IEEE GEOSCIENCE and REMOTE SENSING Newsletter

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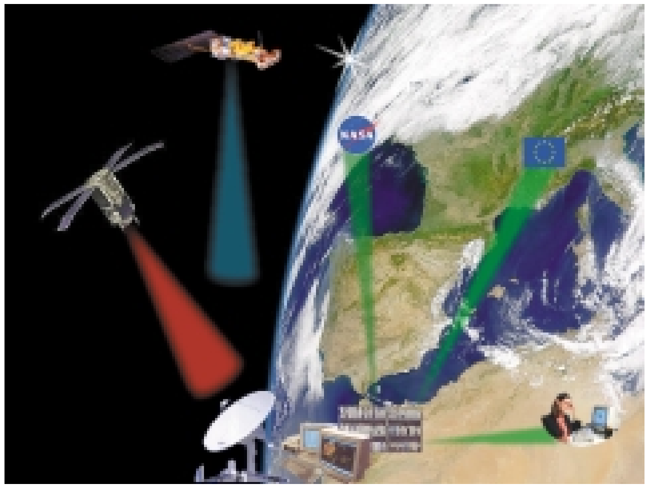

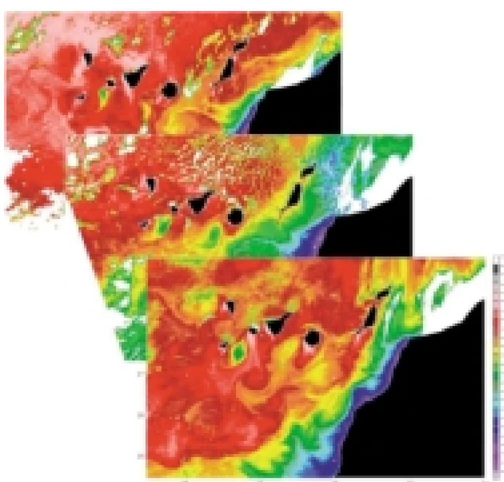

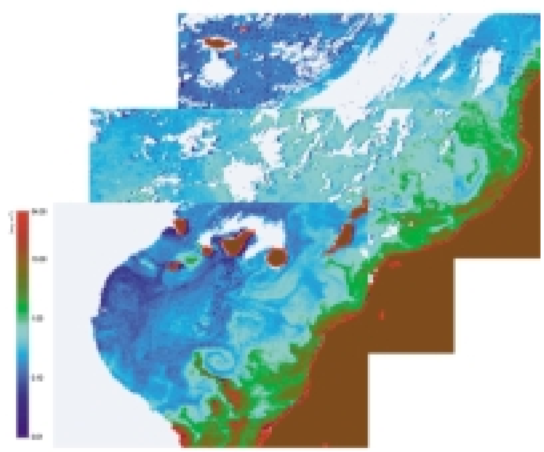

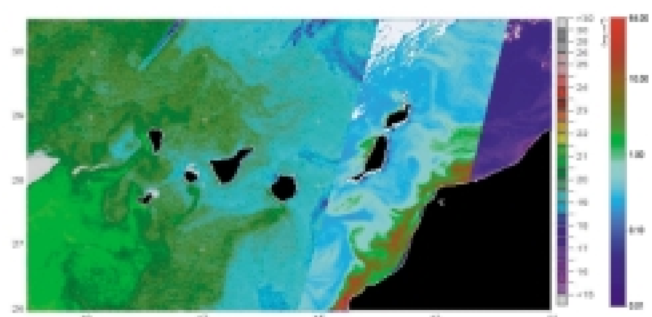

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IEEE

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GRS-S Newsletter Schedule

Month	Dec	March	June	Sept
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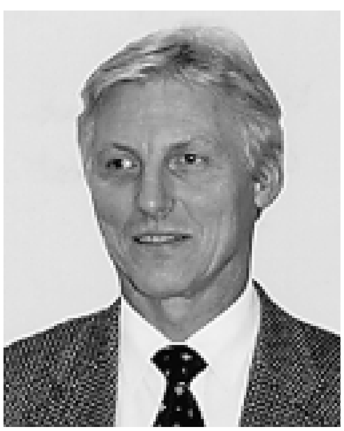
This issue of the GRS-S Newsletter contains a feature article, two industrial profiles, and new color advertisements for upcoming IGARSS symposia. The first industrial profile describes the recent activities of ProSensing Inc., a systems engineering firm in Amherst, MA, specializing in custom-built radar and radiometer systems for a wide range of environmental remote sensing applications. The profile includes brief descriptions, with accompanying color photographs and data images, of L-band radiometer systems for salinity mapping and millimeter-wave radars for cloud detection. The feature article of this issue describes recent development of a real-time system in the Canary Islands for acquisition, processing and distribution of AVHRR and SeaWiFS imagery. The cover figure illustrates the system and the utility of combined imagery to investigate the coonnections between sea surface temperature (SST) and phytoplankton concentration. The system is operated by the Remote Sensing Center at the University of Las Palmas, Spain. The second industrial profile describes recent research and development at Definiens AG in Munich, Germany. Their recent progress centers on the improvement of remote sensing image analysis techniques by using multi-resolution segmentation and rule-based classification, based on fuzzy logic operations. Definiens' analysis software stores attributes and contextual information with each image object in the hierarchy, thereby enhancing the capabilities of data fusion and classification.

On a different, farther reaching note, the events of September 11 have undoubtedly touched us all. Along with Werner Wiesbeck and the GRS-S Newsletter editorial board members, I extend my deepest sympathy to those who were affected by the events on September 11.

Message from the President



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The message that I originally had in mind prior to the events on the 11th of September is no longer appropriate. No internal IEEE activities and tasks, nor GRS-Society occurrences are relevant enough to express the feelings or required actions of all people of the free world.

Religious terrorism has existed since the earliest days of humankind. Recall, for example, actions occurring under the cover of voodoo or under the name of Christianization for more than a thousand years. We have become accustomed to believe that these events belong to the past, since most of them date at least 300 to 500 years ago. It seems, however, that not all religious activities of this kind have overcome the Middle Ages, and thus terror continues.

The question for us now is what can remote sensing contribute to peace, to well-being, and to the future of humankind. In my mind telecommunication and remote sensing have the greatest potential to secure for the whole world a future that is worth living.

continued on page 4

Cover Figure Information

Top: Data acquisition, processing and distribution system for AVHRR and SeaWiFS imagery in the Canary Islands.

Middle: Composite of multitemporal and multisensor images acquired and processed at the Remote Sensing Center of the University of Las Palmas, Spain.

Middle left: Sea surface temperature (SST) images from August 1999,

Middle right: Ocean color images from March 1998,

Bottom: Multisensor SST and phytoplankton pigment concentration images on 24 April 1999.

See the article beginning on p. 10 for details.

President's Message

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Within the GRS-S we can take heart that as a professional society we strive in every way to apply remote sensing technology to the betterment of humankind. This outstanding attitude is prevalent in our pursuits of, for example, improved landmine detection, severe weather monitoring, agricultural management, natural hazards detection, and disaster management — to name just a few areas. There are also many military activities in remote sensing, not so well known to most of us, for surveillance of strategically hard and soft targets such as missile launchers, command centers, and nuclear plants, along with recognition of the deployment and test of chemical or biological weapons, and so on. We can take pride in our membership for the positive motivations that guide their work.

I suspect (indeed, I would hope) that each of us will now take some time to dig a little deeper into what should (or even can) the GRS-Society do as a consequence. As society leaders, are we prompting as best as possible the search for yet untapped means of using remote measurements to thwart terrorist occurrences? Are we promoting the development of remote sensing systems to help minimize their consequences, for example, in disaster management? Can we invigorate discussion of the pertinent application issues, for example, the potential and impact of widespread surveillance for public safety? Can we accelerate third-world economic stability by faster realizing the promises of remote sensing? Technical solutions to problems of this nature are rarely obvious, but the charge to seek them now seems to be very clear.

I think I speak for the whole society by extending our deepest sadness and warmest sympathy to all our American and international colleagues who might have been affected on September 11.

Werner Wiesbeck
GRS-S President

P.S.: This message contains passages from correspondences within the Society, especially from Drs. Albin J. Gasiewski and Wooil M. Moon.

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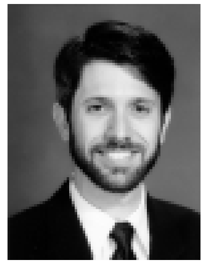

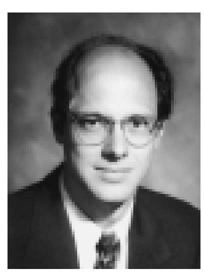

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INDUSTRIAL PROFILE

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Introduction

ProSensing is a systems engineering firm specializing in custom-built radar and radiometer systems for a wide range of environmental remote sensing applications. Founded in June 2000, ProSensing recently merged with Quadrant Engineering, which began building custom remote sensing instruments in the early 1990s. Our company has a highly qualified technical staff, with expertise in electromagnetic scattering and propagation, microwave systems, antenna design, radiometric techniques, radar oceanography, radar meteorology, high speed data acquisition, and digital signal processing. Our customers include government research agencies, university research groups, and large corporations in North America, Europe, and Asia.

Instruments developed by ProSensing and Quadrant Engineering are now in use in a variety of applications worldwide:

- High power polarimetric millimeter-wave cloud radars (ground-based and airborne)
- Salinity mapping airborne radiometers
- Ocean wind vector and wind speed measurement systems (active and passive)
- High resolution W-band radars for surface imaging applications
- Dual polarized, high spatial resolution (1m x 1m) ocean surface imaging radar
- Multi-beam Delta-K radar for ocean current mapping
- Synthetic aperture radiometers operating at 1.4 and 37 GHz
- Chaotic radar for automotive collision avoidance systems

In addition to these instruments, we have also developed a number of high performance data acquisition systems for high throughput raw data storage or for applications requiring real-time processing.

Recent Activities

ProSensing has several recent and current projects that emphasize the interaction of our staff with external scientists and engineers to develop new instrumentation for terrestrial, oceanic, and atmospheric remote sensing.

- Teamed with researchers from NASA GSFC and the University of Massachusetts, we are developing an airborne dual-polarized, two-dimensional thinned array radiometer for soil moisture and salinity imaging.
- We recently completed work with the US Naval Research Laboratory on the development of a precision salinity mapping radiometer employing a secondary radiometer for characterizing surface roughness.
- Our company is working with engineers from Raytheon and scientists from the US Office of Naval Research to add a weather radar signal processor to two electronically scanned tactical radar systems.

Figure 1. Airborne Research Australia's Cessna 404 with the SLFMR mounted beneath the fuselage. The aircraft is equipped with a general-purpose flight data acquisition system and navigational systems that provide precise environmental and positional data which is merged with passive microwave measurements from the SLFMR.

Some examples of custom systems developed by our company are provided below.

Salinity Mapping Radiometer Systems

The Airborne L-Band Radiometer Mapping System was developed by Dr. Mark Goodberlet at ProSensing along with research scientists from NRL and NOAA[1]. The system includes two radiometers: a Scanning Low Frequency Microwave Radiometer (SLFMR) that detects changes in both ocean surface temperature and salinity and a dual-channel infrared radiometer that provides a direct measurement of the ocean surface temperature. The output of these instruments is combined to estimate sea surface salinity with an accuracy of 2-3 parts per thousand (ppt). The latest version of SLFMR, termed

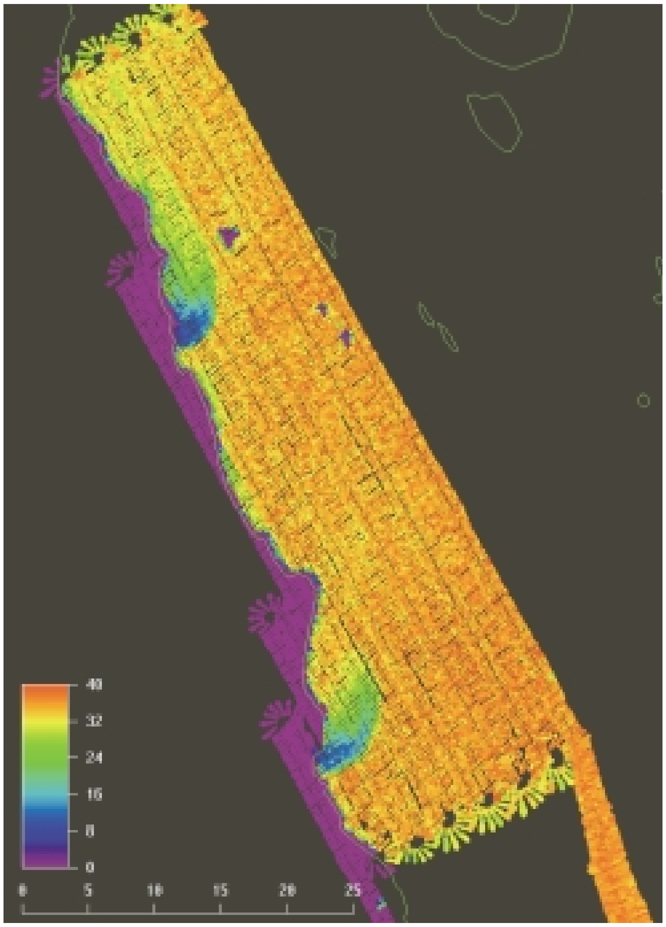

Figure 2. A single airborne surface salinity map obtained during the 2000-2001 monsoon season showing freshwater plumes originating from the Johnstone and Russell/Mulgrave river basins, respectively, in the south (lower) and north (upper) part of the survey domain. A succession of such images obtained during the 1999-2000 field season has been used to study the structure and evolution of the Herbert River Plume [2]. Color scale is in ppt.

STARRS (Salinity Temperature and Roughness Remote Scanner), uses six independent 1.4 GHz Hach radiometer channels to simultaneously generate six cross-track beams. The STARRS system also includes a Stepped Frequency Radiometer (SFMR) that corrects for changes in brightness temperature due to ocean surface roughness. The resultant accuracy is estimated to be better than 1 ppt.

An Australian research group comprised of a consortium of government and academic research agencies recently purchased an SLFMR from ProSensing. The new instrument was deployed on a twin-engine Cessna 404, as seen in Figure 1, owned and operated by Airborne Research Associates of Adelaide, South Australia. This group, led by scientists from Flinders University, James Cook University, and the Australian Institute of Marine Science, has received substantial financial support from two Australian Research Council grants and is actively supported by the Great Barrier Reef Marine Park Authority and other Australian universities. The group is presently utilizing the instrument to investigate the structure and influence of freshwater plumes originating from tropical rivers flowing into the Great Barrier Reef Lagoon, and to study the influences of environmental factors on surface salinity retrievals.

The instrument was flown successfully over the GBR Lagoon during the 1999-2000 and 2000-2001 austral summer monsoons [2]. The field surveys returned a succession of airborne surface salinity maps, shown in Figure 2, which together with surface “sea truth” measurements yielded data useful for classification of the plumes, and for studying plume distribution, dynamics, and evolution. The data are being analyzed to yield vital information on the frequency, extent, and character of freshwater influence on the status and health of the region’s coral reefs, which together comprise the extensive and valuable Great Barrier Reef World Heritage Area.

High Power Millimeter-Wave Cloud Radars

Since 1993, we have built one Ka-band (35 GHz) and five W-band (95 GHz) cloud radars for mobile and airborne operation (see Figure 3). Millimeter-wave cloud radars achieve high sensitivity with small antennas and moderate transmit power due to the enhanced scattering efficiency of small cloud particles at short wavelengths. The transmitter used at both Ka- and W-bands is an Extended Interaction Klystron Amplifier built by CPI, Canada. These tubes generate 1.5 kW of peak output power with a duty cycle up to 15% at Ka-band and 10% at W-band. All of these radars include a complex RF switching network in the front-end, including up to 11 low-loss latching circulators. This network allows pulse-to-pulse polarization switching on transmit and simultaneous reception of vertical and horizontal polarization on receive. Polarimetric data provides information on particle shape and orientation and can aid in the estimation of rain rate and in ice/liquid discrimination. Specific polarimetric data products that can be measured include differential reflectivity, Z_{DR}, linear depolarization ratio, LDR, and the copolarized correlation coefficient, ρ_{hv}. Other data products routinely measured include reflectivity, Z, pulse-pair derived velocity and velocity variance and FFT derived power spectra.

Two of the five W-band cloud radars were designed for airborne use; the first of these was delivered to the University of Wyoming in 1995. Since that time, the Wyoming system has participated in eleven field experiments, successfully flying over one hundred missions in the continental US and Europe [3-5]. In 1996, we were subcontracted by Mitsubishi to build the RF and data acquisition units for SPIDER, an airborne W-band cloud radar operated by Japan’s Communications Research Laboratory (CRL). SPIDER is mounted in a chin pod on a Gulf Stream aircraft, and employs a pressurized, liquid cooled enclosure compatible with flight altitudes up to 42,000

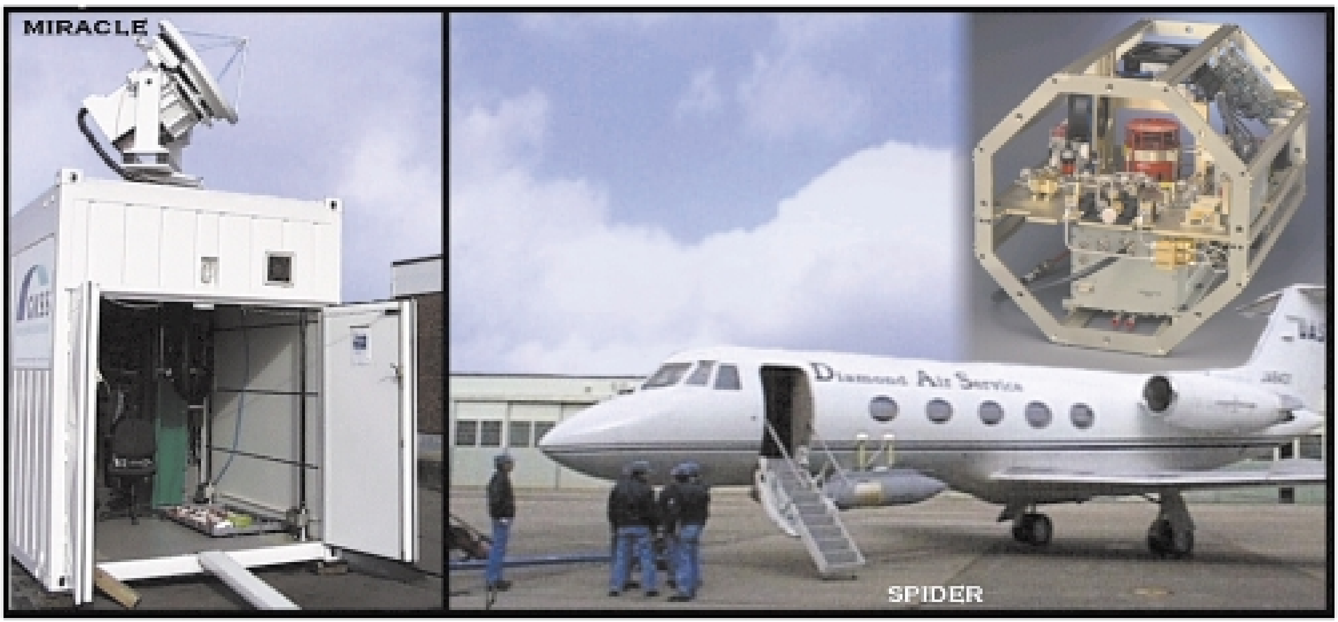

Figure 3. Polarimetric millimeter-wave cloud radars built by ProSensing are currently operated by customers in the US, Germany and Japan.

feet. CRL has also used the SPIDER system in a shipborne installation operating in subtropical regions.

The most recent W-band system, built for Mitsubishi Corporation, the prime contractor, was combined with a Ka-band radar to provide a mobile cloud and precipitation observation system for Japan's National Research Institute for Earth Science and Disaster Prevention (NIED) [6].

Customer web sites for some of the millimeter-wave radar systems are listed below:

- University of Wyoming's Department of Atmospheric Science; WCR system: http://www-das.uwyo.edu/wcr/
- GKSS Research Center; MIRACLE system: http://w3.gkss.de/english/Radar/miracle_engl.html
- Communications Research Laboratory (CRL); SPIDER system: http://www2.crl.go.jp/ka/earth/SPIDER-e.html

Figure 4. Liquid-cooled 95 GHz cloud radar and stand-alone instrument controller. Fans for optional heat exchanger are mounted on ends of RF unit.

Signal Processing Capabilities

Our company has built data acquisition and signal processing systems for a variety of radar and radiometric applications. Recent systems include a 32-channel digital receiver with raw data storage up to 160 Mbytes/s using commercial VXI based digitizers for a digital beamforming antenna application, and a 12-channel cross-correlator card, shown in Figure 5, that can support up to 32 MHz video bandwidth per channel.

Concluding Remarks

Several other instruments are currently under development at our company, including a multi-frequency (10, 35, 95 GHz) radar system for aircraft icing avoidance and a solid-state W-band cloud radar for airborne or ground-based use. Addi-

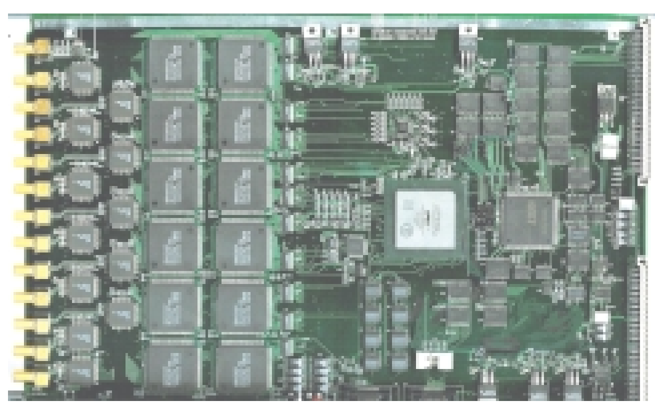

Figure 5. 12-channel correlator, employing 80 MSample/s 10-bit ADCs, ASIC digital receiver with digital LO and decimation filter, and high performance Altera's APEX 20KE family FPGA.

tional information on ProSensing's capabilities can be found on our web site at www.prosensing.com.

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FEATURE ARTICLE

A Real-Time Automatic Acquisition, Processing and Distribution System for AVHRR and SeaWiFS Imagery

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1. Introduction

During the last few years, the growth of remote sensing techniques, along with advances in image processing, has provided a new perspective of Earth's environment. These technologies have expanded scientific knowledge about the complex interactions between the atmosphere and the ocean, affecting climate and the environment.

Remote sensing is of great interest for the Canarian Archipelago, allowing the study of its marine environment. Particularly, oceanographic studies of the mesoscale structures of the water surrounding the Canary Islands have been carried out using data provided by CZCS (Coastal Zone Color Scanner), AVHRR (Advanced Very High Resolution Radiometer) and SeaWiFS (Sea-viewing Wide Field-of-view Sensor).

Remote sensing activities at the University of Las Palmas began in 1987, starting with the Faculty of Marine Sciences, as a tool for understanding the dynamics of the surrounding ocean area of the Canary Islands. More recently, image processing researchers from the School of Telecommunication Engineering at Las Palmas have participated with the Faculty of Marine Sciences in several projects. Finally, an important collaboration has been established with the image processing group of the Polytechnic University of Catalonia. Among the activities accomplished the following stands out:

- Integration of a real time satellite HRPT data acquisition, processing, archiving and distribution system (see cover image, top panel).
- Performing the above processes automatically with the capability to remotely monitor and control the entire system.
- Development of methodologies to process oceanographic images of interest.
- Providing images to several research groups.

In the remainder of this paper, the developed contributions are explained in greater detail, followed by a review of completed as well as upcoming projects.

2. Automatic HRPT Data Acquisition System

The TIROS/NOAA series of satellites are placed in a sun-synchronous polar orbit having a period of about 102 minutes. One of the instruments on board is the AVHRR radiometer, providing data in five (AVHRR/2) or six (AVHRR/3) spectral bands ranging from the visible to infrared (0.58 – 12.5 μm) with a satellite subpoint spatial resolution of 1.1 km.

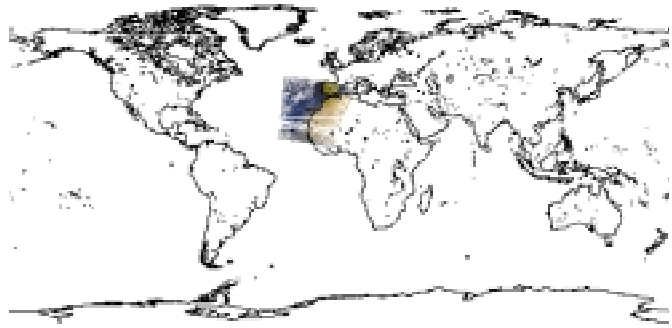

Figure 1. HCAN coverage area within the SeaWiFS Project.

Thousands of researchers around the world have processed the AVHRR data for several motivations and applications. Among them, the early launch of the first TIROS-1 satellite in 1969, the NOAA commitment to guarantee an on-going operational program of polar-orbiting satellites, the frequent revisit time (12 hours with one satellite) and open access to the sensor downlink. This research has led to continuous growth of ground receiving stations, consequently encouraging the appearance of several station manufacturers.

On the other hand, the SeaStar (or Orbview 2) spacecraft was launched in 1997 on a similar orbit as the TIROS/NOAA, flying the SeaWiFS radiometer as the unique payload. That instrument includes eight spectral bands, five in the visible region and two in the near IR (0.412 – 0.865 μm), with the main objective of acquiring ocean color data on a global basis during a period of five years, at the same spatial resolution as the AVHRR. It is worth mentioning that the reception and processing of the SeaWiFS images is carried out within the framework of the *SeaWiFS Project*, managed globally by NASA for the scientific utilization of the data and by Orbital Sciences Corporation (OSC) for the commercial exploitation of the instrument. The receiving ground station, named HCAN, (additional information at http://seawifs.gsfc.nasa.gov/SEAWIFS.html) is an active part of the NASA project. The data received by the sensor is encrypted before transmission to Earth, so all receiving stations require a Seastar Ground Processor (SGP) to successfully retrieve the downlinked data. It is important to emphasize that HCAN station is the only Spanish downlink station with the capability to decrypt the data in real time. Only a few stations around the world have this status. The majority of receiving systems have to store the encrypted data for a period of two weeks before they are allowed to decrypt the data.

For the orbital parameters of both satellites, Figure 1 shows the coverage of the station, which is within a circle centered at the Canary Islands with a radius of approximately 3000 km.

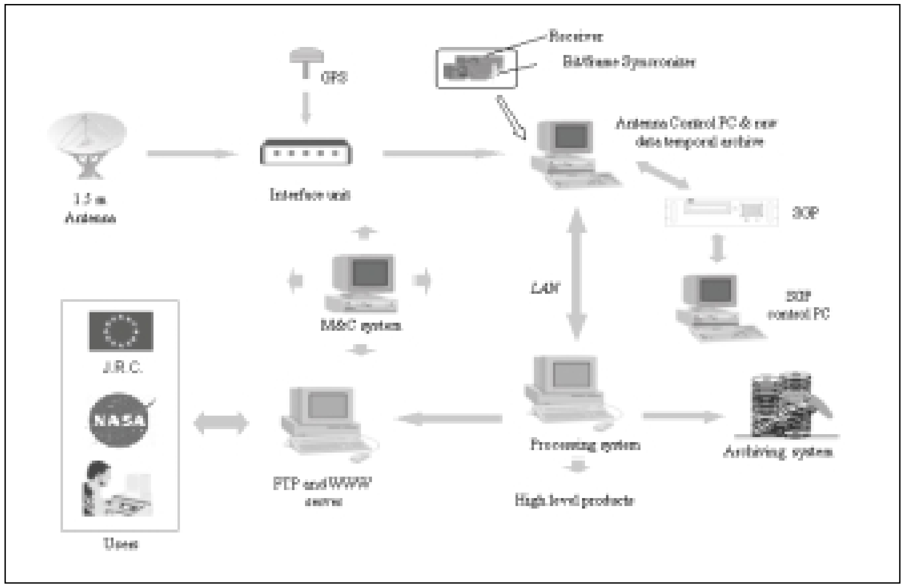

Figure 2. Block diagram of the ground system architecture.

As previously mentioned, it is now possible to buy ground receiving stations for AVHRR and SeaWiFS HRPT data from many suppliers. In general terms most of the users of receiving stations are interested only in obtaining the satellite data and not in the acquisition chain *per se*. However, the goal in this case was to have a modular and open system to make interaction feasible.

The HRPT Data Acquisition System is composed of the elements shown in Figure 2. The general processing and distribution systems shown are described below.

The main local contribution to the original HRPT station was the automation of the daily tasks and the development of a monitoring and control (M&C) system that can be controlled remotely.

2.1 Automation of Processing

The acquisition system automatically tracks the satellites and archives the raw data to the hard disk. In addition, a new step was added to transmit the raw data to the processing workstation via FTP, but only if there is no conflict with downlinking from a new satellite.

For SeaWiFS, the processing to higher levels (1A and 2) is done automatically and the resulting level 2 files are processed to eliminate unnecessary data. In addition, the generated level 1A files are forwarded to the FTP server, and a notification is sent to NASA so they can download the files.

For AVHRR, the subsequent processing steps (radiometric, atmospheric and geometric corrections) are carried out automatically to obtain sea surface temperature maps.

In conclusion, all the daily acquisition and processing activities are performed without human intervention. The only exception is in the archiving chain, where it is necessary to insert

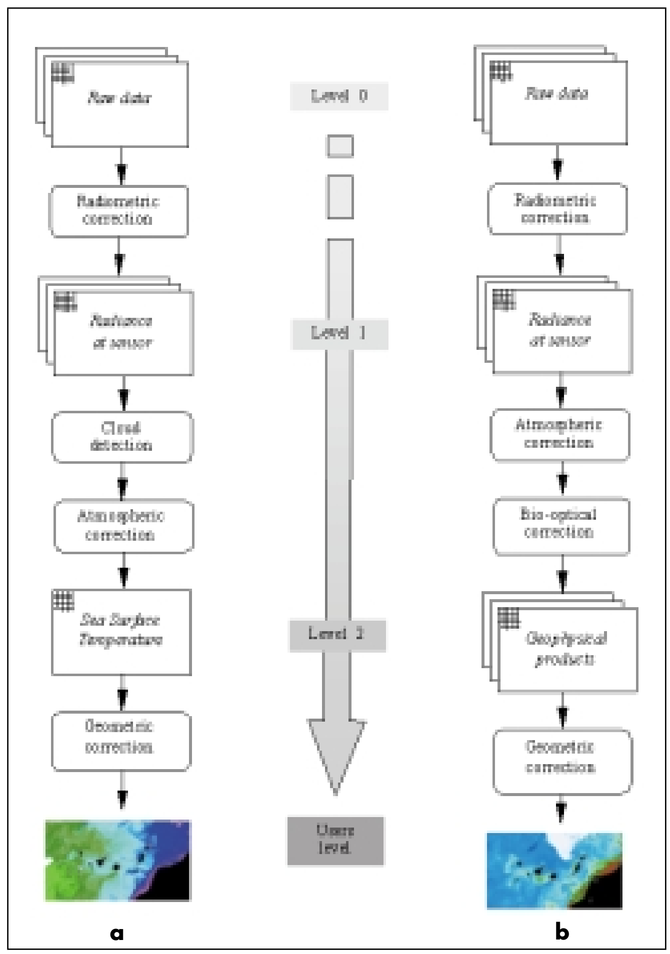

Figure 3. Processing levels hierarchy. (a) NOAA-AVHRR data and, (b) SeaStar-SeaWiFS data.

and extract CDs and Exabyte tapes from the corresponding recording systems.

2.2 Remote Monitoring and Control System

One of the critical requirements for an operational spaceborne system is to maximize the reliability, because any failure could mean a loss of unrecoverable data. In order to achieve complete and permanent monitoring without the need for operator presence in the station, a monitoring and control (M&C) system was developed that can be accessed remotely via Internet in a secure way. The M&C system enables the remote execution of a number of commands, as well as tracking the status and processing level of a variety of images.

If a failure occurs in the acquisition or processing systems, an e-mail notification is generated automatically to provide information about the anomaly and to aid in assessment of the time scale on which a reaction is needed.

To summarize, these two upgrades have been critical for the operation and maintenance of the system, to achieve high reliability and to avoid the need to recruit a staff to operate the entire system. These tools have also been of great importance during oceanographic campaigns to guarantee data availability in real time.

3. The Processing System

Satellite remote sensing technologies can provide large amounts of data on the state and evolution of terrestrial environments. The utility of these radiative data, collected in space to address concrete problems at the surface of the Earth, depends on the capability to extract and interpret useful information on the geophysical processes of interest.

Several factors have necessitated the establishment of a hierarchy of processes to allow the generation of operational products on the user level and the development of precise, autonomous and efficient processing algorithms, (1) the technical complexity of contemporary remote sensing systems, some of which have significantly off-nadir viewing capabilities (i.e. NOAA-AVHRR and SeaStar-SeaWiFS), (2) the different levels of processing involved to obtain geophysical parameters, (3) the interest in multi-temporal and multi-sensor studies and (4) the increasing requirements for accuracy and temporal resolution of satellite measurements.

Figures 3 (a) and (b) shows the flowcharts of the processing hierarchy levels applied to NOAA-AVHRR and SeaStar-SeaWiFS data respectively. The following sections describe briefly the data processing steps to generate operational products, including sea surface temperature (SST) and ocean color imagery, for various scientific fields, such as oceanography, meteorology and fishery [2, 11].

3.1 AVHRR Data Processing

The main goal of AVHRR processing is to generate products, typically SST maps, that are optimized for the science applications following the requirements recognized in the World Climate Research Program [1]. This research work is focused on the development of a systematic method for processing NOAA-AVHRR images [8]. At present, the AVHRR data processing steps have been identified (see Figure 3a, left) and processing tools have been implemented and tested in the Remote Sensing Center, including some improvements in the standard procedure [6, 7]. The following steps summarize these procedures.

1. Radiometric Calibration: For the NOAA-14 AVHRR sensor, a radiance-based nonlinear correction method is used based on that described in [19]. This procedure corrects the instrumental effects of the AVHRR thermal infrared channels centered at 10.8 μm (channel 4) and 12 μm (channel 5), whose Hg-Cd-Te detectors exhibit small but well-characterized nonlinearities in their response to incoming radiation. Additionally, it assigns a non-zero radiance to the response to cold space. That radiance is converted to brightness temperature, which is the quantity of interest, using the inverse Planck function with the appropriate wavelength numbers provided by NESDIS [12].

2. Cloud Detection: The multi-band threshold method proposed in [16] has been extended and adapted to the region of analysis (Canary-Azores-Gibraltar, referred to as CANIGO area) to compute the cloud mask, based on experimental data [6].

3. Atmospheric Correction: The sea surface thermal radiation received at the satellite has propagated through the intervening atmosphere. To obtain SST from the brightness temperatures of different channels, several atmospheric correction methods have been developed which are known collectively as the Multiple Window Method [1]. In general, retrieval algorithms involve linear combinations of satellite brightness temperatures observed in channels 4 and 5 (T4, T5), and follow the so-called split-window form, as reviewed by [1], [18].

A split-window function to perform atmospheric and emissivity correction in the CANIGO area has been developed. Algorithm coefficients were estimated from regression analysis using co-located in-situ and satellite measurements (matchups) and by examining the dependencies on the variables T4, T5 and the satellite zenith angle. Error analysis has shown that theoretically SST can be retrieved to within 0.36 ºC RMS [3], [7]. Data from the AVHRR Pathfinder Oceans Matchup Database were used for validation purposes [15].

4. Geometric Correction: One of the principal difficulties in the widespread use of NOAA-AVHRR images is their distortion due to the Earth's curvature and rotation as well as the satellite's orbit and scanning geometry. A good overview of existing methods for geometric correction of satellite data is given by [2], [17]. In general the procedure for the georeferencing of NOAA- AVHRR images is based on the combination of an orbital model and Ground Control Points (GCPs).

A fully automatic and operational procedure for the georeferencing of NOAA-AVHRR images with high accuracy and without operator intervention has been developed. The algorithm is based on the simultaneous use of an orbital model and a contour matching approach [4], [5], [7]. The latter relies on an affine transformation model, and is used to correct the errors caused by inaccuracies in orbit modeling, nonzero value for the spacecraft's roll, pitch and yaw, and failures in the satellite internal clock. Three different robust and automatic algorithms have been proposed for optimization [9], with a new error estimation technique for assessment [8]. The geometric correction algorithm has proved to be capable of georeferencing a satellite image to within one pixel.

These radiometric, atmospheric and geometric correction processes were implemented using a graphical user interface. Figure 4 illustrates the GUI, showing a NOAA-AVHRR image (RGB).

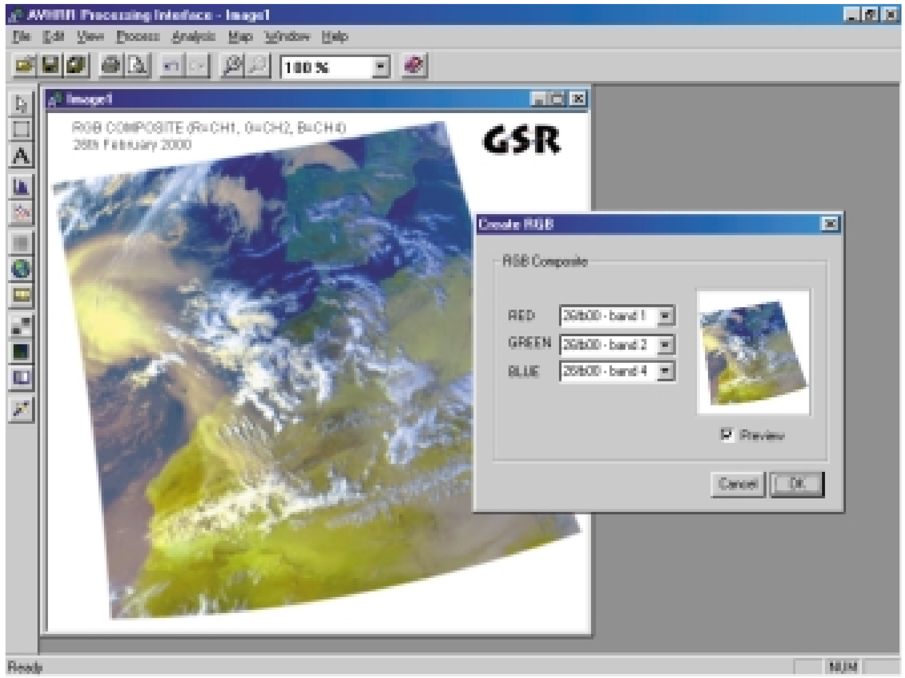

Figure 4. NOAA-AVHRR processing tool interface. This RGB composite image was acquired on February 26, 2000 by NOAA-14 and shows a massive dust storm over the Canary Islands, originating from the Sahara Desert.

3.2 SeaWiFS Data Processing

As previously mentioned, the purposes of the SeaWiFS Project are to obtain accurate ocean color data from the world's oceans for a 5-year period; to process these and ancillary data to obtain meaningful biological parameters, such as photosynthesis rates; and to make these data readily available to researchers.

From a scientific perspective, obtaining ocean color data has been a high priority since the beginning of the 1990s, as recognized in National Research Council reports from the National Academy of Sciences [11].

The SeaWiFS image processing (Figure 3b, right) is performed within the framework of the SeaWiFS project. The data calibration, processing, and validation program includes the SeaWiFS data calibration, algorithms for operational atmospheric correction, and validation of the accuracy of derived products. Atmospheric correction algorithms use external data such as ozone concentrations and surface pressure fields.

Unlike the NOAA-AVHRR image processing, for which ad-hoc algorithms were developed, the different processing levels applied to the SeaWiFS data are included in the SeaDAS (SeaWiFS Data Analysis System) software package, developed under the NASA ocean biochemistry program [13] and made available for research centers and associated users. SeaDAS is a comprehensive image analysis package for the processing, display, analysis, and quality control of all data products and ancillary meteorological and ozone data.

4. The Distribution System

The distribution system is designed to provide any user around the world simple and fast access to the AVHRR and SeaWiFS data, generally via FTP.

At the present time AVHRR level 1B images from the Canary Islands station coverage area are supplied on Exabyte tapes (or CDs) to the Joint Research Center (JRC, Ispra, Italy) and to other Spanish research groups.

For SeaWiFS, access to the data is permitted only for research purposes to NASA authorized users. A typical user requiring real-time data is the University of Bremen. HCAN station has been providing real-time level 1A images to NASA since August 1997 and is at present a very active station, with more than 1700 images already distributed to the scientific community.

5. Imaging Applications

Satellite images are used widely in oceanographic studies. For more than 20 years, sea surface temperature has been estimated from all the oceans. The AVHRR, onboard the NOAA satellites, has been the leading sensor for this purpose. In contrast, phytoplankton pigment concentration images were obtained for two separate periods: 1978-1986 from the CZCS onboard the Nimbus-7, and 1997-present from the SeaWiFS on the SeaStar platform.

AVHRR and SeaWiFS have been considered the best candidates for use in studies of climatology and mesoscale phenomena for their high swath, spatial and temporal resolution. In particular, SST and pigment concentration, obtained from these sensors, are the products of principal interest for applied research.

The detection of the presence and evolution of mesoscale structures in the surface layers of the ocean increased after the launch of these satellites. After considering the ocean as a laminar flow, oceanographers began to study the ocean as a turbulent flow filled with mesoscale structures, such as eddies and upwelling filaments [10], [14]. These mesoscale phenomena are clearly detected in the cover image. The middle two panels of the cover image are a composite of three consecutive days of SST and phytoplankton pigment concentration images, respectively. The bottom panel of the cover image shows a composite of SST and phytoplankton pigment concentration images for the same day. This last image was created by superposing a portion of a phytoplankton pigment concentration image (from approximately 13º to 15ºW) over the SST image. In the cover image, high values of phytoplankton pigment concentration and cold sea surface temperatures are observed along the northwest African coast. From there, long filaments of high phytoplankton concentration and cold water were flowing offshore. The correspondence between cold water coming from the African coast and high phytoplankton concentration is unambiguous.

South of the Canary Islands, cyclonic eddies detectable by their cold sea surface temperature and high phytoplankton concentrations are observed in all the images shown. They are located downstream from the islands at their west flanks. The three consecutive images clearly show the shedding and southward displacement of these structures.

6. Related Projects

The favorable results of the aforementioned cooperation between the image processing groups and the oceanographic researchers have spawned follow-up projects that are outlined below.

Image registration and fusion: Spatial registration of multidate or multisensor images is required for many applications in remote sensing, such as the construction of image mosaics, DEM generation from stereo pairs, orthorectification and multitemporal analysis. Once registered, the images can be fused in a way that improves information extraction. The idea is to combine the data from several sensors such as NOAA-AVHRR, SeaStar-SeaWiFS, TERRA-MODIS, and ERS-ATSR in order to obtain operational products while developing automatic and accurate registration techniques.

Automatic detection and tracking of oceanographic features: Upwellings, eddies and wakes play an important role in the study of ocean dynamics and fisheries. The aim of this project is to use different image processing tools to implement an automatic method for the detection and characterization of these structures, allowing very accurate location, contouring and tracking of the evolution of the oceanographic structure, as well as predicting its trajectory.

Cloud and aerosol detection in satellite images: The majority of techniques applied to detect and mask clouds make use of multiband thresholds [6], [16]. The objective is to automatically and accurately detect the cloudy areas in any region for any sensor. On the other hand, the detection and characterization of atmospheric aerosols is of great importance for a variety of reasons including the frequent appearance of dense aerosols in the Canary Island area (e.g., Figure 4).

Feature detection in high resolution images: In general terms, land and some oceanographic applications usually require high resolution images. To this end, the processing of Ikonos or similar sensors is being considered in order to provide operational services to municipal governments and environmental agencies, for example, crop evolution and planning, and coastal pollution monitoring.

Acknowledgments

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INDUSTRIAL PROFILE

Definiens Imaging GmbH: Object Oriented Classification and Feature Detection

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Definiens Imaging GmbH

Definiens Imaging GmbH is based on the former Delphi2 Creative Technologies GmbH, founded in 1994 by Professor Gerd Binnig, a 1986 Nobel Laureate in physics, and Dieter Herold, a journalist. Delphi's aim was to develop knowledge-based systems that extract information from a complex environment. These systems are designed to operate using "real world" intelligence, i.e. human judgment encoded into algorithms and software. Following this aim and partially funded by the German Environmental Fund (Deutsche Bundesstiftung Umwelt), Delphi2 Creative Technologies created an object-oriented multi-scale image analysis system, eCognition, and developed other innovative approaches to automated information extraction.

In order to allow Delphi to develop into a corporation delivering products to worldwide users, the venture capital company tvm (technology venture management), Munich/Boston invested in Delphi2 in early 2000. At that time, the company changed its name and legal status to Definiens AG and added new management and additional scientific, technical, marketing and administrative staff. At present Definiens AG has more than 30 employees and is located in Munich, Germany. Definiens AG's goal is to provide software solutions for remote sensing analysis, knowledge management, traffic management and navigation for a growing global market.

To address these different technologies and market requirements, the company was divided into three business units.

- Geomatics & Imaging
- Knowledge Management
- Traffic Information & Navigation

In order to allow the "Geomatics & Imaging" business unit to focus on its dedicated market, it was converted into a company of its own: Definiens Imaging GmbH.

Definiens Imaging GmbH develops and markets eCognition globally, supported by resellers, including PCI Geomatics of Canada as the global prime reseller. Definiens is involved in several national and international projects to optimize eCognition for specific applications and to work together with future clients. One project focuses on the development of new systems to extract information from high-resolution polarimetric SAR data on an operational basis (OSCAR as part of ProSmart II).

eCognition: Object Oriented Image Analysis

eCognition is a system for extraction of information from remotely sensed images. It is optimized for cost-effective classification of very high spatial resolution land data (e.g. one-meter satellite imagery or sub-meter aerial photos) and radar imagery. It addresses the geoinformatics market as a new product for analyzing or classifying digital imagery derived from orbital satellites as well as aircraft. The object-oriented approach is one of its principal advantages. An image object, defined as an area with shape and spectral homogeneity, provides a greater number of and more meaningful features for classification than single pixels or sliding windows around pixels. Subsequent classifications can use this large number of independent features to assign land cover classes to image objects. Additionally, when using this object-oriented approach, the number of units to be handled is drastically reduced, accelerating the classification process. Class refinement and even a transition from pure land cover assignment to land use assignment are possible due to features definable in eCognition using the hierarchical network of image objects. Relations between classes within one scale and within the hierarchy of scales automatically support the final land cover classification or extraction of features and allow the production of valuable information from remote sensing products. As such, eCognition is already being used to analyze not only aerial photography and satellite imagery, but also medical and biological imagery.

A. Segmentation in eCognition

Input layers to eCognition's segmentation can be data from multiple sensors and additionally thematic raster and vector layers with, for example, cadastral information. Adjacent, similar pixels are aggregated into segments as long as the heterogeneity in the spectral and spatial domains is minimized. Neighboring segments are fused to a new segment if the resulting heterogeneity is minimized and below a specified level. The definition of heterogeneity is flexible and consists of a trade-off between homogeneity in the spectral domain (e.g. backscatter values in various channels) and form/shape in the spatial domain. Homogeneity in the spectral domain is defined by a weighted standard deviation over the spectral channels. Homogeneity of shape depends on the ratio of an object's border length to the object's total number of pixels (compactness), and the ratio between the length of an object's border to the length of the object's bounding box (smoothness). Compactness is minimum for a square; smoothness is minimum if the object borders are not frayed.

eCognition's technology mimics the hierarchical approach of image and scene analysis used in human perception. Human perception typically analyses on several resolutions where the most suitable level is used for each object of interest. It explores the relationship of objects on different levels in order to overcome ambiguities.

The patented multi-resolution segmentation technique in eCognition finds image objects even in textured data, such as SAR images, high-resolution satellite data or airborne data. It provides the possibility to easily adapt the extraction of meaningful image objects to specific tasks and specific image data. The hierarchical network of image objects allows the representation of image information at different resolutions simultaneously. Fine objects are sub-objects of coarser structures. Hence, each object contains information about its context, its neighborhood and its super- and sub-objects. Context and neighbors again refer not only to features of neighboring pixels or groups of pixels but also to the rich features of neighboring image objects. Operating on this network, interrelations among objects can be defined to utilize this additional and often essential contextual information. eCognition is designed to take full advantage of the interrelations among image objects.

B. Rule-based Development in eCognition

In eCognition the segments, or native objects, are assigned to membership classes. Two major strategies are used to implement classification, nearest neighbor classification and development of classification rules using fuzzy logic operations. In either case, no single pixels are considered, but instead only the features of native objects. This approach has several advantages: it significantly increases signal-to-noise ratio in the objects and it decreases computational requirements. Most important, additional object features, which are not available or are less meaningful for pixels; such as geometry (length, width, smoothness, compactness) relationships to neighbors within one level and between levels, can be used for the classification.

Supervised classification based on "nearest neighbor" is a well-known technique. In eCognition, however, the object-oriented approach significantly reduces the number of necessary training samples, since the object segments already

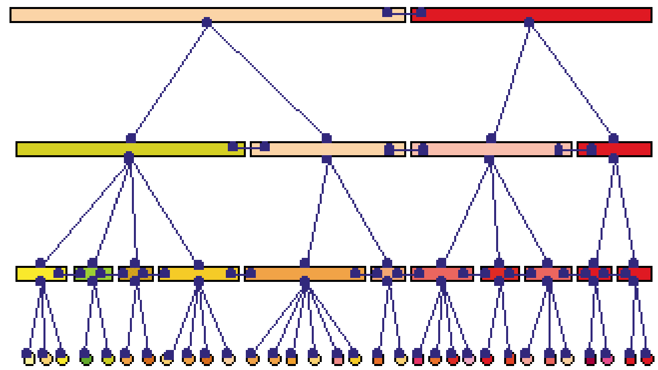


Figure 1: Hierarchical network of image objects: Each object knows its surrounding objects, its sub- and super-object. These interrelations are valuable features for classification of remotely sensed images. eCognition's fuzzy classification system takes full advantage of these aspects.

aggregate similar pixels. Additionally, all the object features (e.g. shape and relationships within the hierarchical net) are available for this simple "click & classify" approach, allowing efficient classification.

If relations between object features and defined classes are known, they can be integrated into the classification process and define the rule base, even if the relations are only of a vague and semantic nature. This is possible due to the fuzzy-logic approach to classification.

Each object typically belongs to several classes. The ratio of membership in different classes represents the reliability of class assignment and class homogeneity within the object. This information is important for remote sensing, because the mixture of class membership is typical in the reduced resolution, and a completely reliable classification is not possible for all classes over the whole data set. It is helpful to perform automatic classification in a semi-automatic environment and to mark the few uncertain objects for subsequent manual inspection. Using eCognition's rule-based classification and the feature "membership in class" it is possible to clearly visualize misclassifications among distinct classes and to view this information not only in a statistical way, but also for each image object and thus as an additional thematic layer. Manual corrections are easily possible as well.

C. eCognition's Advantages and Applications

eCognition allows the discovery of hidden contents in remote sensing imagery. It calculates more than the usual spectral or textural features. Hierarchical dependencies in the data can be visualized and used in the classification process. eCognition enables modeling of expert knowledge with a robust fuzzy-logic rule base. Even semantic relationships in classification can be explored.

This contextual information is most important in SAR image analysis. Typically only corners of buildings are identified instead of the buildings themselves, which are required in

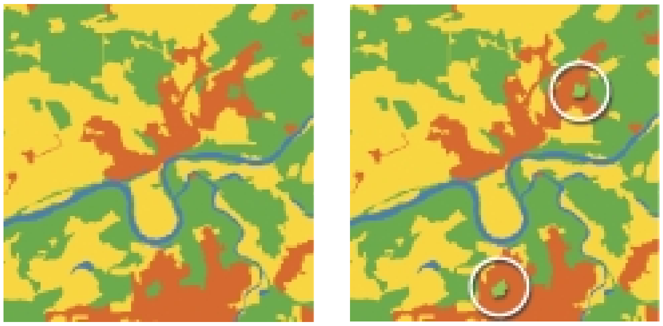


Figure 2: Trees are either assigned to forest (left image) or to park (right image), depending on their surroundings (see white circles). The rich contextual feature in eCognition and the possibility of integrating vague concepts into the fuzzy rule base allow assignment of land use in addition to land cover.

geoinformation systems. However, using contextual information it is possible to identify entire developed areas.

This semantic and contextual information reduces the number of spectral features necessary for the identification of certain classes. This adds increased reliability and allows rule-based development independent of sensors and specific scene characteristics.

eCognition enables powerful data and information fusion. Data can be combined from a variety of sensors and platforms. Information can be fused from low and high level remote sensing products. For example, sea surface classification based on backscatter values of one or more sensors can be improved using meteorological information. Other thematic layers from GIS can be integrated as well.

Analysis of High Resolution Polarimetric SAR Data

Current developments at Definiens Imaging GmbH will further increase the usefulness of eCognition for remote sensing. One such development is the availability of sensor specific features. First, emphasis is being placed on exploring the unique capabilities of polarimetric SAR to support users of current airborne polarimetric sensors and upcoming spaceborne radiometric sensors including Envisat and Radarsat-2.

This development is being performed as part of the project OSCAR (object oriented segmentation of advanced SAR), which is part of the national project ProSmart II (08/2000 – 04/2002), led by Infoterra GmbH, partially funded by BMBF (German Ministry of Research and Technology, #50EE59).

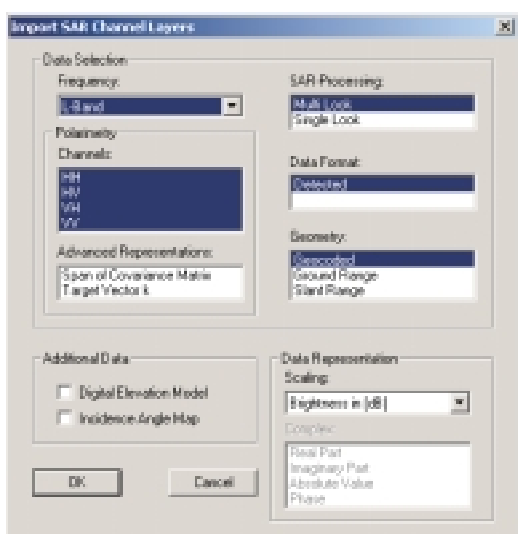


Figure 3. New eCognition E-SAR interface

The research project ProSmart II for the development of Geo-Information Products and Technologies with European contribution, is composed of:

Product Development Partner:
Infoterra GmbH, HUGIN AG, DELPHI-IMM AG, ILV-Fernerkundung GmbH, EADS-Dornier, IÖR, DLR-HR

Innovation Partner:
University of Bonn, Technical University of Munich, Institute for Navigation of the University of Stuttgart, FAL, CESBIO

Technology Development Partner:
Definiens GmbH, CLK GmbH, GeoSystems, ERDAS

Reference Clients:
BASF, StoraEnso, Soil & Water, national administrations for landuse

Geoinformation is extracted at selected test sites for precision farming, forestry and urban mapping on a pre-operational basis. DLR's airborne sensor, E-SAR, delivers polarimetric SAR data to simulate future spaceborne sensors, in particular the TerraSAR satellite.

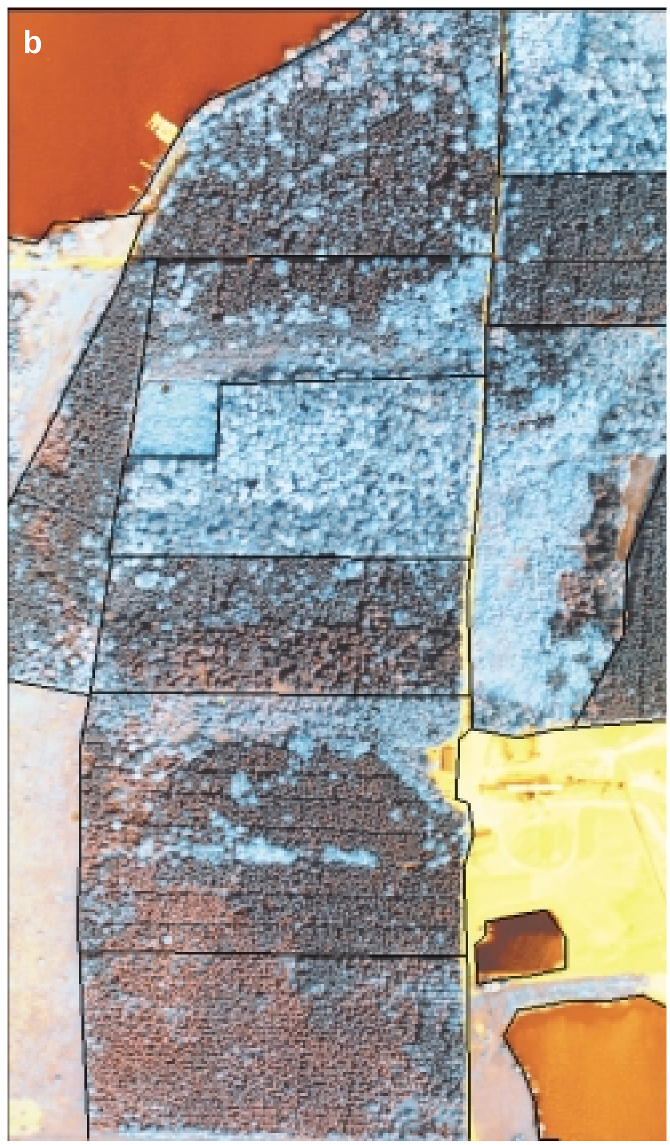
To use the unique capabilities of SAR data, eCognition goes even further "beyond pixels." Not only are objects considered instead of pixels, but also the input values are no longer regarded as image samples. The information content of the complex backscatter, indicating specific electromagnetic scattering mechanisms of the imaged land surface and sub-surface, will be represented using advanced feature extraction. This will enable users to explore valuable information about detailed biological and physical parameters. The parameters retrieved from these observables include not only the land cover type, but also the soil moisture, surface roughness and biomass.

Polarimetric decompositions are a current research topic. It has yet to be determined which polarimetric representations are most suitable for a specific application and what level of accuracy and robustness can be obtained. eCognition will integrate these advanced methods to allow convenient testing on a broad range of data sets and extensive comparison with ground-truth measurements within the ProSmart II project and provide results to users with the launch of the eCognition radar module in 2002.

The synergy of the object oriented approach of eCognition, its semantic analysis, its GIS functionality, the powerful signal processing methods a

Class	Rel. Area of Coniferous Sub Objects(1)	Rel. Area of Deciduous Sub Objects(1)	Rel. Area of Coniferous dry Sub Objects(1)	Rel. Area of Clearing Sub Objects(1)	Number of Tree Centers Sub Objects(2)
stand 11	0.769897	0.102605	0.104580	0	779
stand 9	0.035819	0.942355	0	0	371
stand 10	0.920663	0	0.032409	0	134
stand 16	0.164133	0.094229	0.729948	0	1578
stand 6	0.779327	0.189189	0.030238	0	560
stand 8	0.193378	0.732715	0.051642	0	437
stand 7	0.426074	0.438378	0.022209	0.101892	497
stand 3	0.680416	0.288647	0.008129	0	1105
stand 2	0.057326	0.934045	0	0	175
stand 4	0.879843	0.107598	0	0	385
stand 13	0.506318	0.255329	0.208227	0	1797

Figure 4 a (above) and b (right). Statistical evaluation of tree stands from CASI (Compact Airborne Spectrographic Imager) data was performed, including consideration of cadastral information. Multi-resolution segmentation of 10 bands from CASI and simultaneously from the cadastral thematic layer (overlayed on the false color composite of the CASI channels as black lines in Figure 4b enables eCognition to adapt its segmentation to the cadastral borders and produce an evaluation with regard to the individual stands. Statistics are shown in Figure 4a.



for SAR data and new powerful airborne and spaceborne sensors will lead to valuable new information products.

The first step to integrate SAR polarimetry into OSCAR has already been performed. Definiens developed a convenient interface to read polarimetric SAR data from E-SAR into eCognition.

eCognition recognizes this specific data format and allows meaningful identification of the available products according to polarimetric channels, frequency, geometry and processing mode. Additional polarimetric pre-processing is also available. At present, the span of the covariance matrix, the total polarimetric power, can be evaluated or, if complex polarimetric data are given, the target vector k : $k = (S_{hh} - S_{vv}, S_{hh} + S_{vv}, 2S_{hv})$ is evaluated, where each component describes specific scattering mechanisms of the surface. If a digital evaluation model and an incidence map are available, they can be added as additional layers or for enhanced representation, e.g. to obtain brightness and σ_0.

The next steps in the development will be to include polarimetric speckle filtering to optimize segmentation processing for single-look complex data and to integrate geocoding of information products derived in slant range.

However, segmentation strategy and fuzzy-logic rule bases have been developed for basic land cover classes from high-resolution polarimetric SAR images. The initial results are very promising.

The analysis of basic land cover classes significantly helps in subsequent focusing on specific topics such as forest inventory, urban planning and precision farming. The time required for computation, data transfer and storage can be reduced for these high level product-generation processes.

Conclusions

eCognition's advantage over conventional pixel-based procedures is the use of attributes of image objects rather than the values of individual pixels. Serving as information carriers for subsequent classification, image objects offer the fundamental advantages of accessibility of a greater quantity and more condensed information (shape, texture) and spatial relationships among the hierarchy and neighboring objects can be used.

eCognition's classification system takes full advantage of the multitude of features of these image objects. It allows efficient supervised classification ("click & classify") and alternatively, or in combination, classification by explicit rules and fuzzy logic functions.

The procedure implemented in eCognition results in high classification accuracy, better semantic differentiation and addresses a range of new classification tasks that until now could not be processed by existing analysis systems. With sensor-specific developments, such as for SAR, eCognition creates a synergy between advanced signal processing and the sensor-independent object-oriented approach, linking the physical and human approaches to image understanding and thereby allowing adaptable, automated generation of information from remotely sensed data.

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Please send letter of nomination describing the specific contributions of the nominee directly to:

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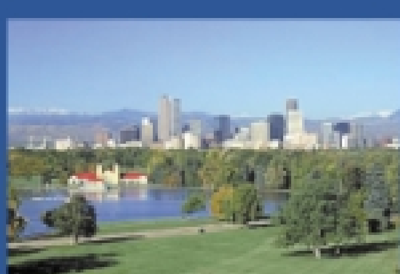

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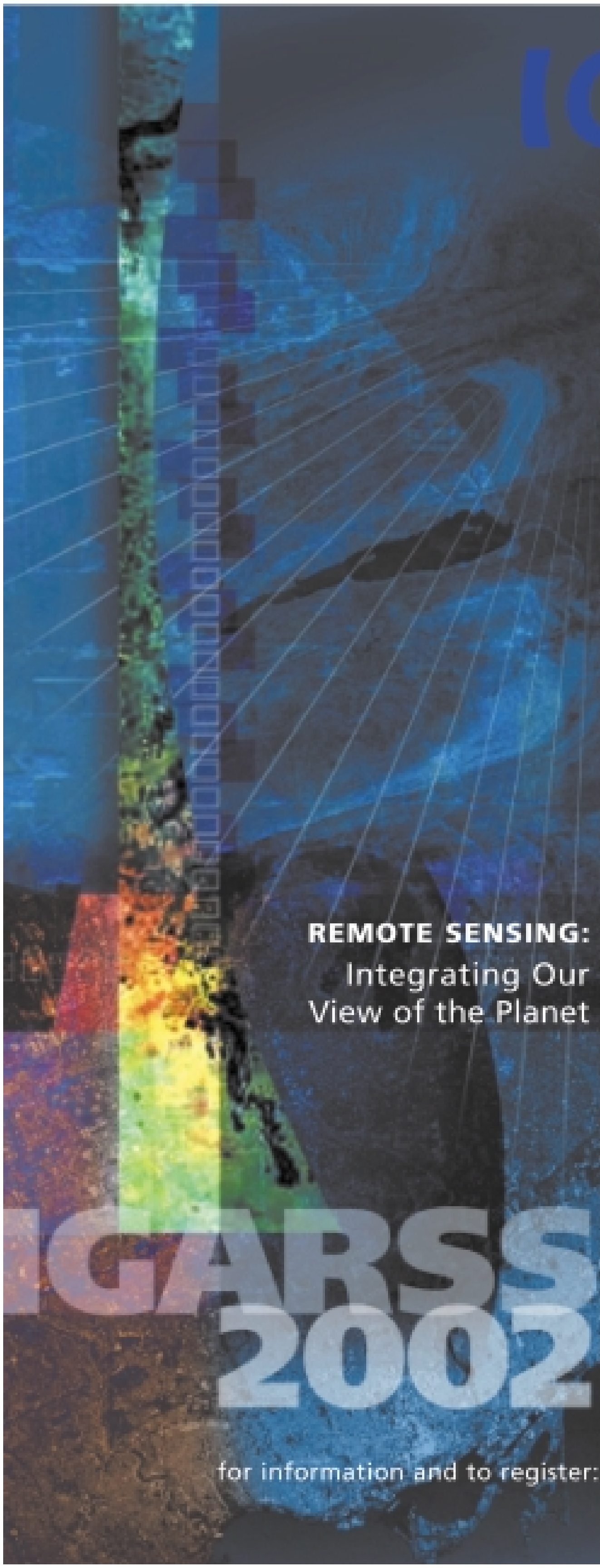
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Fax: 617-258-8766
Email: piers@ewt.mit.edu, kong@mit.edu
URL: http://www.piers.org

Name: **6th WSES/IEEE Multiconference on Circuits, Systems, Communications and Computers (CSCC 2002)**
Dates: July 7-14, 2002
Location: Rethymna Beach, Crete Island, Greece
Contact: Prof. Nikos Mastorakis
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Email: cscc@worldses.org
URL:
http://www.softlab.ntua.gr/~mastor/cscc02.htm

Name: **2002 IEEE Sensor Array and Multichannel Signal Processing Workshop (SAM)**
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Location: Washington, DC
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Dept. of Applied and Engineering Statistics
George Mason University
Fairfax, VA 22030-4444 USA
Phone:703-993-1707
Email: kbell@gmu.edu
URL: http://ite.gmu.edu/sam2002

Name: **PCV '02, Photogrammetric Computer Vision, ISPRS Commission III Symposium 2002**
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Location: Graz, Austria
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Contact: Dr. Ed R. Westwater
CIRES, University of Colorado
NOAA/Environmental Technology Laboratory
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Boulder, CO 80305 USA
Email: Ed.R.Westwater@noaa.gov
URL: http://www.etl.noaa.gov/mrs01

Name: **IEEE/ISPRS Joint Workshop on Remote Sensing and Data Fusion over Urban Areas**
Dates: November 8-9, 2001
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Contact: Dr. Paolo Gamba, Technical Chair
Department of Electronics, University of Pavia
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p.gamba@ele.unipv.it
Email: urban_2001@ele.unipv.it
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