ENVISYS - A Remote Sensing System for Detection of Oil Spills in the Mediterranean

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ABSTRACT: The Mediterranean Sea is a fragile ecological and economic area with with frequent oil pollution, both intentional and accidental. An EU financed project has undertaken the task to develop a demonstrator for a remote sensing system to detect and monitor oil spills and possibly other large-scale environmental emergency situations. The system will include automatic screening of SAR imagery for oil spill detection building on an algorithm developed previously to the project. The algorithm has three main parts: (i) detection of dark spots; (ii) feature extraction; and (iii) dark spot classification. If a dark spot has been classified as an oil slick, an alarm sounds and an operator has to inspect the probable oil slick manually. The initial results from SAR image screening experiments have shown that the concept of automatic detection is very promising, however, it has to be refined. This will be one of task undertaken by the ENVISYS project.

1 INTRODUCTION

1.1 Oil spills in the Mediterranean

The Mediterranean Sea is an area with busy ship traffic allowing access to Southern Europe, North Africa, the Middle East and the Black Sea. The result of this extensive traffic is a high risk of oil pollution, both intentional and accidental. As well as the obvious ecological risks associated with such pollution in a closed sea area, it is in the interest of all nations bordering the Mediterranean to protect their coastal zones on which they depend for tourism and other activities.

The deliberate dumping of oil in the Mediterranean is illegal. It is estimated that around 330,000 tonnes of oil are deliberately dumped there each year. Other figures indicate that there may be as much as 1,000,000 tonnes dumped each year (five times the Amoco-Cadiz pollution), perhaps demonstrating that too little is known about the full extent of the pollution problem in the Mediterranean, a problem that remote sensing may be in a position to solve.

There are two important economical activities that can be affected by oil pollution and which would benefit from any measure taken in the direction of oil spill monitoring and detection: tourism and fishing. We only give a qualitative benefit analysis, as the quantification of it is rather difficult.

Tourism: Tourism can be considered as the most important Mediterranean industry, and the majority of the tourism activities are based on coastal resources. The negative effects that oil spills can have on tourism are obvious. In this case, the main concern is focused on the arrival of the pollution to the vicinity of the seaside.

Fishing: Fishing is a traditional economic activity in the Mediterranean. Although most of the captures are done far from coast, coastal fishing is not to be forgotten. Furthermore, the importance of fish farming is steadily increasing. These two latter activities can be seriously affected by the presence of oil pollution.

1.2 Oil spill detection with remote sensing

Unfortunately, in addition to the international regulations, there is a need to verify the observance of such regulations. So, it is of main interest to have operative techniques for the monitoring and detection of oil spills.

Today, most oil pollution monitoring in the Mediterranean is carried out using aircraft and ship-based sensors (cameras, radiometers etc.). The coverage of is normally limited by the availability and cost of operating such surveillance platforms in a monitoring role. In comparison, the use of satellite data has long been recognized, as in many monitoring activities, as a source of regular extensive geographic coverage.

The use of ships or aircrafts for sea monitoring is not fully adequate, however, as they present two basic problems: the limited coverage and the operational costs. Recently, with the advent of remote sensing with Synthetic Aperture Radar (SAR), interest is devoted to their use for oil spill monitoring and detection, especially in the North Sea.

Although there is not any ideal remote sensing instrument for the operational detection and monitoring of oil spills, satellite-borne SAR presents a number of advantages over other systems: worldwide regular coverage, day-night imaging capability, independence of cloud coverage and ability to detect both oil spills and ships. Three operational satellite systems (ERS-1 and 2 and RADARSAT) have the capability of oil spill detection, and more are coming soon (e.g. ENVISAT).

Norway got interest in oil-spill detection using SAR images more than ten years ago, and has been in the forefront of developing this technique towards operational application in the North Sea (Wahl et al. 1996). In response to ESA's science Announcement of Opportunity for ERS-1 in 1986, a Norwegian oil spill detection project was proposed. The project is chaired by the Norwegian Space Centre (NSC) and is supervised by an international steering committee with representatives from NSC, Norwegian Pollution Control Authority (SFT), European Space Agency (ESA), Marine Spill Response Corporation, Esso Norge A.S. and Statoil. The project had the following main phases:

- 1990-91: Literature surveys, prelaunch preparations, planning of field experiment.
- 1991: A dedicated oil spill experiment (DOSE'91) was carried out at Haltenbanken shortly after the launch of ERS-1.
- 1992-93: Digital SAR images were manually inspected for oil slicks at the Norwegian Defense Research Establishment (NDRE) shortly after acquisition. Alarms were reported to SFT.
- 1994: Tromsoe Satellite Station (TSS) took over the part of inspecting the SAR images as a pre-operational near real-time service.

Other countries in North Europe also got interest in oil spill detection by remote sensing within this period. The North Sea countries have, under the North Sea Treaty, established collaboration regarding data interpretation and follow-up routines for oil spills. The techniques have also been demonstrated in the waters of Britain and The Netherlands.

Within some years, there will be several remote sensing satellites with SAR in orbit resulting in about daily coverage. Manual inspection of all these SAR images will be very work demanding. Therefore, the Norwegian Computing Center (NR) has focused some of its research on automatic oil-slick detection. A pathfinder project was carried out in 1992 (Weisteen et al. 1993). The study involved a very limited data set, but promising results were achieved. This study was continued in 1995 under a contract with TSS, this time with a larger data set (Solberg et al. 1996). The study refined the algorithms from 1992. High detection rates were achieved, however, more research is required to develop algorithms that are reliable for operational use.

Some other research have also been carried out for oil spill detection, however, this research has not covered the important problem of discrimination between real oil spill and look-alikes. Barni et al. (1995) used fuzzy sets to detect oil spills in SAR images, and NDRE incorporated an algorithm for automatic slick detection in their ship detection system (Lindberg et al. 1995, Wahl et al. 1993).

1.3 The ENVISYS project

An EU financed project within the Telematics Programme with partners from Greece, Spain and Norway has undertaken the challenge to develop a remote sensing system to detect and monitor oil spills and possibly other large-scale environment emergency situations. The project will develop an demonstrator of a near real-time system, ENVISYS, processing remote sensing imagery. The system will be demonstrated in the Mediterranean, and will, hopefully, result in an operational system covering the whole area within 3-4 years.

The project started in February 1996, and is currently investigating user requirements and is developing the system design. The technical solutions and algorithms presented in the following sections are, therefore, only preliminary and based on early studies and the general experience from the automatic oil slick detection research carried out at the Norwegian Computing Center.

2 EMERGENCY DETECTION WITH ENVISYS

ENVISYS is intended to be a tool for detection and management of environmental emergency situations. This means it will not only cover the oil spill application, but also other emergency situations like forest fires and floods. This may seem surprising since these situations are so different with respect to remote sensing techniques. The intention is that ENVISYS will be a building block system. Therefore, it will be possible to substitute the oil slick detection module in the system with a detection module for other emergency situations. Other important tools in ENVISYS, building on database and GIS functionality, will be about the same for all emergency situations.

ENVISYS is not only intended to be a detection system, it will also be a system for management and support when the emergency situation lasts for several days.

The three following sections comments on the three emergency situations in focus - oil spill, forest fires and floods:

2.1 Oil spill

Oil-spill detection by SAR is based on the dampening effect oil has on capillary and short ocean surface waves. The microwave backscatter from the ocean surface is reduced in areas where oil is present. The result is that oil slicks turn out as dark areas on a brighter background (Lichtenegger 1994). The effect on the microwaves is dependent of the frequency and incident angle of the SAR. The described situation is true for ERS-1, ERS-2, and Radarsat and ENVISAT in certain modes.

A problem with oil-slick detection is, however, that there are other ocean-surface phenomena that make effects very similar to oil slicks ("look alikes") (Bern et al. 1992; Bern et al. 1993). Hence, an oil-slick detector has to be more advanced than a simple spot detector (Wahl 1995). Higher-level analysis based on special characteristics for oil-slicks has been tested to a limited degree, and showed promising results (Weisteen et al. 1993; Solberg et al. 1996).

2.2 Forest fires

Forest fires is a major problem in southern Europe. 1994 was an extremely hazardous year in Spain with loss of human lifes and large economic consequences. At least 20 people died, and 138,000 hectare burned down. Early detection and effective monitoring for assessment and management of fire fighting will have great impact.

Forest fire detection is based on data from the visible or thermal infrared part of the spectrum. The signature in thermal infrared is easiest to detect. The energy emitted by the fire will create high intensity compared to the surrounding areas. State-of-the-art image processing techniques are able to detect such bright spots. In the visible part of the spectrum, the smoke from the fires is most prominent (Wagner 1994). It is usually not difficult to detect visually, but harder to discriminate from a heterogeneous background by automatic methods. Most optical satellites provide data from the visible part of the spectrum. Satellites/sensors like Landsat TM and NOAA AVHRR provide thermal data (Hall et al. 1985).

2.3 Floods

During the last years, several major floods have occurred in Europe. Use of a satellite imagery in combination with other data sources can represent a very cost-effective tool to monitor large areas and provide decision support for counteractions.

Floods are detected by major changes of a waterbody's border. This can be detected well at both optical and microwave wavelengths (Blyth et al. 1993). At optical wavelengths, especially in the infrared, the radiance is very low from water, making it easy to distinguish it from land. At microwave wavelengths, the reduction in backscatter when water is present, can be used. Change detection algorithms are suitable for automatic detection of floods. Such techniques have been tested in similar applications with very good results. Necessary data sources are present today and are the same as mentioned for oil spill and forest fires above.

3 SYSTEM DESIGN

3.1 Functionality

The ENVISYS system will contain two main parts: a core system and a set of additional modules (see Figure 1). The core system will be general for all kinds of environmental emergency monitoring based on remote sensing. The additional modules will be application specific.

Note that the system can be run simultaneously at several locations by operators with complementary responsibility. E.g. the emergency management system may be located in the office of an oil-spill clean-up operator, while the oil spill detection is run by a central pollution authority or a contractor to them. This functionality will set special requirements for telematic techniques.

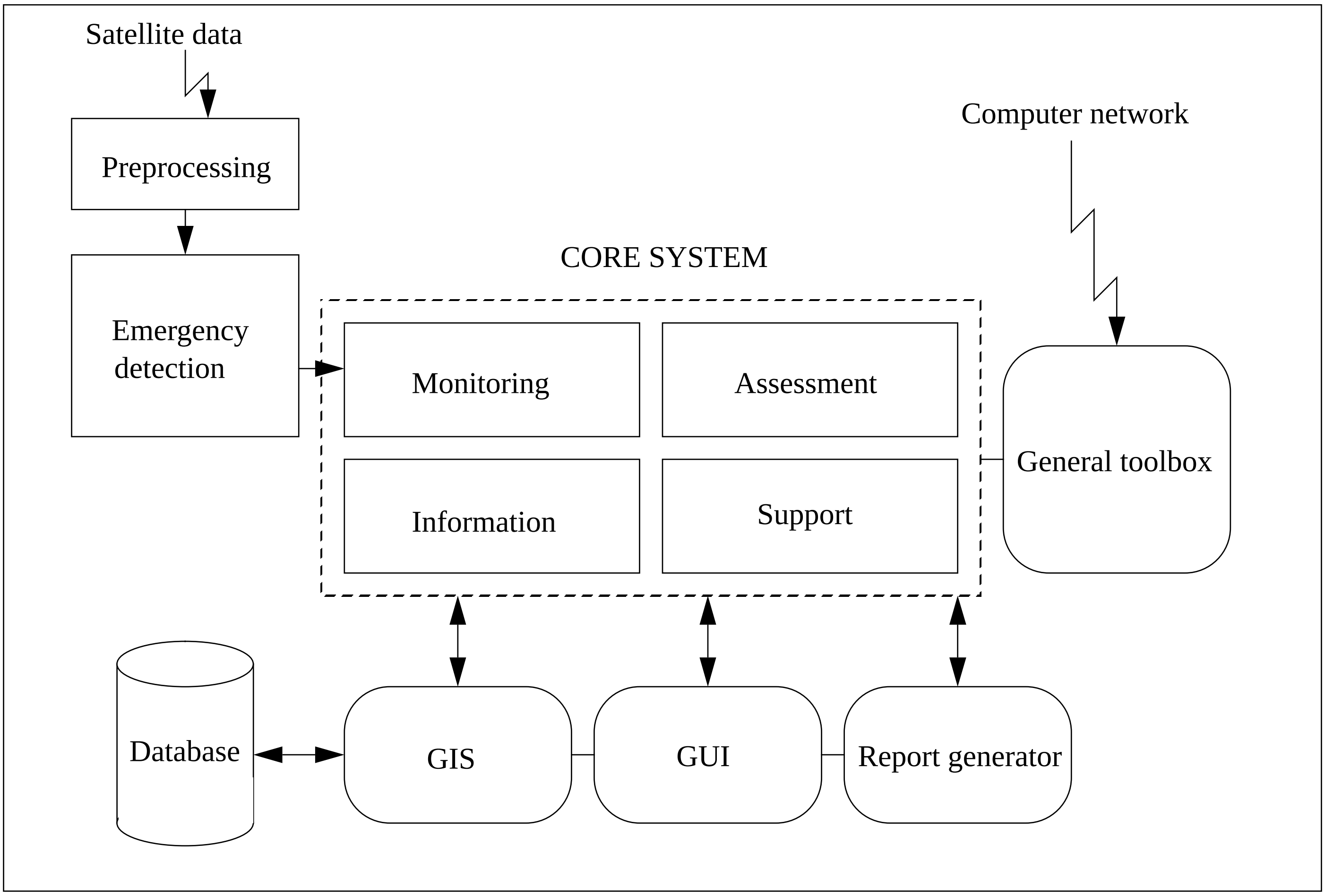

Figure 1. The main design of ENVISYS. The core system consists of general modules that can be applied to several types environmental emergency situations. The surrounding modules are application specific.

3.2 The core system

The core system consists of four modules. They represent different operation types or modes in the system:

Monitoring. The objective is to inform the user about environmental emergency situations. Remote sensing data from the geographical area of interest is analyzed as the data enters the system. If a possible emergency is detected, the remotely sensed data is put into a geographical context and presented to the operator for manual evaluation.

Assessment. If the operator can confirm a possible emergency situation, the system is switched to the assessment mode. The objective of this mode is to verify the emergency situation and assess how serious it is. An aircraft may be directed to the area based on a preliminary report from the system giving the location and extent of the emergency. The system integrates geographical, meteorological and ancillary information, combines it with a report from e.g. an aircraft when it arrives at the emergency area.

Support. This mode is for management support of an operation to reduce or eliminate the emergency situation and its environmental consequences. It includes two-way communication with the field operation and tools for continuous planning of the operation. Among the planning tools are a simulator for different scenarios of the emergency development. The simulator will make it easier to make strategic decisions for operations trying to limit the emergency.

Information. Various organizations and the public may be informed initially and later on the development of the situation. The system will make reports semi-automatically for specially predefined recipient groups.

3.3 The application-specific and support modules

A series of application-specific modules are connected to the core system. Several modules are connected to the outside world via a computer network. Important partners in the network will be ancillary data suppliers (e.g. meteorological data), an assessment aircraft operator, general information recipients (e.g. pollution authorities and the public) and managers of a field operation.

External remote sensing system. ENVISYS is lin-

Figure 2. The main algorithm for automatic oil slick screening.

Figure 3. An ERS-1 image covering an area in Arkhangelsk region. One of the dark spots in the image is a very likely oil spill.

ked to an external remote sensing system. The external system consists of one or more operational remote sensing satellites, a ground station, and possibly a remote sensing data preprocessor. The ground station can be a general, national site or a local, application-specific site. In the first case, there must be a permanent high-speed link between the ground station and the ENVISYS operation centre. If a remote ground station is used, the preprocessor may be located there, otherwise, it will be a part of the local system.

Emergency detection. The emergency detection module receives remote sensing data from the preprocessor. Image analysis methods are used to screen the data for possible emergency situations. If a potential emergency is detected, a map mask delimiting the emergency area and remote sensing image data are sent to the core system for further analysis.

Information report generator. The report generator uses templates to generate recipient-specific reports, e.g. to pollution authorities (local and central) and the general public (including reports to the media).

Communication, planning and simulation. This is actually a set of sub-modules supporting the support module in the core system. In addition to specific communication and planning tools, it has a sub-module for simulation of possible emergency development. The simulator combines geographical and meteorological data and the efforts from the field operations to simulate various, possible developments.

Basic tools. The toolbox contains functions that are used by more than one of the core modules. This will include at least a geographical information system (GIS), a graphical user interface (GUI), a database and report generators.

4 AUTOMATIC OIL SPILL DETECTION

The concept for automatic oil slick detection presented below was developed on a very early data set from the ERS-1 satellite in 1992 (Weisteen et al. 1993). The details of the algorithms have to be refind in the ENVISYS project, however, it is likely that the general outline will follow the description below.

4.1 Overall design

An algorithm for semi-automatic detection of oil spills is presented. The algorithm has three main parts: (i) detection of dark spots; (ii) feature extrac-

Figure 4. The dark spots detected by an adaptive threshold algorithm. The spots are candidates for further analysis.

Figure 5. The result after classification. The probable oil slick is marked in white with the SAR image as background.

tion; and (iii) dark spot classification. The dark spot detection locates all spots which can possibly be oil slicks in the image. For each slick, a set of backscatter, textural, and geometrical features are extracted. The dark spots are then classified into possible oil slicks and "look-alikes" based on the extracted features.

4.2 Spot detection

The developed algorithm for detection of dark spots is based on adaptive thresholding. This thresholding is based on an estimate of the typical backscatter level in a large window. The adaptive threshold is set to k dB below the estimated mean backscatter level in the region. The window is moved across the image in small steps to threshold all pixels in the scene.

4.3 Feature extraction

For each dark spot, a set of features is computed. The features constitute of general, standard descriptors often applied for regions, and additional features particularly suited for oil slick detection. Examples of features are the contrast of the dark spot area to the surrounding sea, the border gradient and the shape of the spot. These features are calculated for each of the dark spots found by the spot detector.

4.4. Classification

The classification is based on the feature vector calculated for each spot. Various classifiers may be used, e.g. a Gaussian classifier or a hierarchical classifier (see Jain et al. 1988; Venables et al. 1994). However, it should be a supervised classifier that makes it possible to refind the performance as the data set of confirmed oil slicks and verified look-alikes grows.

4.5 User verification and learning

Dark spots classified as oil slicks have to be controlled by the operator. By image enhancement tools and experience the user should be able to verify whether a slick is oil or a look-alike. In the case of a very probable oil slick, an surveillance aircraft may be redirected to the area for verification. Information about verified oil slicks (or false alarms) will be fed back into the statistical data base to make the system learn by experience.

4.6 Results

Some of the algorithms applied in the concept described above were refined in 1995 (Solberg et al. 1996). An evaluation of the procedure developed on a data set consisting of 42 oil slicks and 2471 look-alikes gave the following results: 14% of the oil slicks were wrongly classified as look-alikes, and 4% of the look-alikes were classified as oil slicks.

These results are promising, however the performance should be improved for application in an operational system. In particular, a very small percentage of the oil slicks should be allowed to be classified as look-alikes. The opposite situation with some look-alikes classified as oil slicks is not so dangerous, but even this percentage should be very low to make the automatic oil slick detection usable in practice.

5 CONCLUSIONS

The Mediterranean Sea is a fragile ecological and economic area with heavy ship traffic. The result is high risk of oil pollution, both intentional and accidental. Oil slick detection by means of remote sensing became possible with the advent of the ERS-1 satellite. The dampening effect that oil has on capillary and short ocean waves creates a significant contrast between an oil slick and its surroundings in situations with medium winds.

An EU financed project with partners from Greece, Spain and Norway has undertaken the challenge to develop a remote sensing system to detect and monitor oil spills and possibly other large-scale environmental emergency situations. The project will develop a demonstrator of a near real-time system, ENVISYS, processing remote sensing imagery. The system will be demonstrated in the Mediterranean in 1997, and will, hopefully, result in an operational system covering the whole area shortly after that.

A concept of automatic oil spill detection has been developed and tested previously to the ENVISYS project by one of the project partners. The main algorithm has three main parts: (i) detection of dark spots; (ii) feature extraction; and (iii) dark spot classification. The dark spot detection locates all spots which can possibly be oil slicks in the image. For each slick, a set of backscatter, textural, and geometrical features are extracted. The dark spots are then classified into possible oil slicks and “look-alikes” based on the extracted features. If a dark spot is classified as an oil slick, an alarm sounds and an operator has to inspect the probable oil slick manually.

The results from oil slick screening experiments have shown that the concept of automatic detection is very promising, however it has to be refined. This will be one of the tasks undertaken by the ENVISYS project.

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