TOWARDS A NEW CONCEPT OF AIRBORNE SURVEILLANCE SYSTEM FOR OIL POLLUTION FIGHTING

Stéphane Charron
Thales Airborne Systems
10, Avenue de la 1ère DFL, 29283 Brest, France
stephane.charron@fr.thalesgroup.com

Jean-Michel Negret
Thales Airborne Systems
10, Avenue de la 1ère DFL, 29283 Brest, France
jean-michel.negret@fr.thalesgroup.com

Georges Peigne
CEDRE
Rue Alain Colas BP 20413, 29604 Brest, France
georges.peigne@ifremer.fr

Erlinda Biescas
Institute of Geomatics – IG
Campus de Castelldefels, Barcelona, Spain
erlinda.biescas@ideg.es

Dario Tarchi
Joint Research Centre – JRC
21020 Ispra (VA), Italy
dario.tarchi@jrc.it

ABSTRACT: *RAPSODI (Remote sensing Anti-Pollution System for geOgraphical Data Integration) is a European Community funded program. Within this program, remote sensing, radar and oil spill control specialists, associated with airborne system designers, have gathered their efforts in order to propose a new concept of airborne surveillance system for oil pollution fighting. This paper describes the main tasks carried out in the RAPSODI project. Firstly, we describe the real size experimentation campaigns at sea with voluntary controlled releases of crude oil and other chemicals which were conducted to collect data for the project. These campaigns have involved many aerial and naval assets from various organizations. Secondly, the development of an airborne SAR (Synthetic Aperture Radar) sensor based upon the existing Thales Ocean Master X-band radar is presented. This sensor is able to generate high-resolution images and allows detecting sea pollution in almost any environmental conditions. It is the key sensor of the proposed system. Thirdly, we introduce the innovative technique of images processing developed and assessed in the frame of RAPSODI. These techniques allow extracting oil spill airborne SAR signatures even in very unfavorable conditions. Fourthly, we stress a major technical issue: the GIS (Geographic Information System) approach chosen for the system. Since an airborne system for oil pollution fighting relies on various sensors and, moreover, as their data can be geocoded, the use of GIS improves the efficiency of an airborne system in merging sensor data, chart data and tactical objects. Finally, we describe the proposed airborne system. Its architecture is based on software and hardware on the shelf components. It is generic in order to be adaptable to different types of carriers, types of missions and crew concepts.*

Introduction

Remote sensing plays a key role to meet regulations and to fight against important black tides. Besides the satellite imagery provided by Radarsat, ERS, etc. numerous coastal countries are equipped with airborne systems, which carry different types of sensors.

Unfortunately, so far, no sensor itself can meet the requirements of remote sensing under all conditions. Sensors such as Infrared (IR) and Ultraviolet (UV) line scanners or visible cameras only cover small areas and are degenerated on the environmental conditions. Another one, the SLAR (Side Looking Airborne Radar), produces images over large areas in all conditions, but with a very low resolution which results in false alarms, confusing for example local wind variation or slick of natural biological origin with oil spills.

In the framework of a European Community funded program named RAPSODI (Remote sensing Anti-Pollution System for geOgraphical Data Integration), a multidisciplinary consortium of experts in airborne maritime radars and systems (TAS : Thales Airborne Systems), in satellite remote-sensing (JRC : Joint Research Center), in radar signal processing (IG : Institute de Geomatica) and in spill control operations (CEDRE : Centre de Documentation, de Recherche et d'Expérimentations sur les Pollutions Accidentelles des Eaux), proposes a new concept of airborne surveillance, which allows detecting oil spills with a very high confidence level providing a more accurate and comprehensive information. With this goal, the RAPSODI team has based its program upon real size experiments. In two different campaigns, a set of voluntary spills was released in order to collect at the same time data from different sensors. These data collection allowed us to access and validate our approach both at sensors and system levels. Moreover, RAPSODI backs on the new trend of remote sensing techniques and takes advantage of the diversity of sensors. In particular, the project is focused on the design of a new high resolution SAR (Synthetic Aperture Radar) processor to replace an existing SLAR sensor based on an airborne coherent X-band radar. The SAR sensor is used in association with other existing sensors such as IR/UV or satellite images. Moreover, the system takes advantage of advanced techniques, like the image processing for oil spill detection and the techniques based on a Geographic Information System and a dedicated Man Machine Interface devoted to decision support.

Experimentation campaigns

One of the main operational tools in order to develop the RAPSODI system was a real-sized experiment.

So far two experiment campaigns were carried out under the responsibility of the French Navy CEPPOL (Commission d'Etudes Pratiques antiPOLlution) and organised by CEDRE in May 2001 and in May 2002. The measurement campaign involved several ships and aircrafts. In both campaigns, the commanding ship was a supply ship chartered by the French Navy. Its tasks were to coordinate the experiment, creating crude oil and chemical spills. The second main ship was a French Navy school ship, whose main duty was to spray dispersant for the slick treatment. Moreover, assistance ships were in charge of the water surface and water column sampling.

During the experimentation campaigns, a MARISONDE buoy of Météo France measured atmospheric data (wind, temperature and humidity). The knowledge of the wind direction and strength and the difference of temperature between the air and water are particularly important for the analysis of the radar measurements[1-2]. The sea state was measured using a WAVERIDER buoy from the CETMEF (Centre d'Etude Technique Maritime et Fluvial, of the French Ministère de l'Equipement).

During the first campaign, the "pollutant" ship created two oil slicks in the experimentation area that were 36 NM away from the Penmarc'h Point. Each oil slick was 300 to 400 meters wide and the distance between them was half a mile. Buoys marked each slick: two NORDA and a IESM belonging to the SHOM (Service Hydrographique de la Marine). An helicopter and an aircraft tracked the drift of the spills; a slick drift predicting model of Météo France (MOTHY model) was also used.

During the second campaign, in the same zone, the "pollutant" ship created 4 slicks : soja oil, ricin oil, oleic acid and dioctyl phtalate.

Each slick was sampled using the CEDRE instruments and dispersed at different stages. The physical-chemical parameters extracted from the onsite samplings were viscosity, density, emulsion stability, water content, evaporation, flash point and oil dispersibility.

During the first experiment three flights of the Mystere-20 plane from the French Test Flight Center (CEV) equipped with a Thales Ocean Master coherent X-band radar were carried out. An aircraft of French customs dedicated to oil pollution, the POLMAR-2, collected SLAR data and IR/UV images. Moreover, two Radarsat satellite images of the experimentation area have been acquired. As for the second experiment, remote sensing data were collected by the French POLMAR-2 and an oil fighting German plane.

Airborne SAR

Synthetic Aperture Radar (SAR) is able to generate a high-resolution backscattering image by coherently integrating the responses of several pulses along the aircraft trajectory (azimuth). A good resolution in the cross track direction (slant-range) is achieved by using pulse compression techniques[3].

A new SAR processor has been developed and validated within the scope of the project. This processor has been particularly designed to process the data coming from the Thales Ocean Master radar.

Oil slicks on the sea surface are visible in a SAR image because the oil dampens out capillary and very high frequency surface waves, reducing the radar backscattering and making these areas darker than the surrounding water. A SAR system is an active microwave system, which does not require solar illumination and can image through clouds and rain. These features make it very useful for maritime pollution detection. In order to detect oil patches, however, certain wind conditions are required[4-5].

The SAR raw-data collected during the first experiment have been processed by IG with the new processor developed in Rapsodi project.

For the SAR systems that are mounted on aircrafts, the deviations from a straight trajectory with constant speed are considerably high. For the generation of the SAR images motion variations have to be accurately measured by a navigation system (GPS/INS) and compensated during the SAR processing[6].

All images obtained during the campaigns were geo-referenced to a common standard cartographic reference system (projected into a UTM grid, see Figure 1). This process of converting data acquired with a given sensor (referenced to its particular geometry) into a standard cartographic coordinate system is required for a successful integration of multi-sensor data into the prototype developed by Thales.

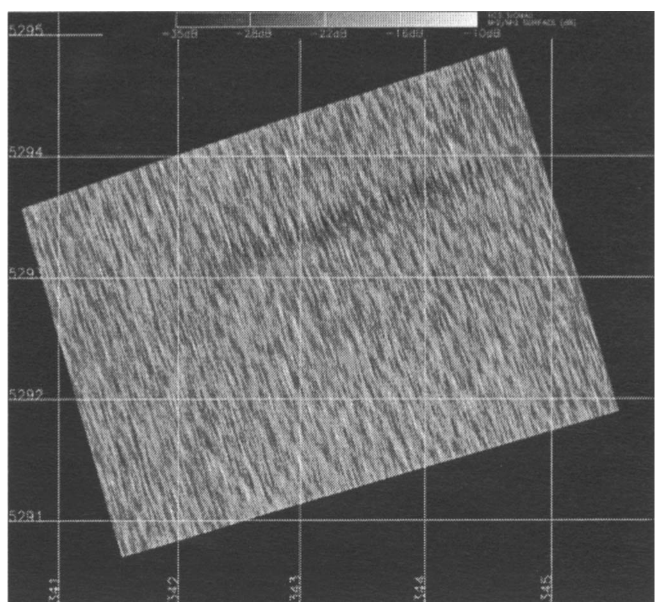

Figure 1. Georeferenced oil spill SAR image.

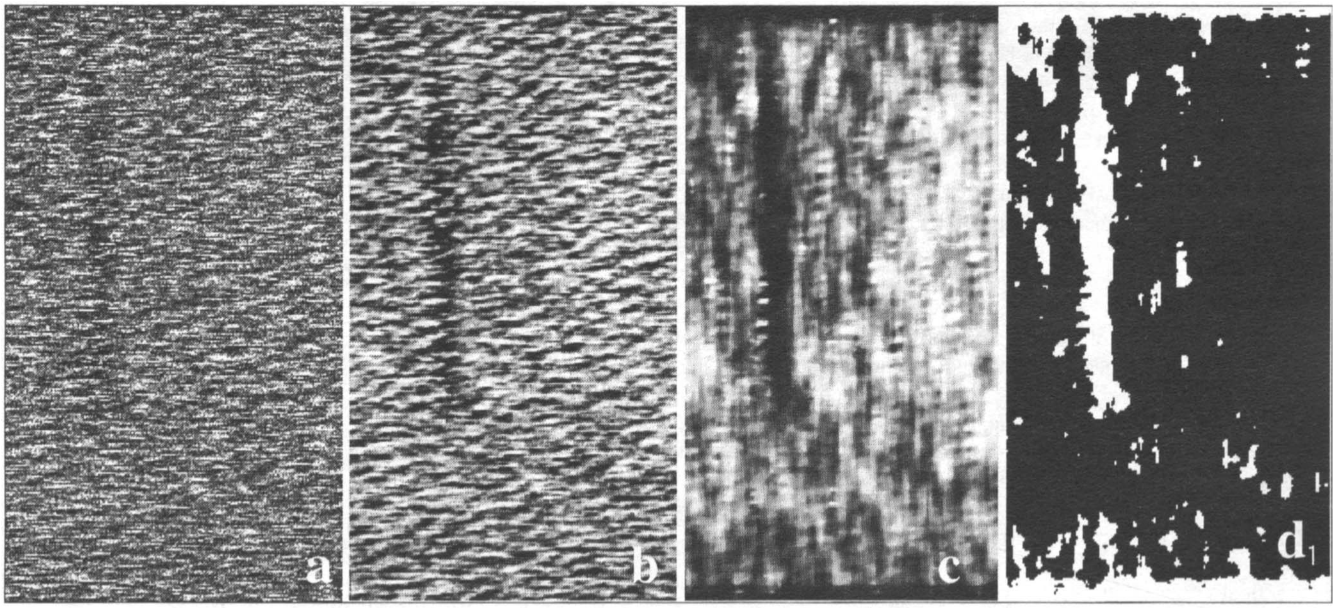

Figure 2. Oil slick detection and extraction of the oil slick contours on an airborne SAR image of the RAPSODI campaign. Original SAR image (a); image smoothed with the classical median filtering (b); image smoothed with an adaptative filtering (c); final binary image obtained by a thresholding applied on the previous image (d).

Images processing

An important task of the RAPSODI system is the detection of the oil slicks and the extraction of the oil slick contour along with key features. A spilled area is usually detected in a SAR image because of the dampening effect of the oil film on the wind generated short gravity-capillary waves. These waves are the main structures responsible for radar backscattering from the sea surface. As a consequence, provided that at least a light wind field is present, the oil slick will appear as a dark features contrasting with the brighter surrounding clean sea.

In the case of the airborne SAR system developed within the frame of RAPSODI and employed to collect images during the experimentation, the oil spill detection and contour extraction represents a quite difficult task due to the peculiar characteristics of the SAR images, which were acquired with very high incidence angles. In addition the sea conditions at the time of the experimentation were very unfavorable for the detection of oil spills. The combination of the two above-mentioned elements decreases the oil spills detection possibility. In fact, at near grazing incidence angles the contrast between radar signature of spilled and clean sea surface is strongly degraded by different dynamic and periodic structures on the sea surface, like the long gravity waves, the boundary layer rolls (wind helical motion, which is aligned approximately in the wind direction), Langmuir circulation (sea strikes that are aligned approximately in the wind direction) and sea spikes (strong radar returns due to wave movement and breaking, which are aligned in the azimuth direction). In such a condition the traditional oil spill detection algorithms, mainly developed for space-borne observations, give very unsatisfactory results, not being able to properly recover the information on spill shape. Two innovative filtering techniques, specially tailored for SAR airborne images, have been developed and tested on SAR images acquired during the experimentation with good results. The first approach is based on an adaptive filtering technique while the latter relies on a directional spectral filtering technique.

The image sequence in the figure shows an example of the result that can be obtained with the new adaptive filtering approach and compare it with the result that can be obtained with a traditional approach using a median filter. It should be noted, as the adaptive filter is able to identify quite exactly the area of the spill - it is identified as a single patch. On the contrary a traditional median filter fails to identify the spill as a single patch. This fact has a very negative consequence on the further steps of the processing chain aiming at discriminating between oil spills and look alike objects. In particular the fundamental information on the spill shape is lost. The new algorithms for image filtering, which are now being tested on a variety of different situations, including space-borne images, are effective in identifying correctly dark patches in airborne SAR image also in very difficult conditions. As an additional positive consequence the spill contour extraction can be based on the use of traditional agoritharithms.

A GIS based decision support system

The proposed system for oil pollution fighting consists of an aircraft equipped with optical and radar sensors, and of a ground segment. As pointed out above, there is no single sensor that provides all the needed data, and hence a combination of sensors has to be used. Moreover, most of the involved sensors provide images of the sea surface or at least locations of oil spill detection that can be geocoded.

The use of a Geographic Information System (GIS) offers an appropriate tool to provide a decision support to the airborne operator and gives a suitable framework to merging the output of different sensors.

The main issue is the constraint in the data exchange between the airborne system, the ground segment and other anti-pollution actors.

There are two main types of data: the reference data and the technical data. The first defines the data, which do not evolve during the airborne mission as the data related to geographical features. The Reference data have to be uploaded from the ground system to the aircraft in order to provide an accurate and up-to-date database to support the airborne system.

The most important geographic reference data for spill control operations are:

- the electronic nautical chart data,
- the aircraft navigation chart data,
- the land chart data.

The tactical objects or technical data include:

- All targets of interest within the scope of a sea-spill detection and control mission: oil spill contours, aircraft track history, surface ship targets, wakes, buoys, spill cleanup operations;
- All the data of the geographic environment which may change during the airborne mission span: swell, wind sector and force, anti-pollution sensors swath, temporary sensitive areas, etc…
- Other data reported by airborne sensors, by visual observers, etc

The tactical objects have to be recorded in-flight and downloaded from the plane to the ground segment at the end of the mission for replay, for further analyses and for help collecting concerning the pollution.

Concerning the electronic charts for reference data, for the RAPSODI project, the S-57 standards proposed by the International Hydrographic Organization (IHO), have been chosen. The S-57 data types detailed in the next table are considered of major interest for the conduct of the mission. This data represents only a subset of the more than 150 layers contained in the standards dedicated to Maritime Navigation. Indeed, for ergonomic reasons, a complete S-57 nautical chart would not be useful for the airborne operator.

RAPSODI Airborne system

Based on its experience on civilian and military Maritime Surveillance-Patrol Activities and, in particular, on the AMASCOS (Airborne MAritime Situation and COntrol System) product line, Thales Airborne Systems has developed a demonstrator of the proposed airborne system for oil pollution fighting.

The generic RAPSODI airborne system global architecture is structured as follows (figure 2):

- Two **Multi Function Display units (MFD)** dedicated to operator machine interface (OMI). A MFD offers a state-of-the-art OMI with a Cursor Control Device (CCD:

Table 1. S-57 oceanographic data of interest for an airborne anti-pollution system.

Anchorage area	Coastguard station
Coastline	Contiguous zone
Custom zone	Deep water (route, center line)
Dumping ground	Exclusive economic zone
Ferry route	Fishery zone
Fishing ground	Free port area
Harbour area	Hulk
Ice area	Incineration area
Land area	Land elevation
Light vessel	Local magnetic anomaly
Magnetic variation	Military practice area
Offshore platform	Offshore production area
Pipeline (area, overhead, sub/on land)	Pontoon
Precautionary area	Radar (line, range, station)
Recommended route centreline, track, traffic lane part	Rescue station
Restricted area	See area / named water area
Sea-plane landing area	Seabed area
Shoreline construction	Sounding
Straight territorial sea baseline	Submarine transit lane
Swept area	Territorial sea area
Traffic separation line, scheme boundary, crossing, lane part, rountabout, zone	Underwater / awash rock
Unsurveyed area	Weed / kelp
Wreck	

Legend:

(shaded)	Data layers of immediate interest for the sea pollution airborne mission
(unshaded)	Other interesting layers

trackball or mouse for instance), a large color screen, a keyboard, and a touch-screen. The MFD also includes a powerful CPU; this optimizes the overall processing capability and the Local Area Network (LAN) load and makes future processing extensions possible (new sensor integration, data fusion, etc...). Taking into account the operator qualification profile and workload, it seems advisable to propose two MFDs in the system:

- one for the mission commander (MISCO): TO (Tactical Object) management, navigation, global oil spill evaluation, reporting by voice or Data Link (DL);
- one for the sensors operator (SENSO): equipment monitoring and set-to-work.

Moreover, a networked cockpit display can offer to the pilot limited controls on the mission system and selection of available pages for tactical navigation help.

This definition of the operator's work-share is of course not definitive because it depends on the characteristics of future systems number, their complexity, the number of sensors used, etc. The hardware and software architectures are *scalable* enough to put all functions, if necessary, on a single workstation (MFD) or, to split the tasks in many MDFs on a larger aircraft.

- A **Tactical Data Processing unit (TDP)** dedicated to sensor management, intensive data processing, data base management and raw data logging (Hard Disk Drive capacity to be tailored). A second TDP unit provides full redundancy to the first one, to ensure the required availability and fault tolerance. Each of them are based upon a few Single Board Computers (SBC) interconnected both with VME backplane and Ethernet.
- A **tactical LAN** dedicated to connections between MFDs and TDPs over TCP/IP standard protocols. This LAN is a switched high speed Ethernet LAN (100 Mbps).
- A **video distribution network** providing on MFD raw video images from sensors via a video crossbar located on the TDP and video boards included in the MFD.
- A **Sensors bus** dedicated to connect the TDP and the sensors, including the pollution detection sensors and the navigation subsystem. If possible, this bus will be a high speed Ethernet LAN. This concept avoids a complex point to point and specific wiring to any sensor and also gives an excellent *extensibility* for future equipment connection. Additionally, the architecture is open to specific sensor interface through COTS or customized product.
- A **Data Transfer Module (DTM)** used to load the parameters and data designed for a mission (mapping data, flight plan, TO) or to download the information stored during a mission. Basically, this is a laptop computer with a high capacity hard-disk drive.
- A networked color **printer** for specific reports, images and screen snapshots print-out from any MFD.

Moreover, an analog video recorder should be added if some sensor still outputs non-digital video.

The RAPSODI application software, when based on an open framework, will consists of a set of **Plug-In Components** (PIC).

A PIC is a configuration item, which implements a coherent set of requirements compliant with equipment or tactical algorithmic constraints.

The PICs provide the following benefits:

- they can be easily added, removed or distributed elsewhere in the hardware architecture (TDP or MFD);
- they can be modularly and separately designed, tested and integrated according to mission and application criteria instead of software development constraints;
- they are intrinsically provided with human interaction, communications, and data access capabilities.

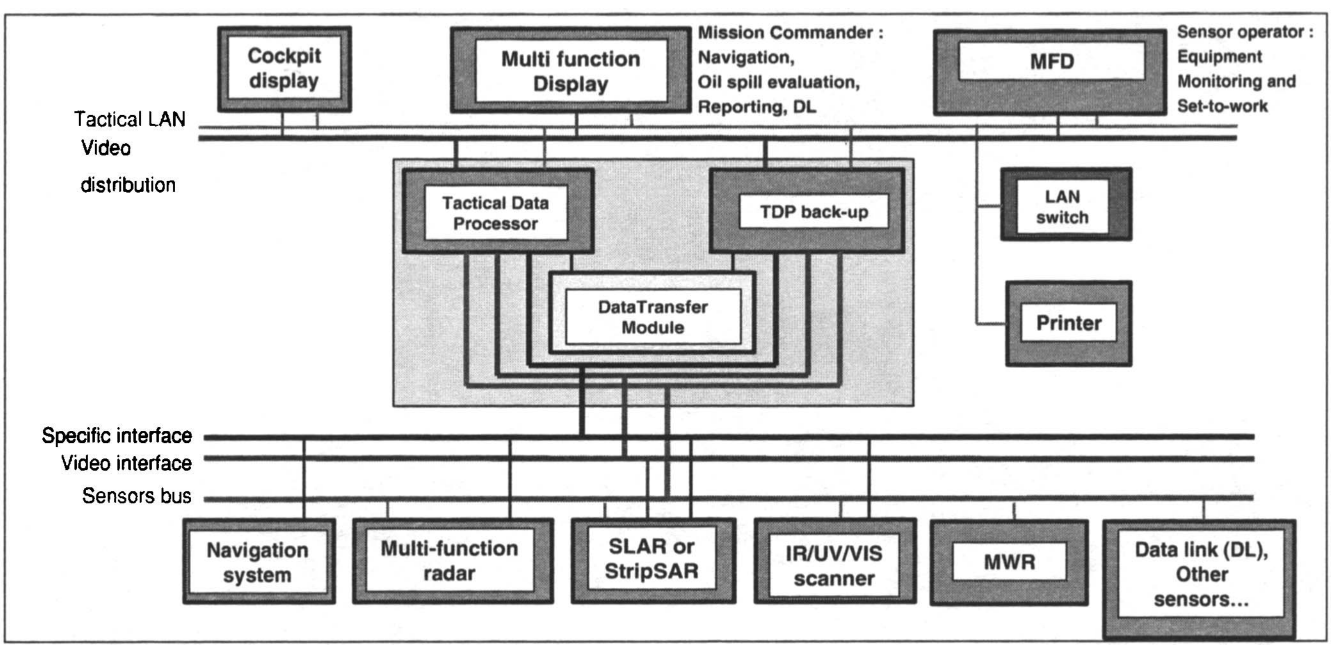

Figure 2: A block diagram of the sea pollution airborne system.

Conclusion

Through the co-operation of a multidisciplinary team within the RAPSODI project, we have succeeded in proposing a new concept of airborne surveillance system for oil pollution fighting. This system comprises the latest developments in the field of airborne patrol maritime surveillance systems. Moreover, it has been designed and assessed on the basis of real size experimentation campaigns, which is a very rare opportunity.

The major innovative aspects of the system are the following:

- first, the use of a SAR sensor instead of a SLAR sensor,
- second, the resort. to new image processing techniques such as adaptive filtering,
- and, finally, the utilisation of a GIS based decision support system with S57 electronic charts.

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