# Past and Future of Airborne Pollution Control

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**Abstract**

During the last two decades airborne remote sensors have evolved into common instruments for the operational surveillance of oil pollutions. Todays mostly used sensor arrangements include a SLAR (SideLooking Airborne Radar) and an IR/UV (InfraRed/UltraViolet) linescanner. Whereas the former sensor is used for far range detection of pollutions the latter is especially designed to characterize oil spills locally. In addition to this standard there are newer sensors like the Laserfluorosensor (LFS) or the Microwave Radiometer (MWR) that allow an advanced analysis of oil spills concerning the remote identification of oil species and the estimation of film thickness.

The German maritime surveillance aircraft are examples of operationally used airborne surveillance systems incorporating the above mentioned wide range of remote sensors. Recently a FLIR thermal imaging system with a covert laser illuminator was integrated, enabling the operator to read the ships name or investigate areas of specific interest.

Within this work different aspects of modern airborne oil pollution monitoring on the basis of the German systems will be presented. This includes the description of synergetic effects which arise from the use of a multisensor system and a first approach of multisensor data fusion in this special field of remote sensing.

## Introduction

Marine pollution by oil-spills or harmful chemicals is still one of the major environmental problems to be faced. Besides the accidental releases of pollutants the main source is assumed from the controlled release by ship traffic and oil production platforms. Since accidents or violations of regulations can never be completely excluded, precautions and instruments are needed to detect and combat maritime pollutions and a crucial element of this framework is airborne surveillance. Like no other system, airborne pollution control is capable a) to detect possible oil-slicks by radar sensors, b) to verify, quantify and qualify reported pollutions by different near range sensors, c) to secure evidence against polluters and d) to coordinate clean-up operation of ships. Many nations have established such kind of airborne surveillance and also dense networks of international co-operations, since oil-spills are not restricted to national borders. One example is the Bonn agreement of 1983, establishing a trans-border observation between the North-Sea adjacent states (see http://www.bonnagreement.org/).

## Basic airborne sensor equipment

The simplest and most direct method of surveillance and tracking oil spills is visual observation and hand plotting of the data on a map. It requires no costly installations however it is not suitable for night operation and needs skilled observers. Since the spectral characteristics of oil differ from the surrounding water especially in the ultraviolet and above 3 µm (mid-infrared) up to 30 cm (radar) wavelength, remote sensing equipment mainly focuses on the non-visible electromagnetic regions.

During the last two decades airborne remote sensors have evolved into common instruments for the operational surveillance of oil pollutions (Goodman, 1994). Today's mostly used sensor arrangements include a SLAR (side looking airborne radar) and an IR/UV (infrared/ultraviolet) detector. To give an example: Among the 8 contracting parties of the Bonn agreement, contributing 14 aircraft in total, all platforms are equipped with a SLAR and all but one are using IR/UV sensors for the near-range investigation.

The SLAR sends out short X-band radar pulses to the left and right hand side of the aircraft and receives their reflection from small gravity and capillary waves up to a distance of typically 30 km, depending on wind conditions and aircraft altitude. These small waves are suppressed when an oil-film is on the surface. Yet a number of other conditions can lead to false returns that are difficult to distinguish from that of oil on the water, among them algae blooms, freshwater fronts, sand banks and wind shadows. This is also one reason why satellite observations are not sufficient as a stand-alone tool and it is the task of the near range sensors to identify the origin of the missing radar signal area.

The basic near range sensors are the infrared and ultraviolet detectors, often coming together as IR/UV-sensor. They are passive sensors, detecting the surface thermal radiation (8-12µm) or the reflected ultraviolet part of solar radiation (320-380 nm). The nature of the UV-detector makes it depending on sunlight. The nature of infrared signatures on water is depending on thickness of the oil, its weathering and the water temperature. For slicks of thicknesses between 50-500 µm, the oil appears to be at a lower temperature than the surrounding water. When the oil thickness is greater then 500 µm the oil appears warmer. Even worse, water-oil-emulsions behave different then pure spills, a topic that is still under research. As a rule of thumb one can say that the UV signal (if available at daytime) is reproducing the shape of the slick very well as it is sensitive to film thicknesses down to 0.1 µm while the IR signal is showing thicker areas of oil, yet IR/UV systems are not able to measure the absolute oil thickness and are subject to ambiguities.

## Advanced sensors

In addition to the above described standard there are more sophisticated sensors like the laser fluorosensor (LFS) or the microwave radiometer (MWR) that allow an advanced analysis of oil spills concerning the remote identification of oil species and the quantification of film thickness. The two German maritime surveillance aircrafts are examples of operationally used pollution control systems incorporating the above mentioned wide range of remote sensors. Other nations operate comparable systems or are at the step of defining new airborne systems, incorporating these advanced sensors for the second generation of maritime surveillance aircraft.

The imaging airborne LFS as one of the most complex and also quantitatively measuring remote sensing instruments operated on an aircraft is designed with a high energy pulse laser in the UV at 308 nm (Hengstermann and Reuter, 1990). The stimulated fluorescence as well as the scattering of the laser light at the water surface and within the water column are detected with a 20 cm telescope utilizing a conical scanner and then spectrally separated into 12 detection channels. The main features of the sensor are a) estimation of film thickness between 0.1 and 10 µm, b) calculation of the oil volume on the water surface, c) identification and classification of the oil though spectral signature. In addition, the laser fluorosensor may be used for hydrographic measurements (Zielinski et al., 2000).

The line scanning microwave radiometer (MWR) enables quantitative assessments of detected oil slicks by analysing the radiant emission from the sea surface and oil slicks at two or three frequencies (for example 18.7, 36.5 and 89 GHz). But whereas the laser fluorosensor has been developed for thin oil films the microwave radiometer has been designed to evaluate oil films between 50 µm and 5 mm (Grüner et al., 1991). This information is absolutely necessary for clean up operations and the guiding of oil combat vessels.

## Thermal imaging

Since thermal imagers, also known as Forward Looking Infrared (FLIR) devices, became commercially available, they are increasingly installed into smaller and mid-size aircraft. In September 2003 a StarSAFIRE thermal imaging system with a newly developed covert action laser illuminator (CALI) starts operation as part of the second German surveillance aircraft, enabling the operator to read the ships name in the absence of daylight or investigate areas of specific interest. This thermal imaging capability will bring an important step towards night operation and polluter identification. It is also a sensor with a wide range of application, like SAR or border patrol, making it a perfect device for multi-role aircraft, often only equipped with basic maritime surveillance sensors.

The covert illuminator is a 2 Watt laser diode inside the FLIR turret, working around 800 to 820 nm @ 25°C. Therefore it is not illuminating the thermal camera detector (which is using the 3-5 µm mid-IR region) but the NIR sensitivity of the inbuilt CCD camera. These cameras normally use an IR-cut filter during daytime, blocking unwanted NIR radiation from its detector. During night time and in combination with the CALI, this NIR cut filter is removed and the laser illumination is available up to a distance of 1500 m (Fig. 2).

## Need for data fusion

Routine oil pollution monitoring with advanced remote sensing equipment requires a complex network and communication structure to be operated by a single operator. The combination of different data sources towards higher level products is crucial in two ways: First, the operator is struck by the amount of data to evaluate and needs guidelines, alarm triggers and synergetic overviews. Second, the combination of different sensors drastically increases the probability of qualitative and quantitative predictions of the substances observed. Both aspects, combined with the entering of GIS environments in the operator's console, will lead the way to the third generation of airborne maritime surveillance systems.

One of the major problems to overcome is the diversity of different sensors, resulting in varying sampling rates, different sensor geometries, swath widths and different data formats. The direct comparison of sensors like IR/UV and laser fluorosensor for the evaluation of an oil slick or in the case of larger quantities, IR/UV and microwave radiometer requires a good understanding of the sensor characteristics, capabilities and restrictions. Such an understanding may not be suitable for the routine operation by none-scientifically trained personnel. Therefore it is intended to automatically evaluate sensor data and create results in such a way that an assessment may be accomplished by operators that are not necessarily familiar with all sensor characteristics and details. One step forward in such a concept is the generation of a synthetic image from the various sensor images which allows much faster interpretation of sensor data because there is only one image visually describing the whole and often complex situation over an oil slick. It is important to provide such investigative tools in real time because it is obvious that evaluation and assessment of damages, resulting in possible clean up operations, have to be made immediately.

As a contribution to the EU project DISMAR (Data Integration System for Marine Pollution and Water Quality, http://www.nersc.no/Projects/dismar/) five years of available datasets for the German aircraft were analysed. First procedures include a rectification and rescaling of the sensor data. Aircraft angles roll, pitch and yaw are not accounted for by every sensor in the same way and therefore a georeference based correction has to be applied. Secondly, delays between different sensors might exist due to different locations inside the platform or synchronization offsets in the data distribution. This can be addressed by the spatial correlation function if characteristic situations with an input from several sensors are selected. For data reduction in general and for the ultraviolet sensor in special, feature extraction is a useful algorithm. The UV detector is sensitive to the presence of thinnest oil-slicks and thus shows a good image of the size of an oil spill. This information overlaid on an infrared image, volume distribution and spill size is available. Combining the two with the thickness information of the laser fluorosensor (provided by the attenuation of the water-Raman signal) quantitative information is available (Fig. 3 and 4). As the LFS is also able to identify the pollutant, additional metadata can be attached to the image. The analysis of this specific application with neural networks and dynamic attractors is subject to ongoing research (Zielinski et al., 2001; Robbe and Zielinski, 2004) and will also depend on the availability of ground truth data.

## Conclusions

Looking at the present state of marine pollution remote sensing it was outlined that basic and advanced sensors are available for an effective airborne surveillance. While the basic sensors (SLAR, IR/UV) are currently installed in nearly every platform, the advanced sensors are only present at a few, dedicated aircraft. However this is likely to change, since several nations are at the step of defining new sensor systems in the next years. Within these system upgrades, FLIR thermal imagers with a laser illuminator will be prominent, since they offer

- a direct support in securing evidence against polluters at night and
- a wide range of applications, making them perfect for multi-role aircraft.

The need for operator support by means of data reduction and fusion was identified and some steps towards this approach have already been accomplished with existing datasets within DISMAR. The overall objective of this research project is to develop an advanced (intelligent) information system for monitoring and forecasting marine environment to improved management of pollution crises in coastal and ocean regions of Europe. It brings all types and sources of data together (satellites, aircraft, costal radar, ships) in one IT platform and provides (fusion) tools for the extraction of value-added information. On a bigger scale this reflects also the future of airborne surveillance. Utilising improved bi-directional communication links, database information from harbours together with latest satellite reports will be available online. Increased computational resources on-board and advanced algorithms will support the operator in its complex tasks, providing the basis for rapid man-made but machine-aided decisions. And in return, using feature extraction and fused images, pre-analysed airborne sensor information on oil quantities, types and possible origins can be transmitted while in flight to land or ship based command centres, supporting the combat against the dark side of world-wide ship transports.

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# Figures

Fig. 1

The second German maritime surveillance aircraft, a Dornier Do228-212 LM.. Slow flying speeds, good maneuverability, short take-off and landing distances, and long ranges/endurances are typical characteristics of maritime surveillance aircrafts. The SLAR antenna and the FLIR turret are visible.


Fig. 2

First results from the covert action laser illuminator (CALI) inside a FLIR turret in combination with a NIR-sensitive CCD camera. Helicopter approach to a non-moving ship on the Columbia River near Portland, Oregon, at 120 KTAS. Left: Approaching the vessel using the thermal camera and the autotracker. Middle: Close-up to medium field of view, still observing the IR image and using the autotracker. Right: Laser-illuminated stern of the ship, supplied by the CCD camera with disabled NIR-cut filter.

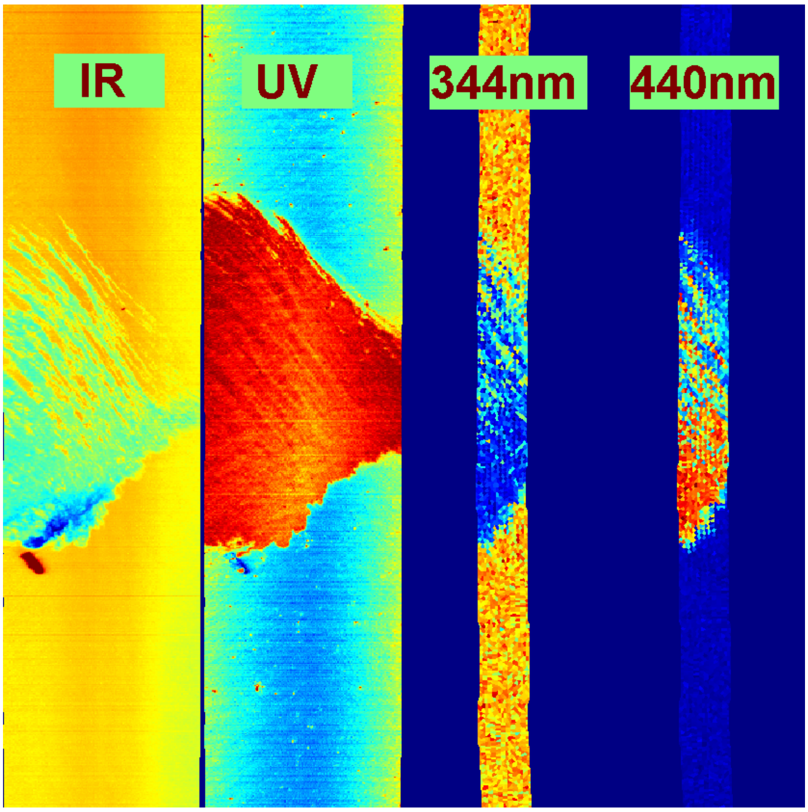


Fig. 3

Sample of data correction, feature extraction and data overlay. From left to right: IR scanner, UV scanner, LFS detection at 344 nanometres and a combination of the first three images. From the UV sensor, the outer dimensions of the spill where identified by feature extraction (black line). The 344-nanometre signal of the LFS is a measure of the oil thickness. All data corrected for roll and pitch. Yaw correction not applied to achieve better comparability of sensor results.

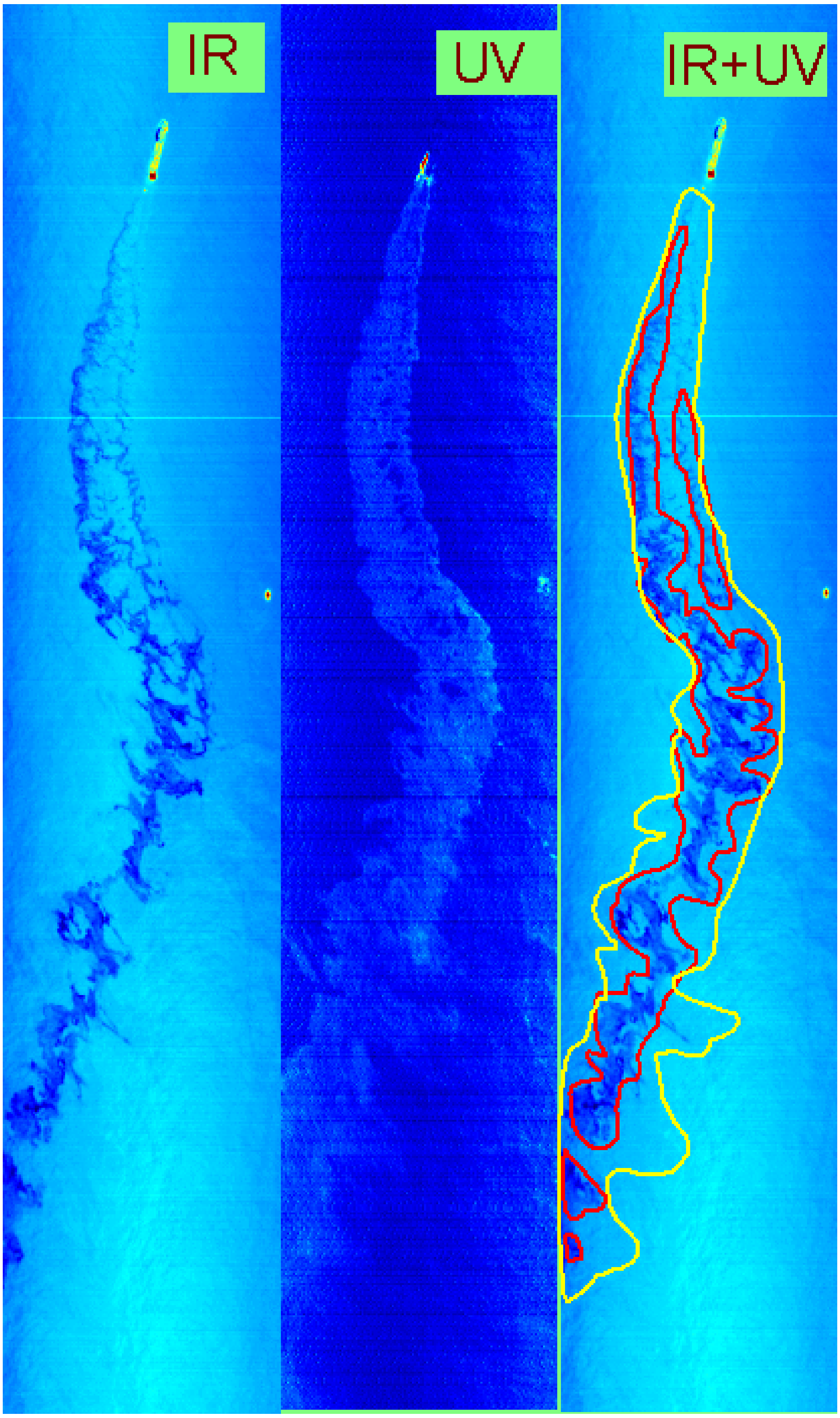


Fig. 4

From left to right: IR scanner, UV scanner and an IR image with IR (red) and UV (yellow) borders illustrated.