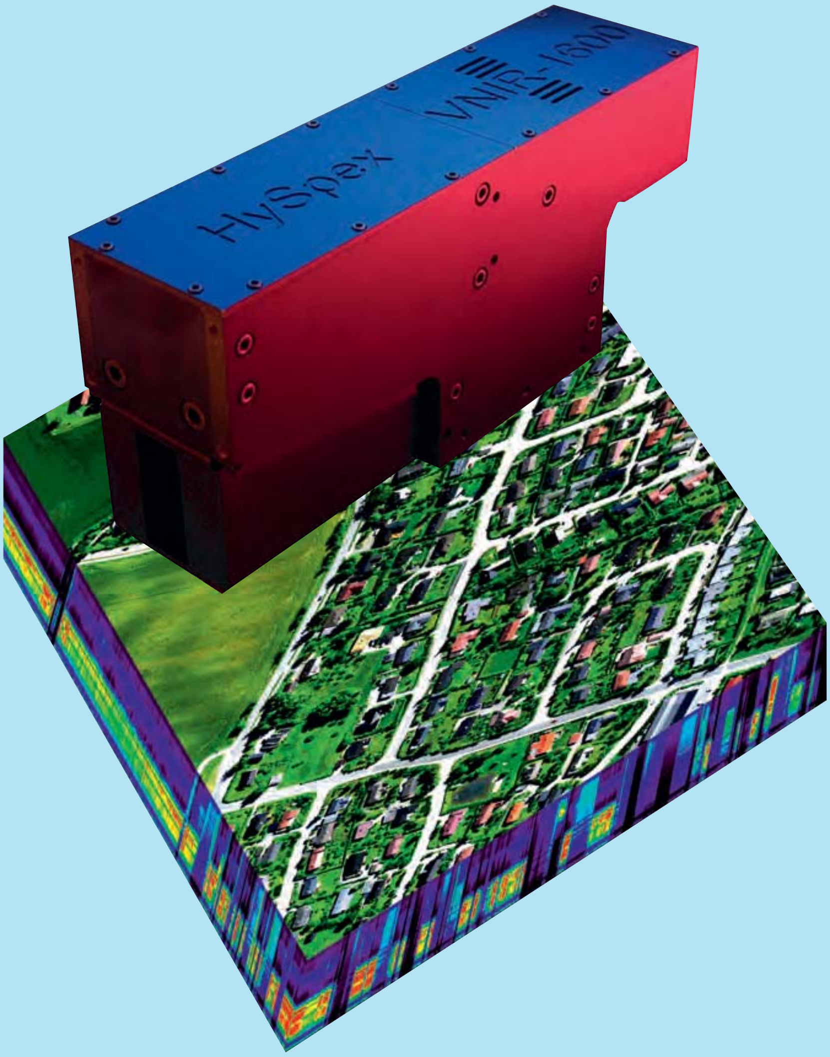
HySpex

High Resolution, High Speed, Hyperspectral Cameras for Laboratory, Industrial and Airborne Applications.



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Introduction

Hyperspectral imaging, or imaging spectroscopy, combines the power of digital imaging and spectroscopy; for every pixel in an image, a hyperspectral camera acquires the light intensity (radiance) for a large number of contiguous spectral bands.

Every spatial pixel in the image contains a continuous spectrum (in radiance or reflectance), which can be used to characterize the objects in the scene with great precision and detail. Figure 1 illustrates the hyperspectral data cube comprising a stack of images recorded at each of the spectral bands of the camera.

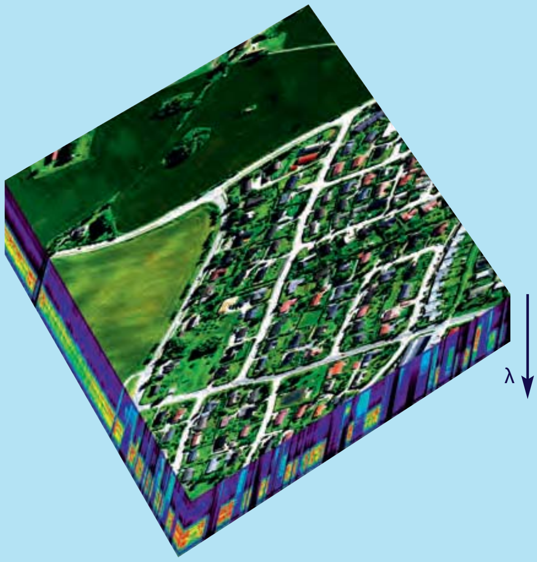

Figure 1. A hyperspectral image cube comprising a full monochrome image at each of the spectral bands. Here, the colors represent the intensity in each band.

HySpex

The HySpex cameras are based on know-how acquired by NEO since 1995 through several R&D projects (initially defense and space applications) in the field of imaging spectrometry. Today, NEO continues research and product development in close collaboration with companies and research institutes utilizing the HySpex cameras in a wide range of applications.

HySpex, NEO's line of hyperpsectral cameras, is a compact, high performance and versatile instrument for a multitude of applications, ranging from airborne to laboratory and industrial use of imaging spectroscopy.

<u>Some of the main features of the HySpex design are:</u>

- Minimization and equalization of point spread function across the FOV and throughout the wavelength range.
- Good matching of point spread function with pixel size.
- Low stray light level.
- Low smile effect and spectral keystone effect.
- Low polarization dependence.
- 2nd order suppression.
- High sensitivity and low noise.
- Automatic shutter.
- High acquisition speed and data rates.
- Real time correction of responsivity and dark offset.

<u>All HySpex instruments are delivered with:</u>

- A dedicated camera control and data acquisition software package.
- Spectral and radiometric calibration data.
- A detailed test report.
- User manual.
- All necessary accessories such as cables and power supply.
- Optionally, an API (Application Programming Interface) in Visual C++ can be supplied for application specific software development.

Exact synchronization with external events (e.g. navigation systems or illumination) is possible through TTL level trigger signals.

In case the HySpex specifications don't meet the requirements of your application, please contact us. NEO designs and delivers customized solutions.

<u>Optional accessories:</u>

- Close-up lenses
- Computers
- Field expanders
- Light sources
- Equalization filter
- Calibration equipment
- Polarizer
- IMU/GPS
- Translation stage
- Rotation stage

General design and operating principle

Briefly, the cameras operate as illustrated in Figure 2. The fore optic (aspherical mirrors) images the scene onto a slit which only passes light from a narrow line in the scene. After collimation, a dispersive element (in our case a transmission grating) separates the different wavelengths, and the light is focused onto a detector array. The net effect of the optics is that for each pixel interval along the line defined by the slit, a corresponding spectrum is projected on a column of detectors on the array. Thus, the data read out from the array contains a slice of a hyperspectral image, with spectral information in one direction and spatial (image) information in the other.

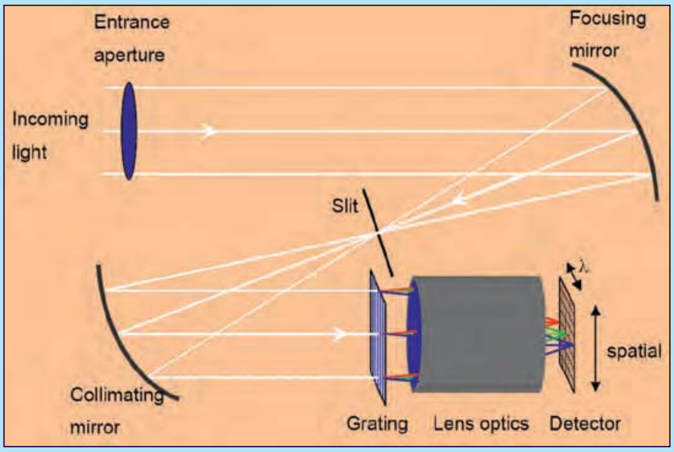

Figure 2. Schematic drawing of the HySpex optical system.

HySpex main specifications

	VNIR-1024	VNIR-1600	SWIR-320i	SWIR-320m	SWIR-320m-e
Spectral range	0.4 – 1.0 µm	0.4 – 1.0 µm	0.9 – 1.7 µm	1.3 – 2.5 µm	1.0 – 2.5 µm
Spatial pixels	1024	1600	320	320	320
FOV across track [1]	16°	17°	14°	14°	13.5°
Pixel FOV across/-along track [1]	0.28 mrad/ 0.56 mrad	0.18 mrad/ 0.36 mrad	0.75 mrad/ 0.75 mrad	0.75 mrad/ 0.75 mrad	0.75 mrad/ 0.75 mrad
Spectral sampl.[2]	5.4 nm	3.7 nm	5 nm	5 nm	6 nm
# of bands [2]	108	160	145	240	256
Spectral binning [3]	2, **4**, 8	**2**, 4, 8	-	-	-
Digitization	12 bit	12 bit	12 bit (CL: 14 bit)	14 bit	14 bit
Max frame rate	690 fps	135 fps [4]	350 fps	100 fps	100 fps
Sensor head weight	TBD	4.6 kg	6.8 kg	7.0 kg	7.5 kg
Sensor head dim. (l x w x h in cm)	TBD	31.5 x 8.4 x 13.8	32.0 x 14.0 x 15.2	36.0 x 14.0 x 15.2	36.0 x 14.0 x 15.2
Sensor head power consumption	~6 w	~6 w	~30 w	~100 w	~100 w
FPA temperature	NA	NA	~260 K	~200 K	~200 K
Camera interface	Camera Link	Camera Link	USB 2.0 or Camera Link	Camera Link	Camera Link

All specifications are subject to changes due to ongoing developments.

[1] Can be doubled with field expander.

[2] At standard binning configuration.

[3] Standard binning mode in bold.

[4] At full resolution. Can be increased by binning/subwindowing.

Airborne applications

High resolution and high speed, combined with low weight and power consumption, make the HySpex cameras very well suited for airborne data acquisition. NEO offers turn-key systems based upon high quality components.

Position- and attitude logging systems (IMU/GPS) from leading manufacturers can be integrated and supplied with the cameras. Alternatively, the HySpex systems can be interfaced with the customer's existing navigational hardware.

For airborne systems, NEO supplies dedicated software and a touch screen for ease of operation. The airborne software comprises programs for: camera control and data acquisition, radiometric calibration of image data, resampling of navigation data to HySpex image data.

The weight of a HySpex camera plus IMU/GPS for an aerial application is less than 7.5 kg.

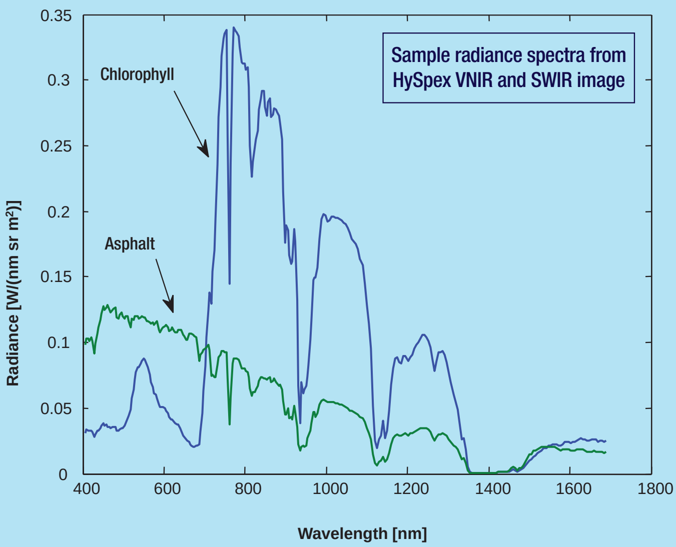

Figure 3. Two radiance spectra extracted from the VNIR and SWIR images shown in Figure 4.

Depending on the space available in the aircraft and customer requirements, HySpex can be delivered with a customized data acquisition unit for airborne operations.

While the standard 19" rack unit is suitable for most aircrafts, more compact micro-ATX and ultra-compact mini-ITX solutions are also standardized and available for use in smaller aircrafts.

With a weight of only 4.5 kg and a power consumption of 50 W, the ultra-compact DAUs are ideal for small aircrafts and UAVs. To ensure the stability and reliability of the system, SSDs are standard in airborne HySpex DAUs.

Figure 4. Airborne HySpex images. Left: VNIR-1600. Right: SWIR-320i.

NEO's airborne HySpex systems have been in operation since 2003.

Airborne HySpex systems can be employed in a variety of application areas, including (but not limited to):

- Geology
- Vegetation
- Glaciology
- Oil spills
- Environmental
- Urban planning
- Governmental
- Forestry
- Search and rescue
- Military

Figure 5. To the left; the ultra-compact DAU for airborne applications (10.5 x 20.5 x 25 cm), HySpex VNIR-1600 and the trans-reflective touch-screen. The total power consumption of this system is less than 75 W. To the right; HySpex VNIR-1600 and HySpex SWIR-320m-e mounted in a vibration damped platform, together with an IMU/GPS unit.

Figure 6. VNIR-1600 image with enhanced chlorophyll contrast, altitude ~1500m.

Figure 7. 3D image generated by the combination of a HySpex image and LIDAR data from the same scene.

Figure 6 above shows a closer view of a section of the VNIR image in Figure 4, where the red channel in the RGB image is chosen just above the chlorophyll edge (720 nm). Figure 7 to the right above shows a 3D image made by combining airborne HySpex data and LIDAR data. This is a very powerful combination in many applications such as forestry and geology. Simultaneous operation of HySpex and commercial airborne LIDAR systems has been done successfully on several missions.

In Figure 8 below, the upper image shows part of an airborne HySpex VNIR-1600 image mosaic from a campaign carried out by SAS ActiMar (Brest, France) over the coastal zone of Normandy. About 150 flight lines have been recorded, including 160 spectral bands between 400 and 1000nm. The spatial resolution of the images is 60cm. Imagery has been recorded during low level spring tides over the whole rocky intertidal areas of the Normandy coastal zone. The images allowed very precise algal biodiversity cartography to be established over the area.

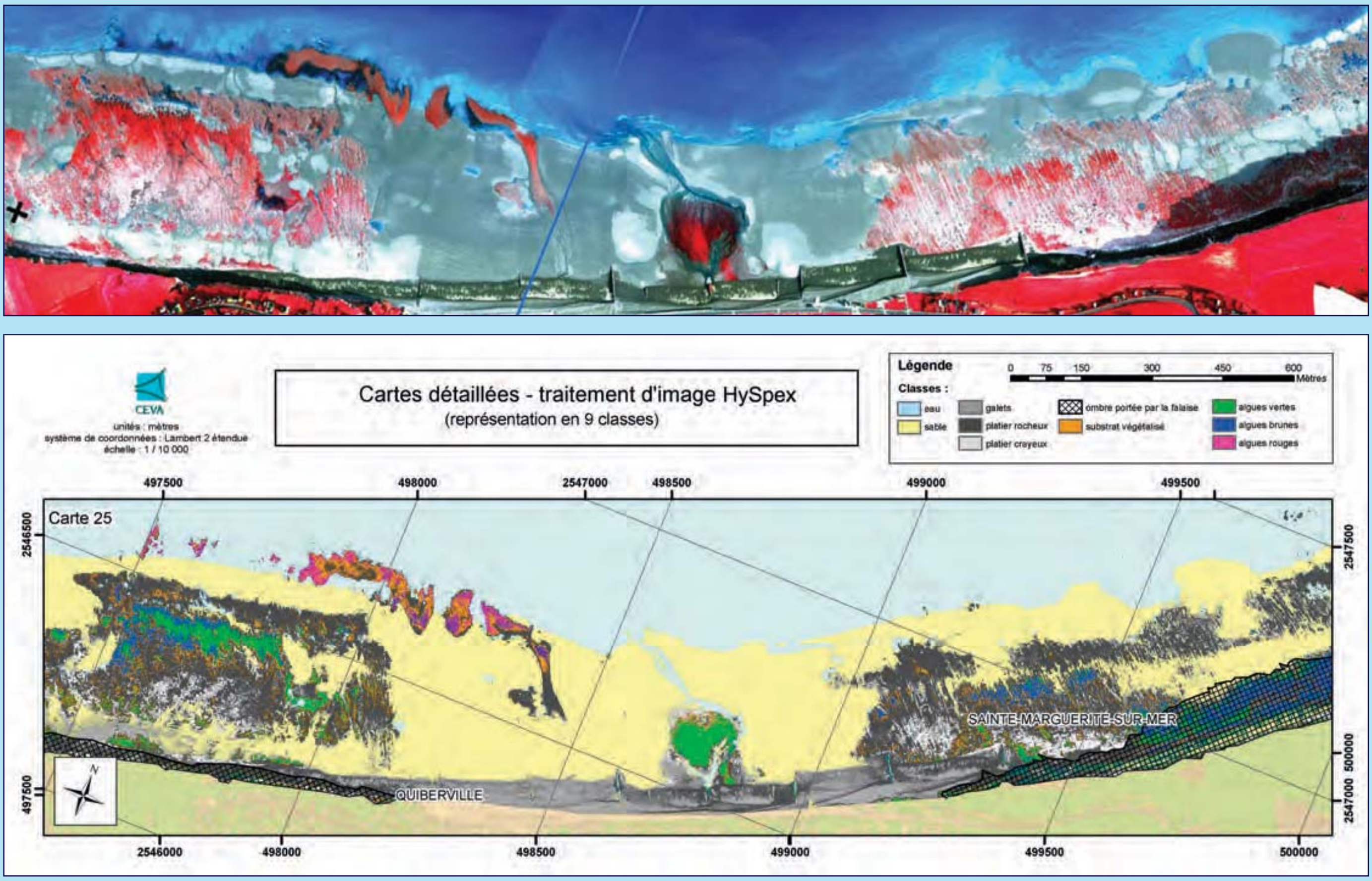

Figure 8. Upper: Geo-referenced HySpex image (RGB= 745nm, 690nm, 550nm).
Lower: Same image processed to final map product showing different types of algae, sediments and water. (Ref.: "Cartographie des estrans rocheux de Normandie par Télédétection hyperspectrale", P. Mouquet, L. Lozach, P. Dion, E. de Oliveira, F. Bruchon, M. Lennon, Colloque CARHAMB'AR (Cartographie des Habitats Marins Benthiques, de l'Acquisition à la Restitution), Brest, France, 3-5 février 2009.

Ground based field or lab applications

All HySpex cameras can be supplied with a rotation or translation stage, a feature making them ideal for acquisition of hyperspectral images of static scenes, either in the field, in a laboratory or a clinical environment. The scanning is fully integrated in the camera control software.

A few of the potential application areas where HySpex systems can be operated on the ground are listed below:

- Medical analysis/diagnostics
- Biological analysis
- Mineral classification
- Surveillance/security
- Chemical analysis
- Life science
- Forensics
- Fluorescence
- Artwork scanning

Figure 9 shows an example of HySpex images employed in a medical/forensics application for age determination of bruised skin.

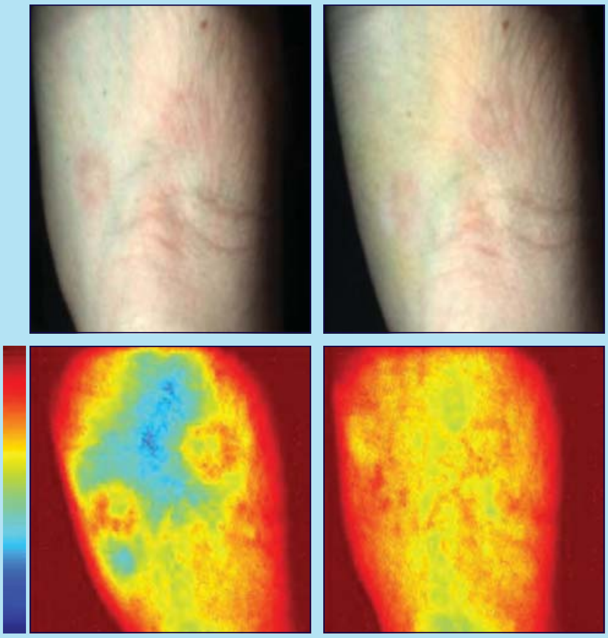

Figure 9. Bilirubin weighted images of bruised skin. Left: 66 hours, Right: 180 hours after impact (Ref. Randeberg et.al., Proceedings SPIE BIOS 2006).

Many minerals exhibit distinct spectral characteristics. Hyperspectral imaging is therefore a powerful tool for mineral classification. Figure 10 shows a set-up for mine face inspection using a HySpex camera mounted on a rotation stage. Data recorded during this mission is shown in Figure 11: an RGB image together with a processed image showing the calculated Kaolinite concentration based on analysis of the hyperspectral images.

Figure 10. HySpex camera and LIDAR set up for mine face scanning.

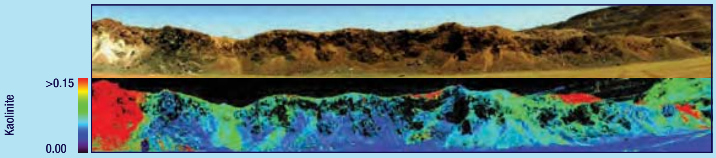

Figure 11. Kaolinite concentration determined from HySpex image (processed by CSIRO).

Figure 12 shows a lab set-up for HySpex cameras equipped with close-up lenses for short range operation. The rigid aluminum frame accommodates two cameras together with a dedicated illumination system and a translation stage.
This set-up is ideal for work with smaller samples, typically < 30 cm x 50 cm (longer translation stages are available on request).

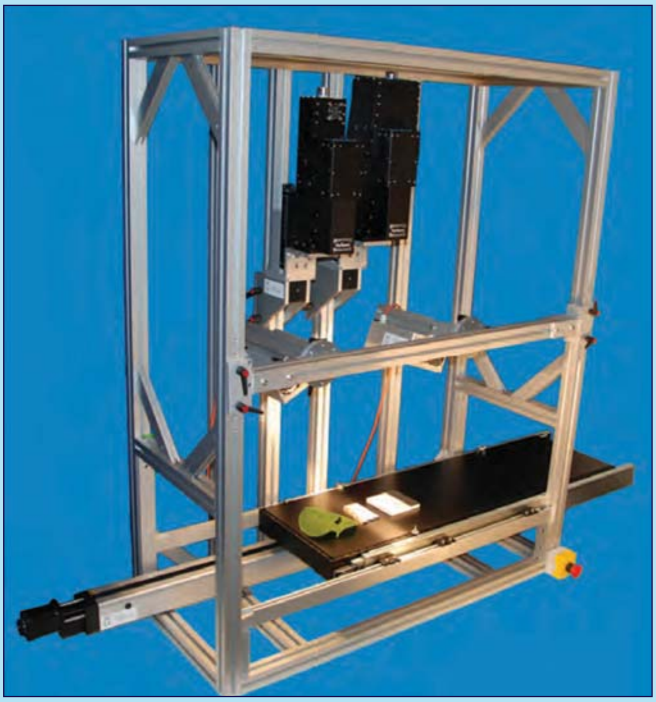

Figure 12. Lab set-up comprising a rigid frame, holding two cameras, illumination system and translation stage for test samples.

Industrial applications

Due to their extremely high acquisition speeds and real-time image correction features, the HySpex cameras are well suited for a wide variety of industrial applications such as material inspection or quality control.

In a typical industrial application, the HySpex camera is mounted statically above a conveyer belt, as shown in Figure 13, using the belt motion for scanning.

Using the VNIR-1024 and 1 meter working distance as an example; the field of view is ~28 cm and the pixel footprint on the conveyer belt is 0.27 mm x 0.56 mm. With these settings and full spectral range and resolution, the maximum speed of the conveyer belt is 46 cm/s. The belt speed can be drastically increased if rectangular pixels are permissible, or by reducing the spectral range or the spatial /spectral resolution.

HySpex systems can be used in a wide variety of industries for both on-line, at-line and off-line measurements. Some of the potential industry areas are listed here:

- Food and nutrition
- Paper industry
- Textile industry
- Pharmaceutical industry
- Chemical industry
- Color printing
- Mining
- Recycling industry

Figure 14 illustrates the successful use of a HySpex system for fish quality control, demonstrating the potential of detecting unwanted substances, such as parasites and blood, based on hyperspectral data analysis. Other quantitative or qualitative parameters in food, such as water or protein content, freshness or color can also be done on-line by hyperspectral data processing.

Custom solutions

NEO also designs and delivers customized solutions with specifications and performance adapted to specific applications. Please contact us to discuss your requirements and needs. This could include development of specialized hyperspectral camera systems and algorithms, enabling real time data processing (detection, classification, or quantification) for on-line use in a variety of sorting, quality/process control, or general PAT (Process Analytical Technology) applications.

Figure 13. A HySpex camera mounted above a conveyer belt in an industrial application.

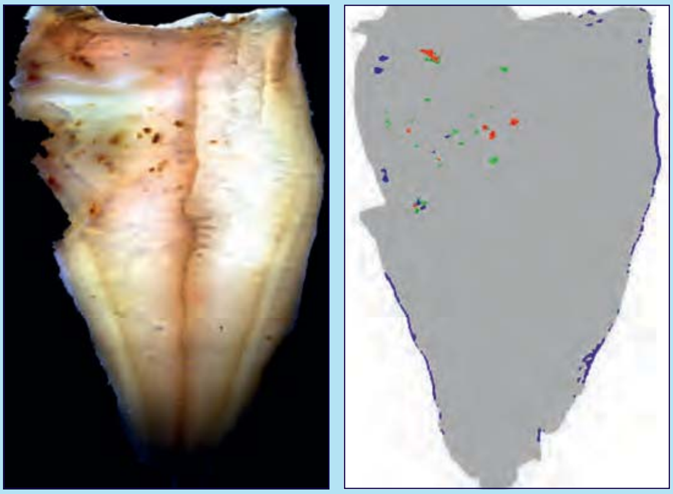

Figure 14. Example of industrial quality control of fish (tusk) filets. Left: RGB image of filet. Right: Classified image where the color codes are: grey=fillet, blue= blood, green = pale nematode, red = dark nematode (courtesy of Nofima Marin).

Figure 15. Close-up detection image of nematode in cod filet.

Selected publications and conference contributions involving HySpex data

"A compact combined hyperspectral and polarimetric imager", T.Skauli et.al., Proc. SPIE vol. 6395, 2006.

"Detection of nematodes in Cod (Gadus morhua) fillets by imaging spectroscopy", K.Heia et.al., Journal of Food Science, 2007.

"Geological outcrop modelling and interpretation using ground based hyperspectral and laser scanning data fusion", T. Kurz et.al., The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B8. Beijing, 2008.

"Clustering of Crop Phenotypes by Means of Hyperspectral Signatures Using Artificial Neural Networks", U. Seiffert et.al., Whispers, Reykjavik, Iceland, 2010.

"Characterisation of vascular structures and skin bruises using hyperspectral imaging, image analysis and diffusion theory", L.L. Randeberg et.al. J.Biophoton. 3, No. 1-2, 53-65, 2010.

"Hyperspectral imaging of atherosclerotic plaques in vitro", E.P.L Larsen, L.L. Randeberg, E.Olstad, O. A. Haugen, A. Aksnes and L. O. Svaasand, J Biomed Opt, 16(2), 2011.

"SYSIPHE, an airborne hyperspectral imaging system for the VNIR-SWIR-MWIR-LWIR region", T. Skauli, S. Blaaberg, T. Løke, A. Fridman, I.Baarstad, S. Fabre, C. Coudrain and L. Rousset-Rouviere, 7th EARSeL Workshop on Imaging Spectroscopy, Edinburgh, Scotland, 2011.

"Potential of field hyperspectral imaging as a non-destructive method to assess leaf nitrogen content in Wheat", P. Roumet, G. Rabatel, M. Ecarnot and N. Vigneau, Field Crops Research 122, p. 25-31, 2011.

"From the land to the sea: seamless cartography of coastal algae using airborne hyperspectral remote sensing", P. Kohaut, S. Smet, M. Lennon and G. Sciot, Proceedings, 7th EARSeL Workshop on Imaging Spectroscopy, Edinburgh, Scotland, 2011.

"Using HySpex SWIR-320m hyperspectral data for the identification and mapping of minerals in hand specimens of carbonate rocks from the Ankloute Formation (Agadir Basin, Western Morocco)", B. Ouajhain, A. Gaudin, P. Launeau, K. Labbassi and R. Baissa,Journal of African Earth Sciences, Volume 61, Issue 1, Pages 1-9, 2011.

"Close range hyperspectral imaging integrated with terrestrial lidar scanning applied to rock characterisation at centimetre scale", T. Kurz, S.J. Buckley and J.A. Howell, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXIX-B5, 2012.

"Hyperspectral imaging as a diagnostic tool for chronic skin ulcers", M. Denstedt, B.S. Pukstad, L.A. Paluchowski, J.E. Hernandez-Palacios and L.L. Randeberg, Proc. SPIE8565, Photonic Therapeutics and Diagnostics IX, 2013.

"A collection of hyperspectral images for imaging systems research", T. Skauli and J. Farrell, Proc. SPIE 8660, Digital Photography IX, 2013.

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