12 discrete channels, modular			
wavelength selection	dichroic splitters, interference			
	and blocking filters			
detectors	head–on PMT, range gated			
A/D converters	12 ch. gated integrator, 11 bit			

The same technology is available for a nadir track profiling laser fluorosensor for hydrological measurments. The main differences to the imaging LFS is the absence of the scanning device. Also the pulse repetition rate is only 10 Hz. For these reasons the complete design uses only about 2/3 of weight, volume and power of the imaging LFS.

Laser Bathymeter – For EUROMAR a scanning laser bathymeter is forseen, which operates with two lasers, a blue–green and an infra–red one.

A laser in the blue–green spectral region, where the light transmission in water is best, is used for determining the bottom topography of shallow water. Because of the large difference in energy between the reflection of the blue–green laser light on the water surface and on the bottom, the system can saturate. An infrared laser, whose light energy is entirely reflected at the sea surface, is therefore used to indicate the instantaneous altitude above the sea level. This information is used to trigger and gate the blue–green laser. Because of the scanning motion an area can be analyzed rather than only a profile be generated. This way local shoals can be detected. The main system parameters are summarized below :

laser type	Nd:YAG		
wavelength	nm	532	1064
pulse energy	mJ	5	
pulse length	ns	5	
pulse repetition rate	Hz	168	
receiver detector	fast avalanche diode (red ch.)		
	photomultiplier (blue–gr. ch.)		
scanner	quasi conical		
tilt angle	degree	15	
rotation rate	Hz	20	
scan width,500m alt	m	250	
profiling depth	up to 70m in clear water		
resolution	m	0.3	

EUROMAR Imaging Spectrometer (EURIS) – EURIS is a modified derivative of the ROSIS (Reflective Optics System Imaging Spectrometer) [3] airborne version. It performs a wide range of ocean/coastal zone water quality measurements. The main applications are the biomass determination through chlorophyll absorption and fluorescence measurements, yellow stuff concentration measurements, discrimination of algae species via the high albedo and spectral resolution, turbidity and sediment transport determination, deposition of chemical waste (soon after event) and a variety of others.

EURIS is a fully electronic scanning instrument (in both, spatial and spectral dimension), and operates with all–reflective objective and spectrometer optics (off–axis system with elliptical mirrors), which allows for a wide spectral range coverage as specified below. The spectral dispersion of a scan line on ground – defined by the spectrometer entrance slit and the individual lines of a matrix CCD detector array as the core of the instrument – is achieved by a dual prism disperser, the dispersed scan line is imaged by the spectrometer optics in a reverse path onto the CCD. Only one quarter of the latter is used as sensitive area to represent the 256 selectable/programmable spectral channels, while the other part is used as an intermediate buffer storage zone.

The most critical subunit of EURIS is the CCD and signal processing electronics which must handle an internal data rate of up to 460 Mbps, and which provides several attractive features such as correlated double sampling to increase the effective dynamic range, spectral fine tuning in 1 nm increments, radiometric correction per pixel, integration over adjacent channels and pixels as well as readout of all spectral channels ("spectrometer mode") at reduced frame rates. The main system parameters are as follows :

altitude	m	1000	4000
total field of view	degree	32	
swath width	m	570	2280
tilt of swath		± 25° foreward/backward	
pixel size	m	0.33	1.32
line frequency		168 @ 220km/h	84 @ 400km/h
spectral range	nm	400 – 1000	
spectral resolution		3,5nm at 400nm	
		2.0nm at 685nm	
		4.5nm at 1000nm	
no. of selectable chan.		256	
no. of readout channels		≤28	
radiometric resolution		12 bit	

Passive optical and infrared sensors – Passive optical sensors work in the visible and in the infrared spectral range. Image intensifiers use the visible and near infrared whereas forward looking infrared (FLIR) sensors detect the thermal radiation in the medium and far infrared (compare table).

Passive optical instruments may be added to other sensors to serve as quick–look and for archiving purposes. They can help, for example, to identify ships causing pollution and as an navigational aid in order to approach the ships as close as possible. In normal day light obviously ordinary video cameras with charge coupled device (CCD) technology are sufficient. During the night, however, low light level TV (LLTV) cameras with image intensification capability based on micro channel plate (MCP) technology with CCD are used for operation in an aircraft, whereas night vision goggles have to be carried by helicopter pilots.

All objects having a temperature greater than absolute zero (0 K) emit electromagnetic radiation over a continuous range of wavelengths, especially in the infrared region. A FLIR detects the thermal radiation of the object surface and generate images which can be interpreted by the human eye. FLIRs serve different purposes. First of all, they are an excellent navigation aid during the night, second they can be used for identifying letters (i.e. names) on ships walls if they are big enough. FLIRs may also detect oil spills, thermal front areas and water temperature mixtures. The main parameters for state of the art systems are given in the table below :

		LLLTV	FLIR	FLIR
wavelength	μm	0.5–1	3 – 5	8 – 12
field of view				
wide WFOV	deg.	30x40	30x40	30x40
narrow NFOW	deg.	3 x 4	3 x 4	3 x 4
thermal sensitiv.	K	–	0.05	0.05
max.abs.temp.	K	–	700	300
illumination level	lux	0.001 – 5	–	–
resolut. WFOW	mrad	1.5	1.5	1.5
NFOW	mrad	0.15	0.15	0.15

integration into platform : stabils.only for NFOV
steering range azim./elev.: ±120deg / ±45deg

On Board Data Handling (OBDH) – The EUROMAR advanced airborne sensor package, shall, when flown, be a selection of sensors chosen to best fulfil the requirements of the particular mission. This interchangeability of the sensors on the flight platform is one of the main design guidelines for this project and to meet this requirement the OBDH design has to be such as to allow the equipment / sensors to be easily and quickly re–configured between missions. For this reason the hardware and software will be implemented in a modular fashion wherever possible so that the deletion or addition of a sensor to or from the system shall not affect the operation of the remaining sensors. By making the OBDH as flexible as possible, the incorporation of different sensors in the future is facilitated, the only hardware / software for the OBDH required being new interface modules chosen to suit the data rates, word size etc. of the sensor being introduced.

A further strong influence on the design of the OBDH has been the high scientific data rate of the imaging sensors and the asynchronous nature of this data. A data recording function with distributed recorders dedicated to individual sensors will be implemented. This increases the complexity of the system in some ways but results in a more cost effective solution and is in line with the modular design philosophy already discussed. The architecture of the OBDH is shown in the figure below.

This in turn has meant the implementation of an enlarged ground segment processing station to provide re–recorded, correlated data to the end user, but due to the different end user requirements already identified, the flexibility provided by this approach will enable us to meet these requirements more easily and once again will enable the system to adapt better to future requirements imposed by the introduction of new sensors or new end users of the data collected.

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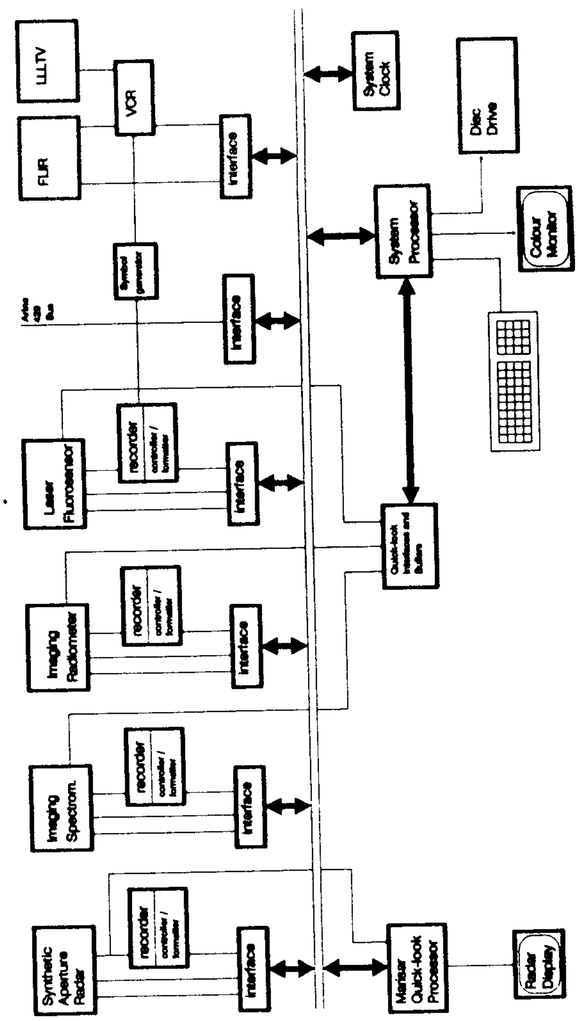

EUROMAR SEASTARS On Board System