The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

SMR 1829 - 23

Winter College on Fibre Optics, Fibre Lasers and Sensors

12 - 23 February 2007

Spectroscopy-based Fiber Optic Sensors

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Useful Books

- T. Okoshi "Optical Fibers", Academic Press Inc., London, 1982
- B.P. Pal "Fundamentals of Fiber Optics in Telecommunication and Sensor Systems", Wiley Eastern Ltd., New Delhi, 1992
- B. Culshaw, J.P. Dakin "Optical Fiber Sensors", Artech House, London
  - vol I: Principles and Components (1988)
  - vol II: Systems and Applications (1989)
  - vol III: Components and Subsystems (1996)
  - vol IV: Applications, Analysis and Future Trends (1997)
- O.S. Wolfbeis "Fiber Optic Chemical Sensors and Biosensors", Vol. I- II, CRC Press,Boca Raton FL, 1991
- K.T.V. Grattan, B.T. Meggit "Optical Fiber Sensor Technology", Chapman & Hall, London, 1995
- K.T.V. Grattan, B.T. Meggit "Optical Fiber Sensor Technology", Kluwer Academic Publishers, Dordrecth, The Netherlands
  - vol 3: Applications and Systems (1999)
  - vol 4: Chemical and Environmental Sensing (1999)
- D.A. Krohn “Fiber Optic Sensors, Fundamentals and Applications”, ISA, Research Triangle Park, NC, 2000
- J.M. Lòpez-Higuera “Handbook of Optical Fibre Sensing Technology”, John Wiley & Sons, Chichester, UK, 2001

On-line bibliography on optical fibers and sensors

- http://www.sff.net/people/Jeff.Hecht/history.html
- http://electronics.howstuffworks.com/fiber-optic5.htm
- http://www.commspecial.com/fiberguide.htm
- http://www.webopedia.com/TERM/f/fiber_optics.html

Outline

- **Optical fiber sensors: basics**
- **Colorimetry**
  - Absorption and reflection spectroscopy
    - Fiber optic spectrophotometers for general purpose applications – Direct / chemically-mediated
- **Scattered colorimetry**
  - Multi-λ and multi-α absorption spectroscopy
- **Hyperspectral colorimetry**
- **Fluorescence spectroscopy**

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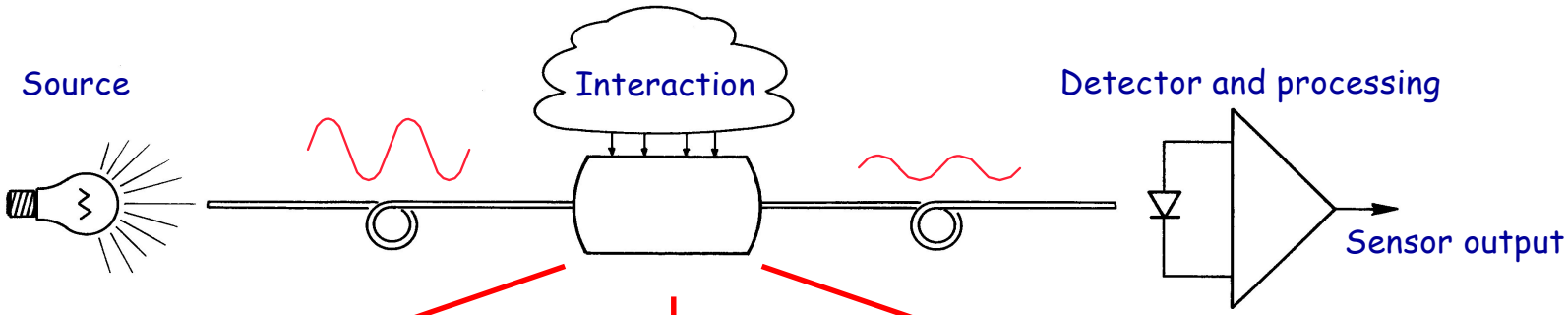
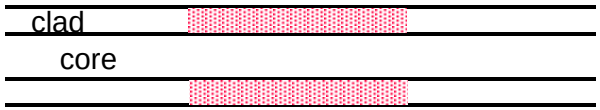
Fiber optic sensors

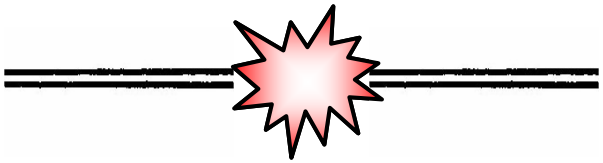
Intensity modulation



Intrinsic
modified core or cladding

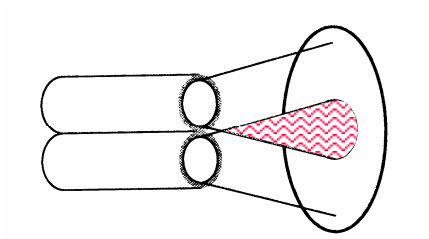


Extrinsic
mechanical or chemical transducer

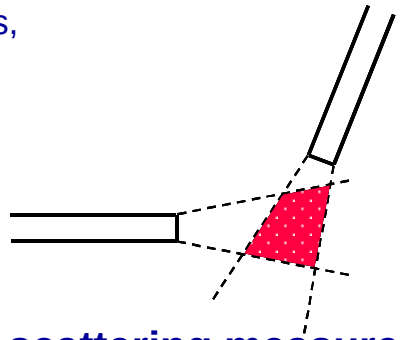


Optical fibers as light guides only
spectroscopy – nephelometry

on-line, real time measurements,
without any sample drawing



direct spectroscopy



direct scattering measurements

Optoelectronic components of optical fiber sensors

Components:

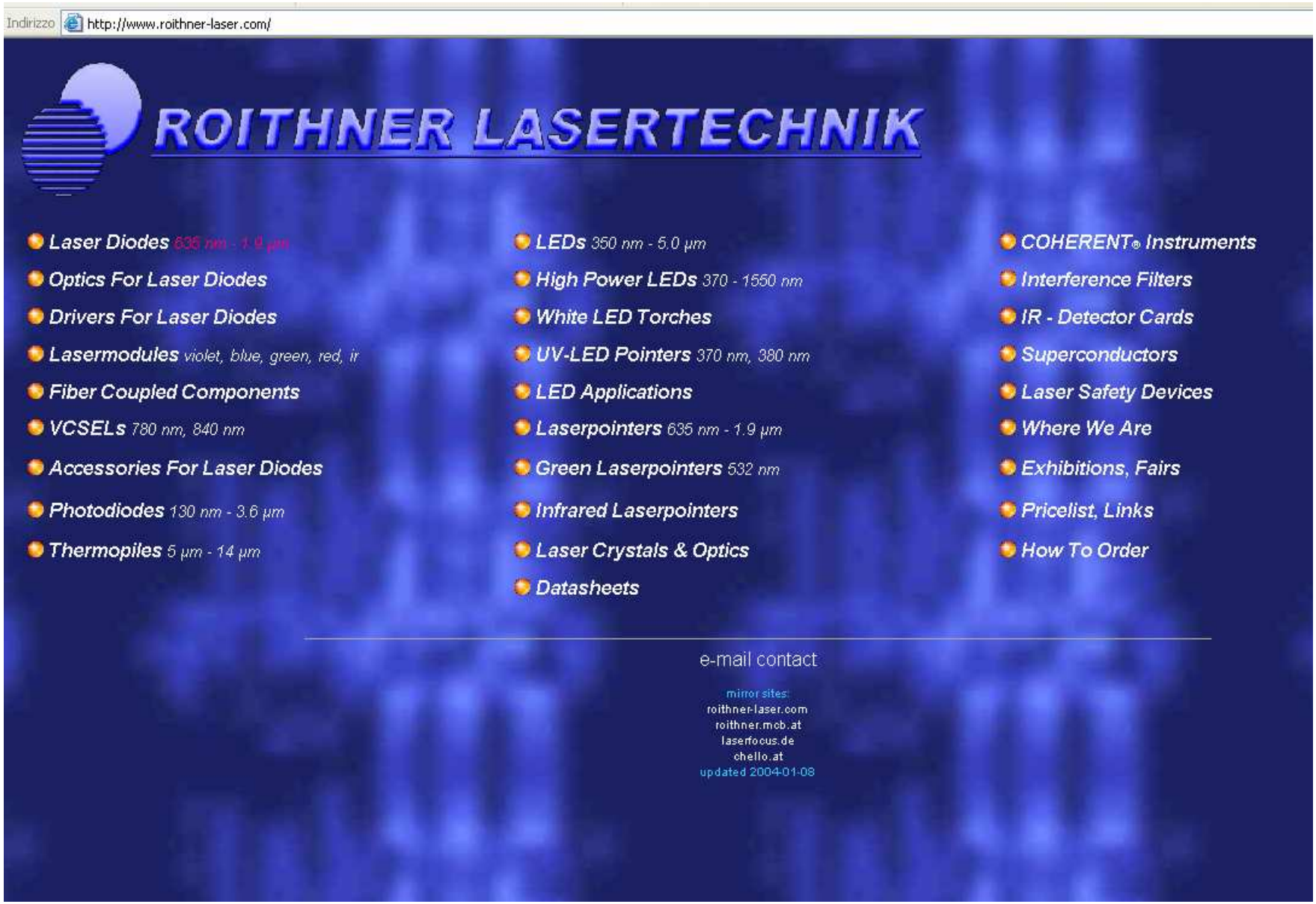
- http://www.fiberoptic.com/site/main/main.asp
- http://www.global-fiber-optics.com/
- http://www.geocities.com/SiliconValley/Circuit/8070/
- http://www.fiberopticeq.com/ (second-hand)

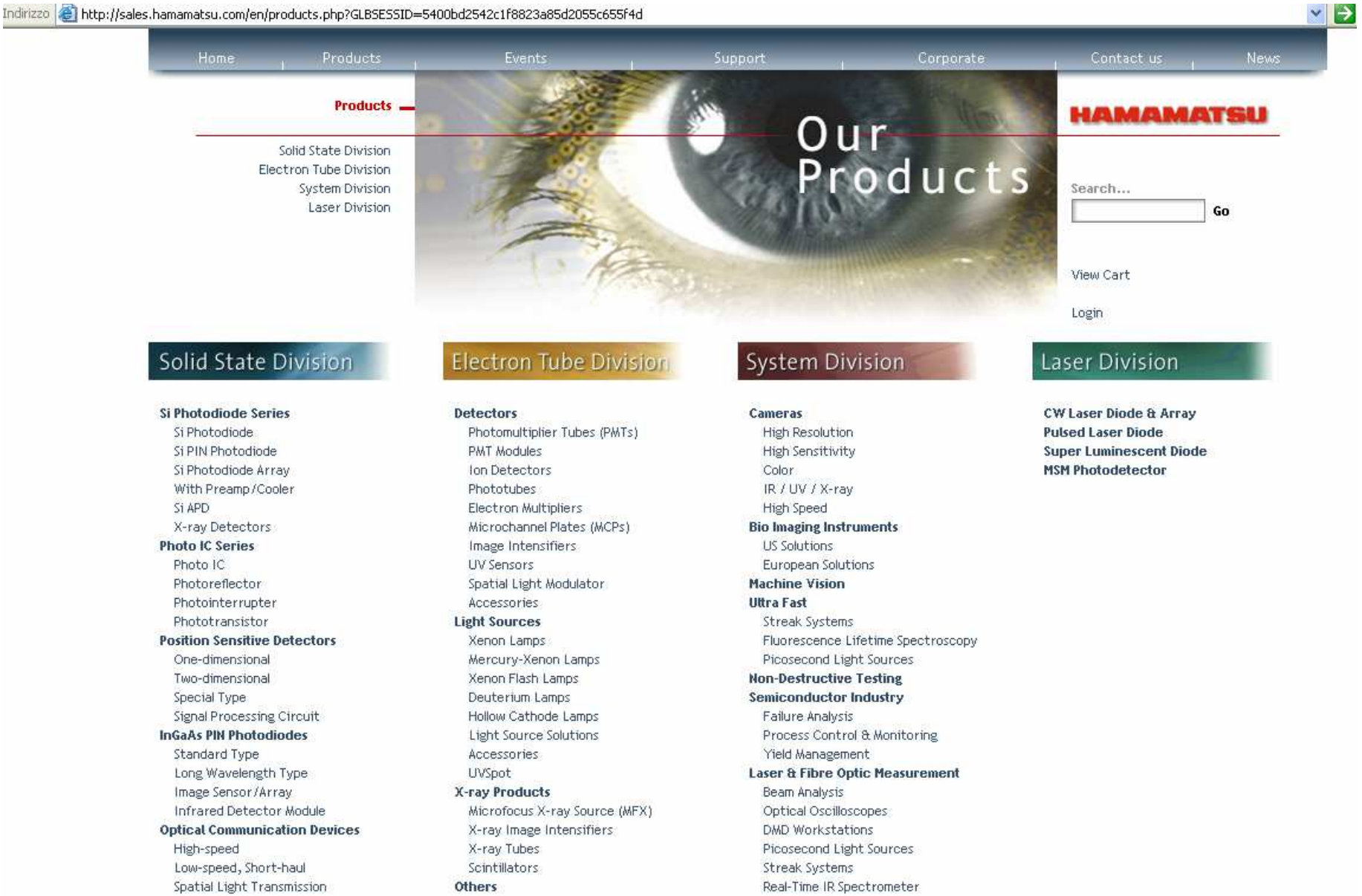
Optical Fibers:

- http://www.corning.com/opticalfiber/ - http://www.fiberguide.com/
- http://www.3m.com/us/util_telecom/optical_oem/
- http://www.artphotonics.de

Sources, Filters and Optics, Detectors:

- http://www.roithner-laser.com/
- http://www.edmundoptics.com/de/
- http://sales.hamamatsu.com/en/products.php?GLBSESSID=5400bd2542c1f8823a85d2055c655f4d
- http://www.oceanoptics.com/ - http://www.controldevelopment.com/ - http://www.stellarnet-inc.com/
- http://www.ezconn.com/en/og.htm


Indirizzo
http://www.roithner-laser.com/
ROITHNER LASERTECHNIK
Laser Diodes 635 nm - 1.9 µm
Optics For Laser Diodes
Drivers For Laser Diodes
Lasermodules violet, blue, green, red, ir
Fiber Coupled Components
VCSELs 780 nm, 840 nm
Accessories For Laser Diodes
Photodiodes 190 nm - 3.6 µm
Thermopiles 5 µm - 14 µm
LEDs 350 nm - 5.0 µm
High Power LEDs 370 - 1550 nm
White LED Torches
UV-LED Pointers 370 nm, 380 nm
LED Applications
Laserpointers 635 nm - 1.9 µm
Green Laserpointers 532 nm
Infrared Laserpointers
Laser Crystals & Optics
Datasheets
COHERENT® Instruments
Interference Filters
IR - Detector Cards
Superconductors
Laser Safety Devices
Where We Are
Exhibitions, Fairs
Pricelist, Links
How To Order
e-mail contact
mirror sites:
roithner-laser.com
roithner.mcb.at
laserfocus.de
chello.at
updated 2004-01-08


Indirizzo
http://sales.hamamatsu.com/en/products.php?GLBSESSID=5400bd2542c1f8823a85d2055c655f4d
Home
Products
Events
Support
Corporate
Contact us
News
Products
Solid State Division
Electron Tube Division
System Division
Laser Division
Our Products
HAMAMATSU
Search...
Go
View Cart
Login
Solid State Division
Si Photodiode Series
Si Photodiode
Si PIN Photodiode
Si Photodiode Array
With Preamp/Cooler
Si APD
X-ray Detectors
Photo IC Series
Photo IC
Photoreflector
Photointerrupter
Phototransistor
Position Sensitive Detectors
One-dimensional
Two-dimensional
Special Type
Signal Processing Circuit
InGaAs PIN Photodiodes
Standard Type
Long Wavelength Type
Image Sensor/Array
Infrared Detector Module
Optical Communication Devices
High-speed
Low-speed, Short-haul
Spatial Light Transmission
Electron Tube Division
Detectors
Photomultiplier Tubes (PMTs)
PMT Modules
Ion Detectors
Phototubes
Electron Multipliers
Microchannel Plates (MCPs)
Image Intensifiers
UV Sensors
Spatial Light Modulator
Accessories
Light Sources
Xenon Lamps
Mercury-Xenon Lamps
Xenon Flash Lamps
Deuterium Lamps
Hollow Cathode Lamps
Light Source Solutions
Accessories
UVSpot
X-ray Products
Microfocus X-ray Source (MFX)
X-ray Image Intensifiers
X-ray Tubes
Scintillators
Others
System Division
Cameras
High Resolution
High Sensitivity
Color
IR / UV / X-ray
High Speed
Bio Imaging Instruments
US Solutions
European Solutions
Machine Vision
Ultra Fast
Streak Systems
Fluorescence Lifetime Spectroscopy
Picosecond Light Sources
Non-Destructive Testing
Semiconductor Industry
Failure Analysis
Process Control & Monitoring
Yield Management
Laser & Fibre Optic Measurement
Beam Analysis
Optical Oscilloscopes
DMD Workstations
Picosecond Light Sources
Streak Systems
Real-Time IR Spectrometer
Laser Division
CW Laser Diode & Array
Pulsed Laser Diode
Super Luminescent Diode
MSM Photodetector

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Colorimetry:

- Fiber-optic spectrophotometers for absorption and reflection spectroscopy
  - Direct:
    - Gasoline blendings
    - Water color monitoring in a recycling plant
  - Chemically-mediated:
    - pH, pCO_2
    - Lighting monitoring in museums
    - Fiber optic multimeter for spectral interrogation of opto-chemical sensor arrays
      - Metal ions in water
      - Artificial olfactory perception of olive oil rancidity

Colorimetry:

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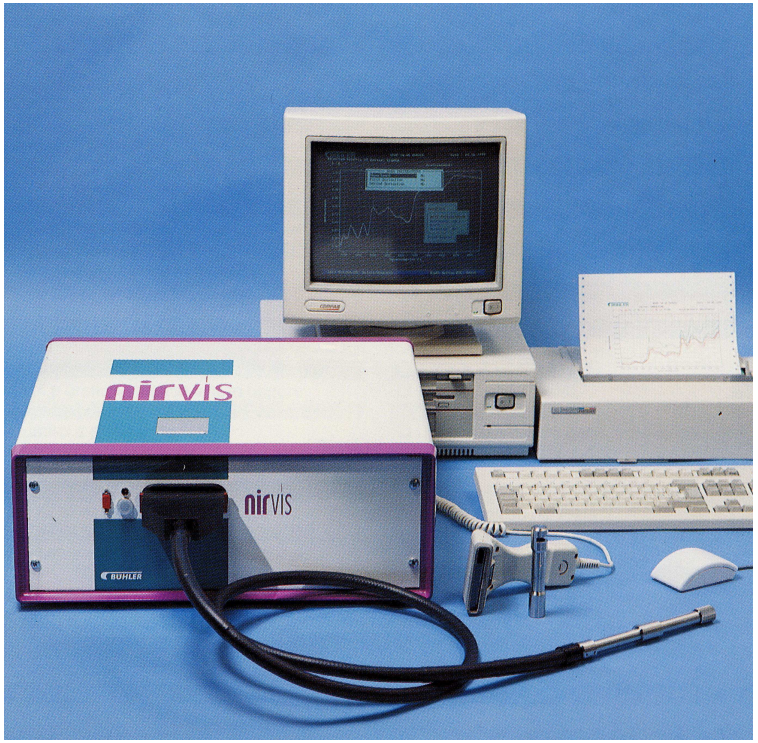
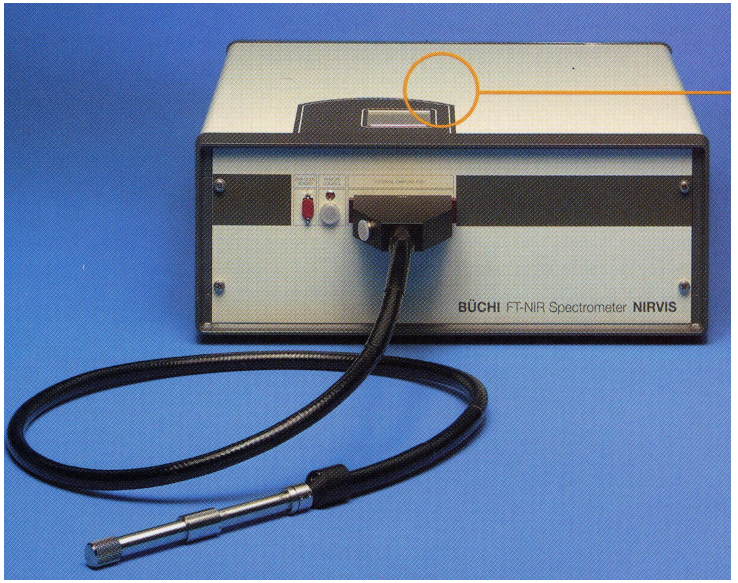
Spectrophotometers equipped with optical fibers

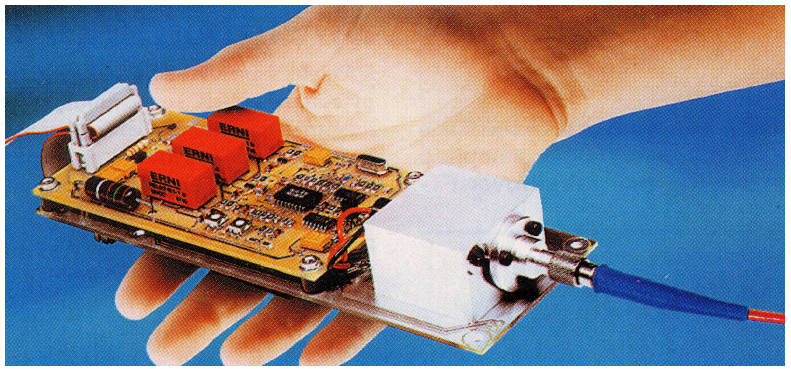


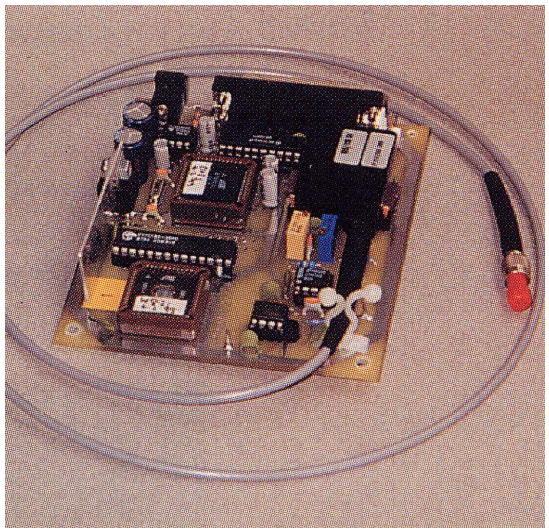


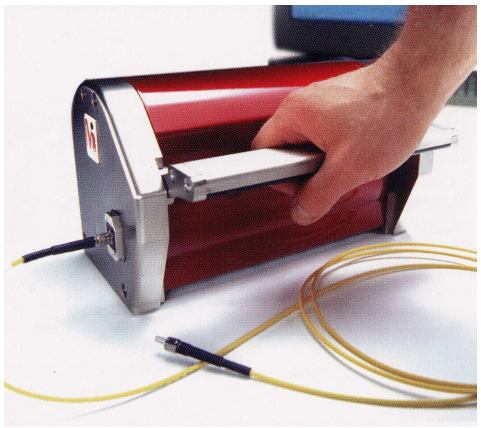
Drawbacks

- limited fiber length
- no multiplexing
- poor compactness

Optical Fiber Microspectrometers







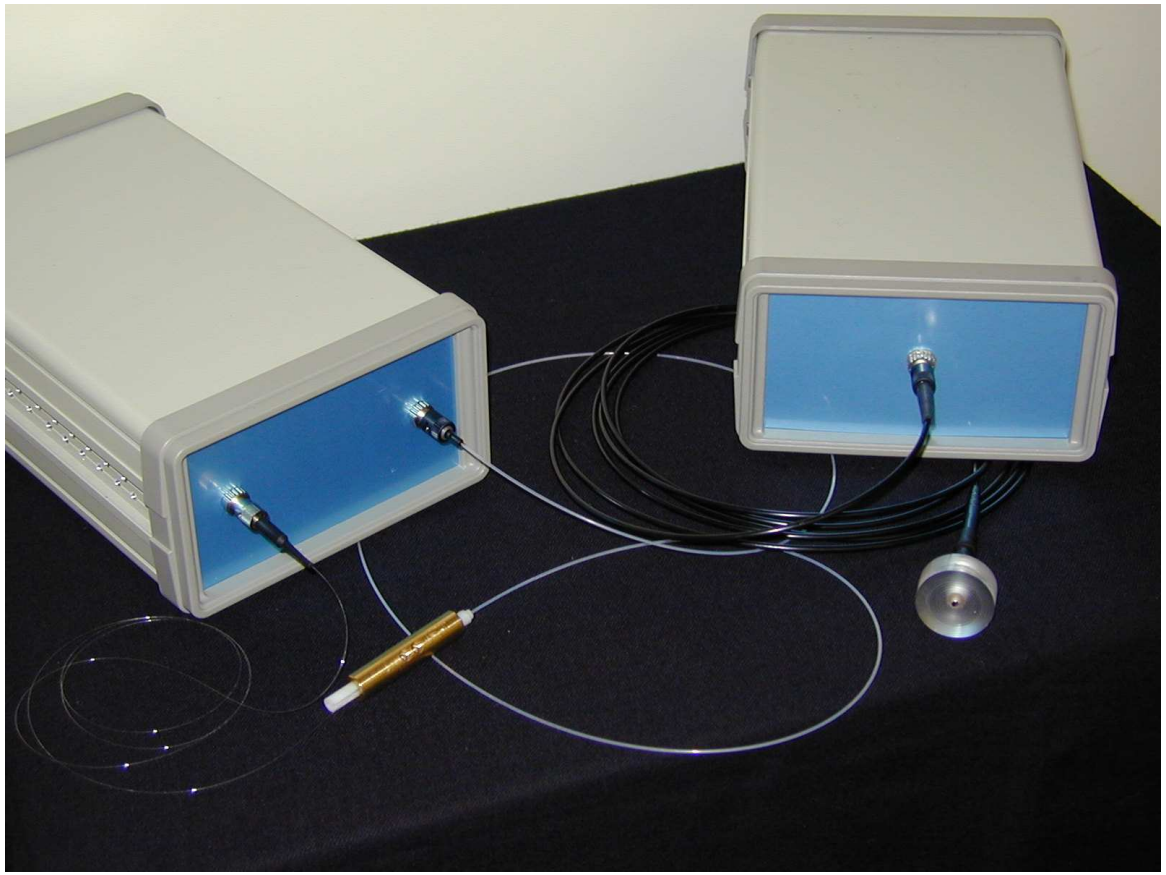
..... and many more

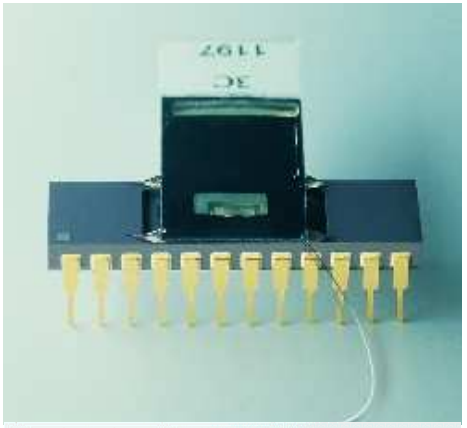
Absorption and reflection spectroscopy

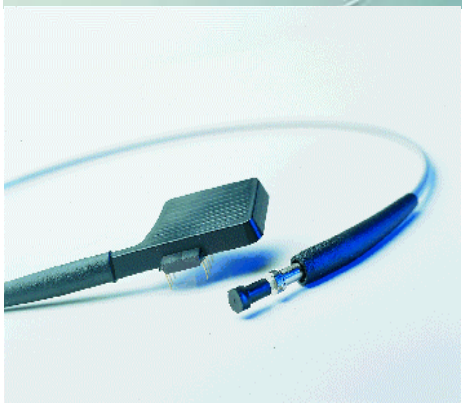
Main requirements:

- High degree of compactness
  - Sources, detectors, and coupling optics must fit into a compact box
  - No mechanical alignments of the optical components
- Low cost optoelectronic components
  - LED sources
  - Fiber optic compatible spectrometer
  - Thermal stability
- Probe using a single optical fiber configuration, rather than bundle
- A flexible software interface friendly enough to be used by operators with little technical background

Compact and low-cost spectrophotometers for absorption and reflection spectroscopy





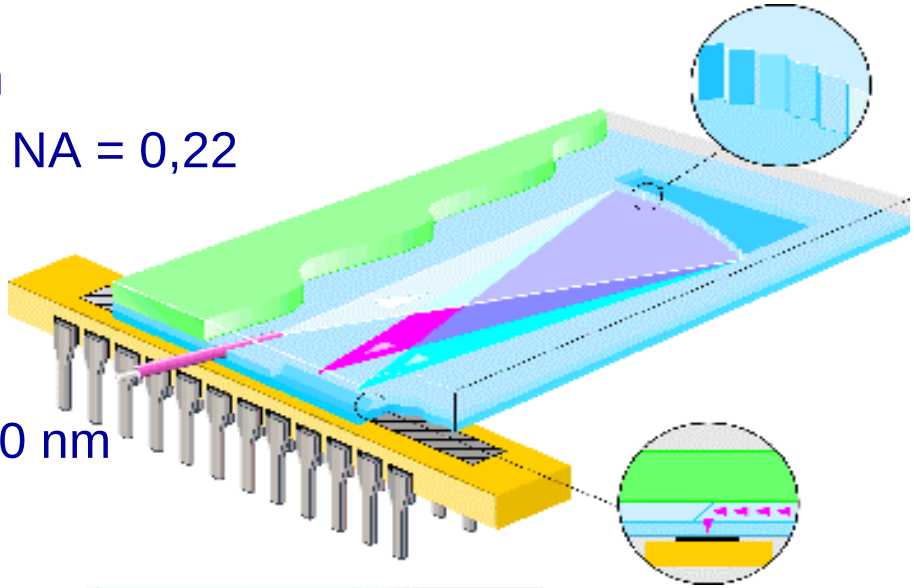


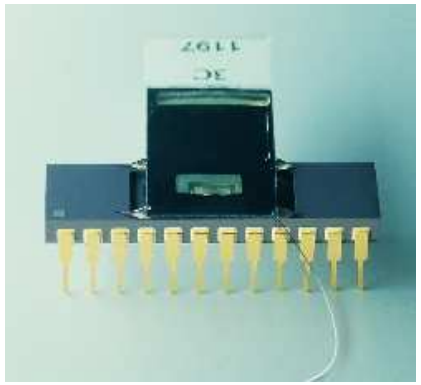
- ✓ spectral range: 400-700 nm
- ✓ resolution: 10 nm

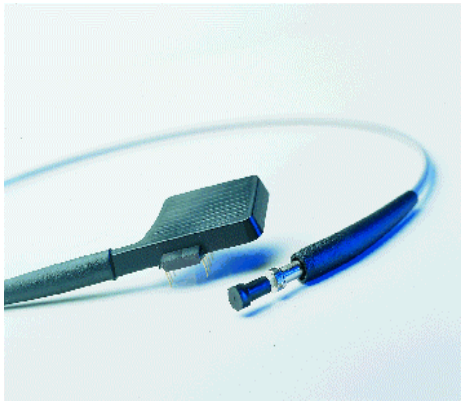
VIS-Microspectrometer

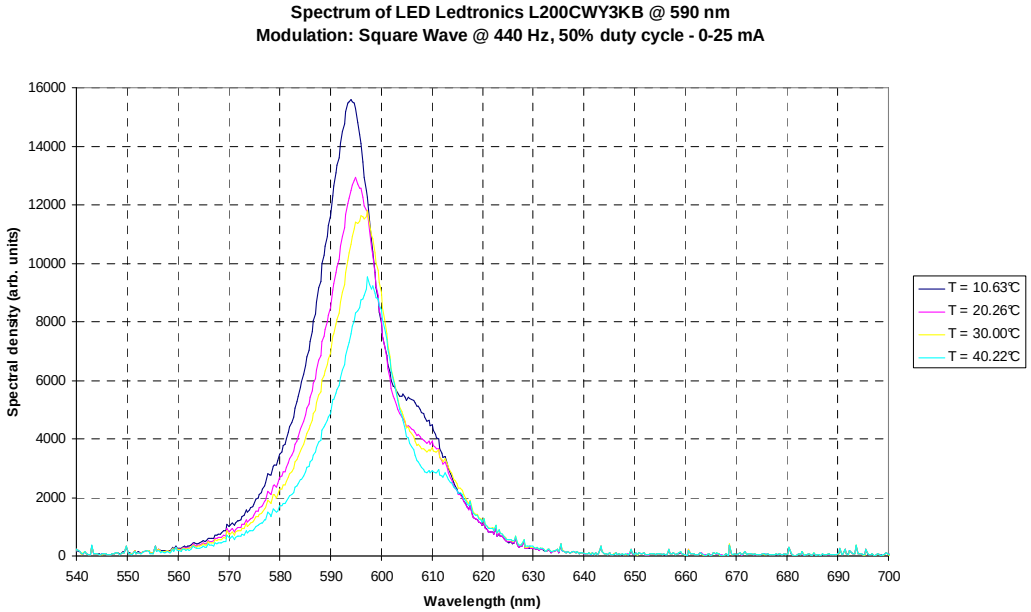
Technical Data:

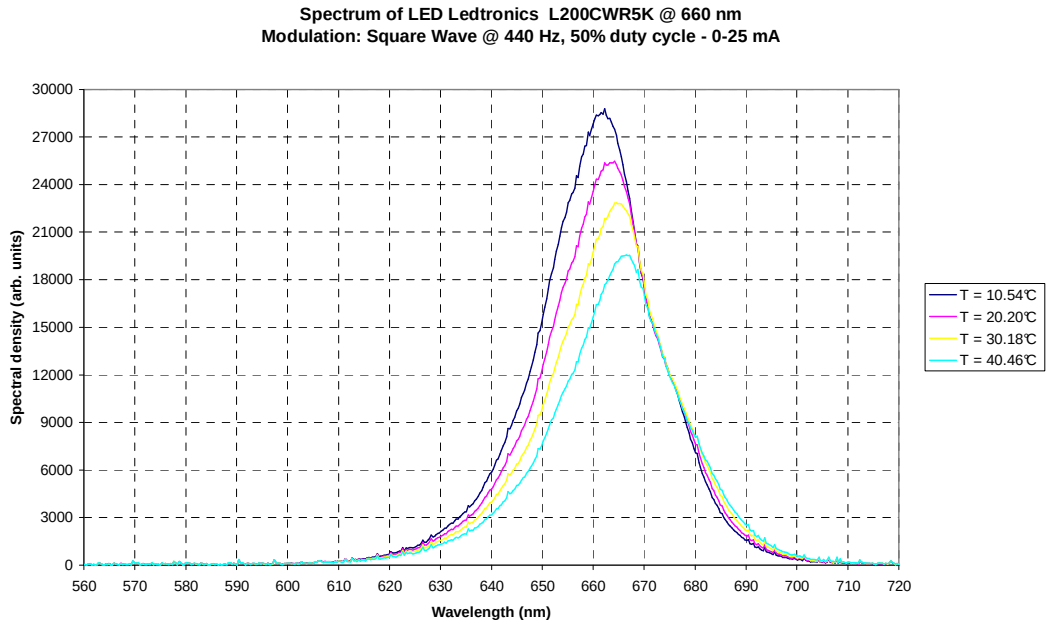
- Spectral range from 380 - 780 nm
- Fibre: 50 / 105 µm core diameter; NA = 0,22
- Blazed Grating: 600 lines / mm
- Dispersion: 2,9 nm / Pixel
- Throughput: 30%
- Spectral resolution $_{FWHM}$: 7nm / 10 nm
- Dynamic ratio: > 10.000



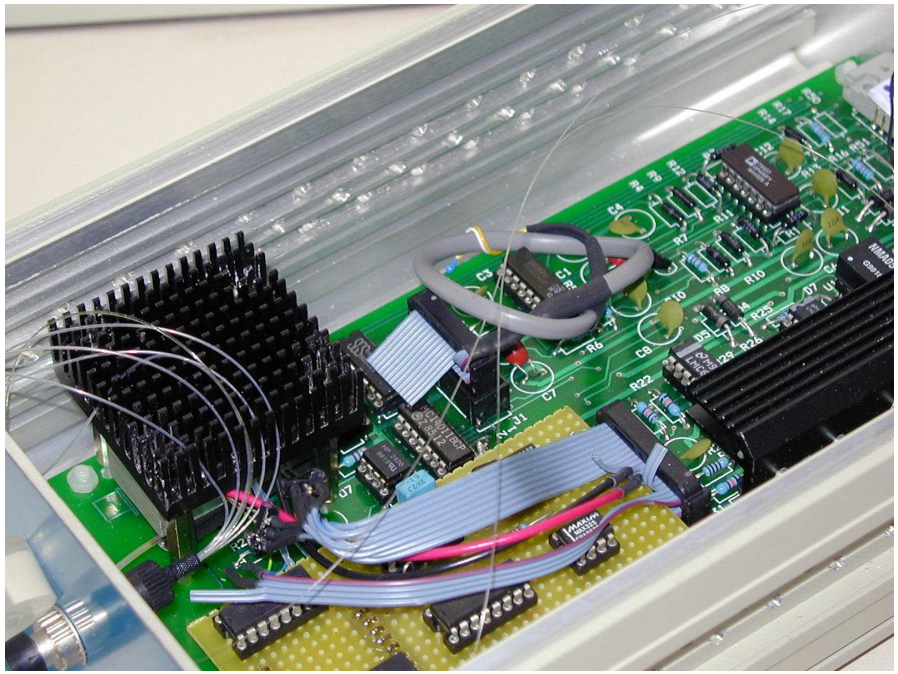




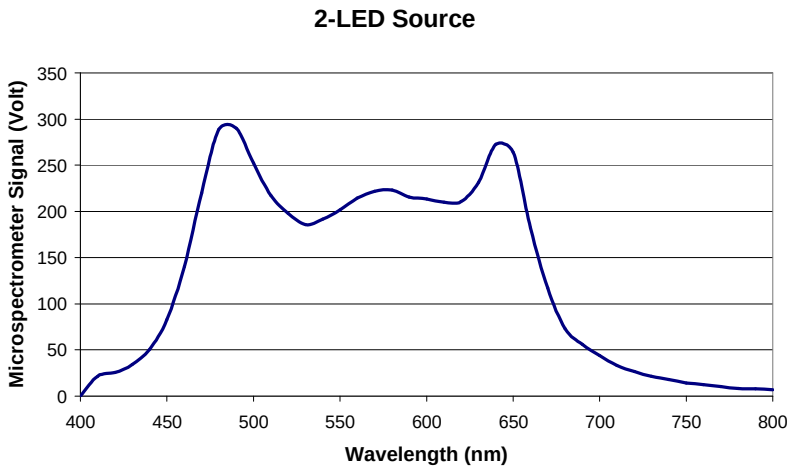

Spectrum of LED Ledtronics L200CWY3KB @ 590 nm
Modulation: Square Wave @ 440 Hz, 50% duty cycle - 0-25 mA
Spectral density (arb. units)
16000
14000
12000
10000
8000
6000
4000
2000
0
540 550 560 570 580 590 600 610 620 630 640 650 660 670 680 690 700
Wavelength (nm)
T = 10.63℃
T = 20.26℃
T = 30.00℃
T = 40.22℃


Spectrum of LED Ledtronics L200CWR5K @ 660 nm
Modulation: Square Wave @ 440 Hz, 50% duty cycle - 0-25 mA
Spectral density (arb. units)
30000
27000
24000
21000
18000
15000
12000
9000
6000
3000
0
560 570 580 590 600 610 620 630 640 650 660 670 680 690 700 710 720
Wavelength (nm)
T = 10.54℃
T = 20.20℃
T = 30.18℃
T = 40.46℃

2-LED source

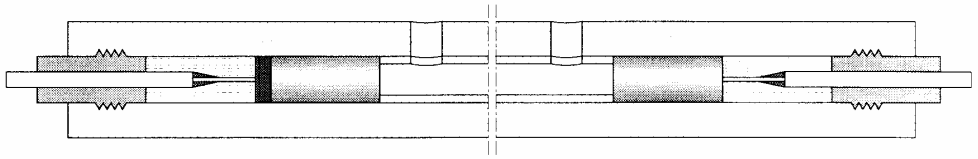


Thermal stabilization and microoptic joint of the module for reflection spectroscopy

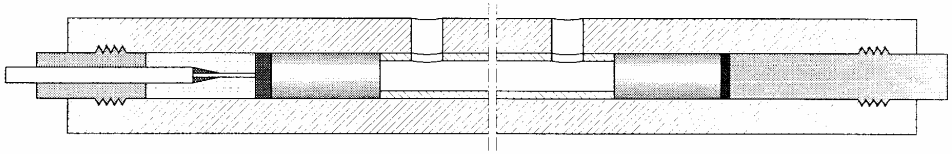


Optical fiber probe for reflection spectroscopy

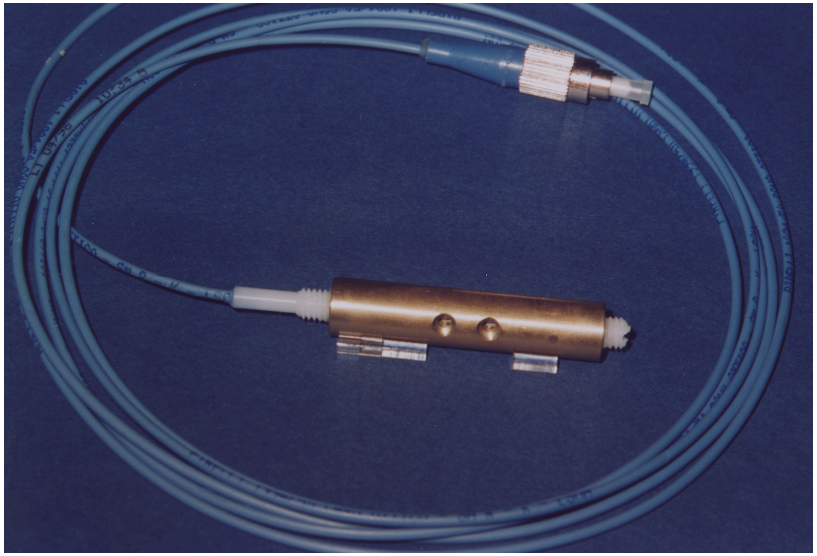
Probes for on-line absorption spectroscopy



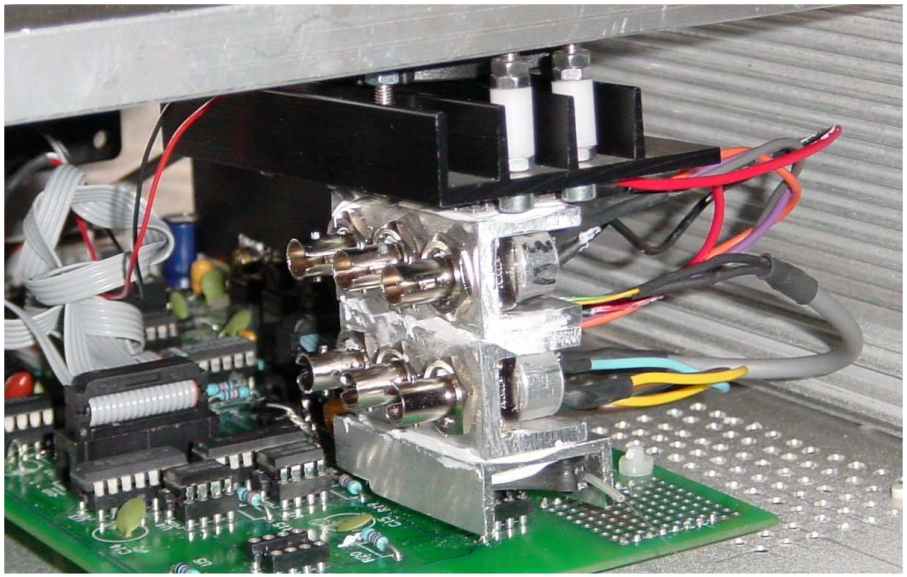
transmissive

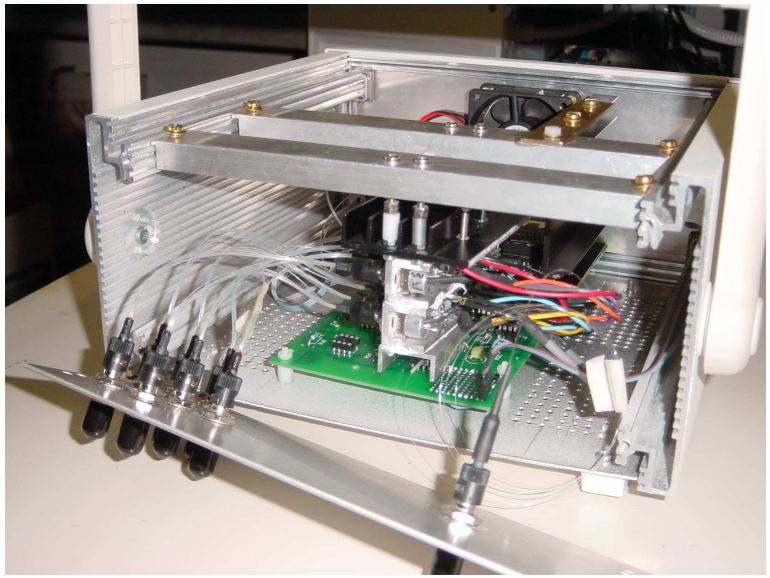


transmissive
folded path

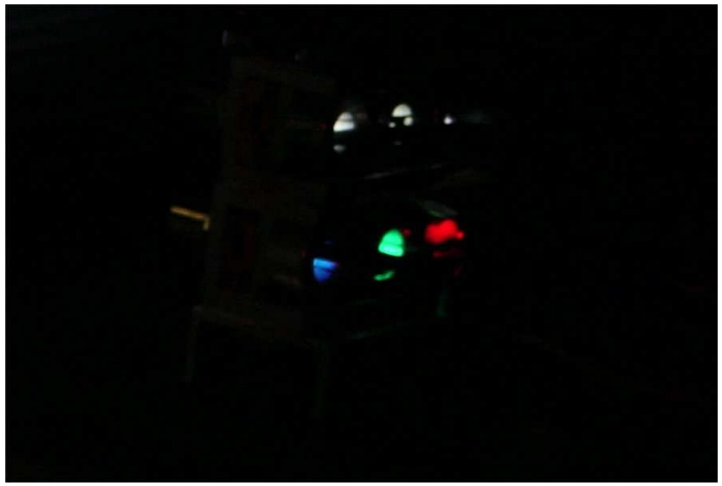


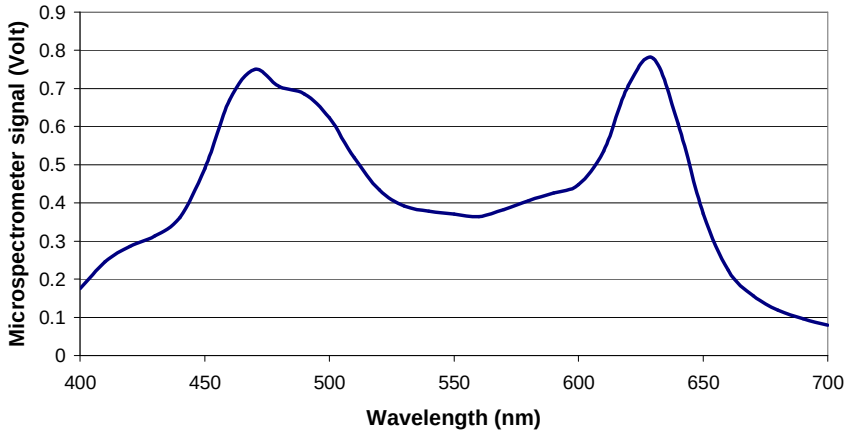
6-LED source



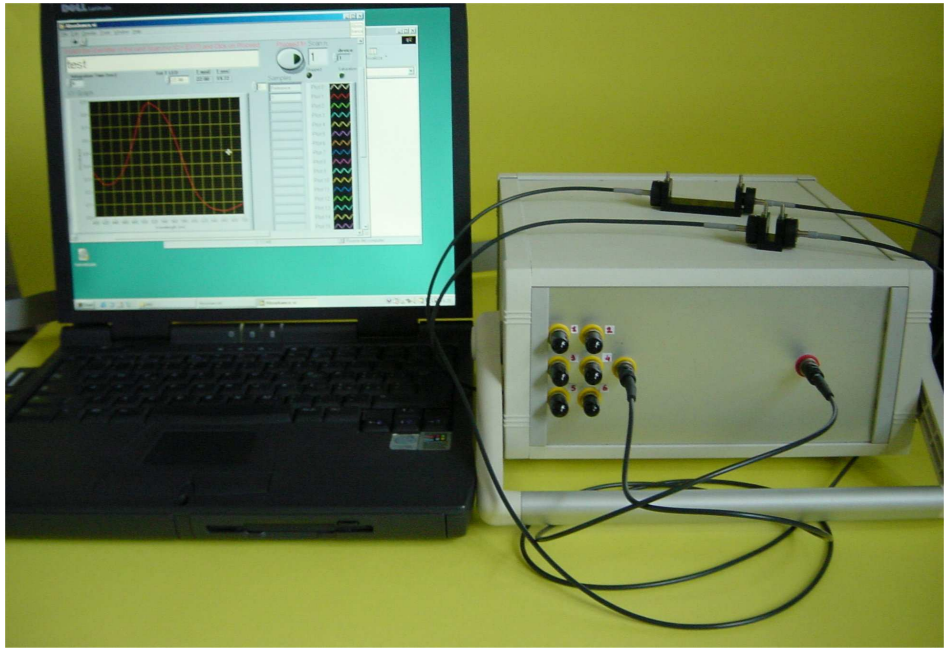


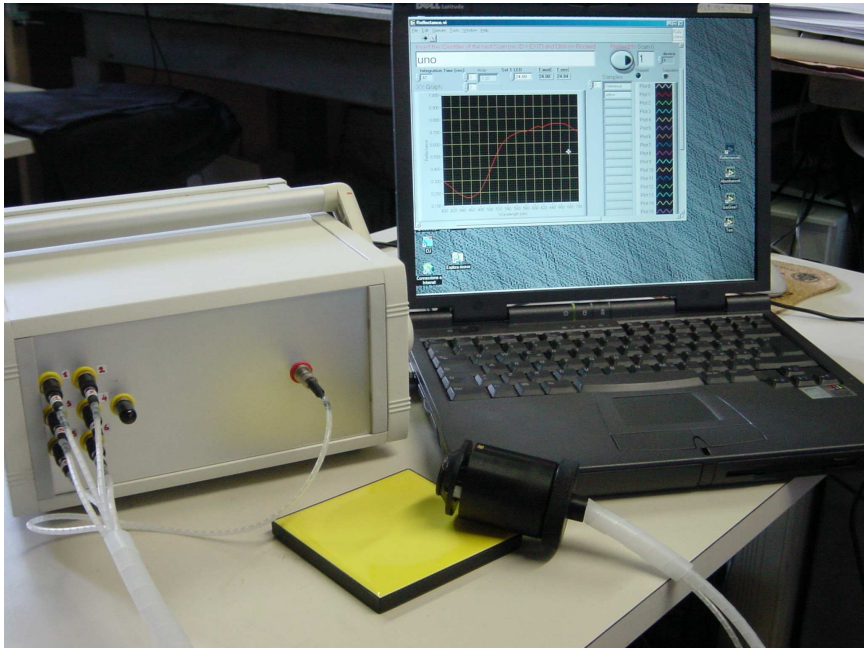
6-LED Source





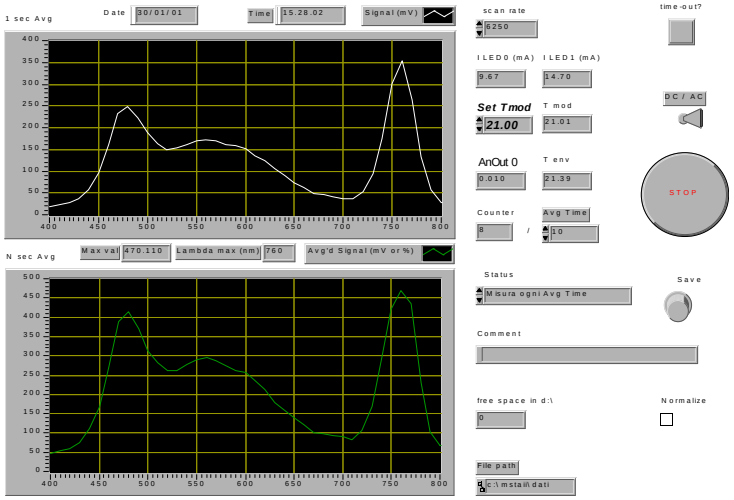
Spectrophotometer for absorption and reflection spectroscopy 6-LED source

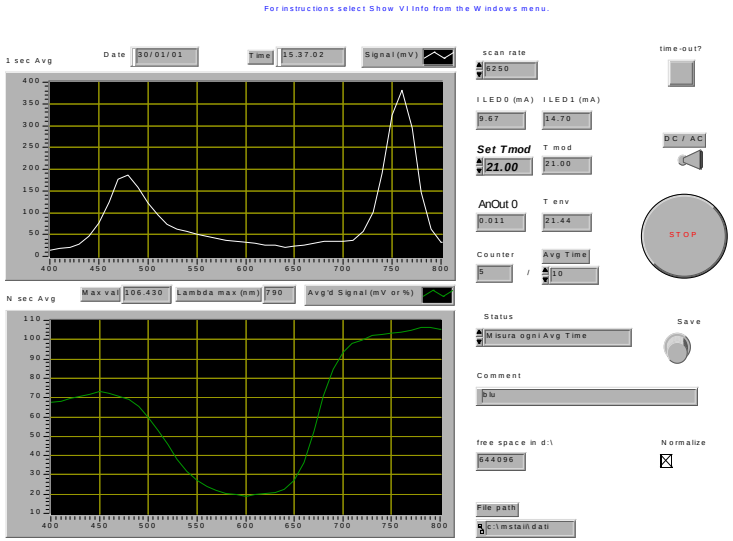


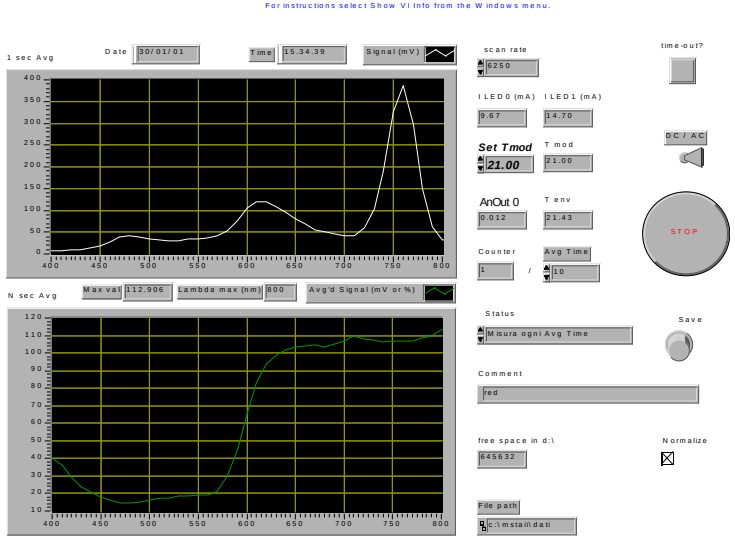


Laptop interface

DAQ1200 card + Labview software







Colorimetry:

- Fiber-optic spectrophotometers for absorption and reflection spectroscopy
  - Direct:
    - Gasoline blendings
    - Water color monitoring in a recycling plant
  - Chemically-mediated:
    - Lighting monitoring in museums
    - Fiber optic multimeter for spectral interrogation of opto-chemical sensor arrays
      - Metal ions in water
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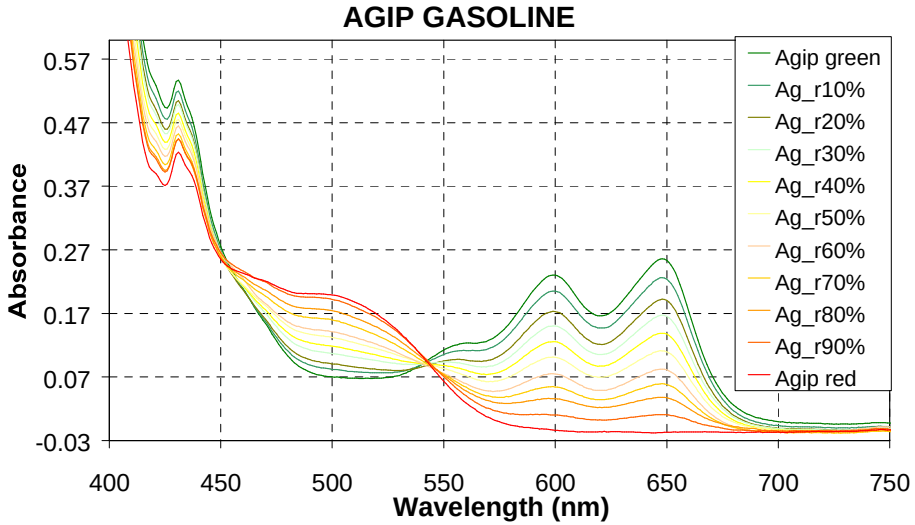
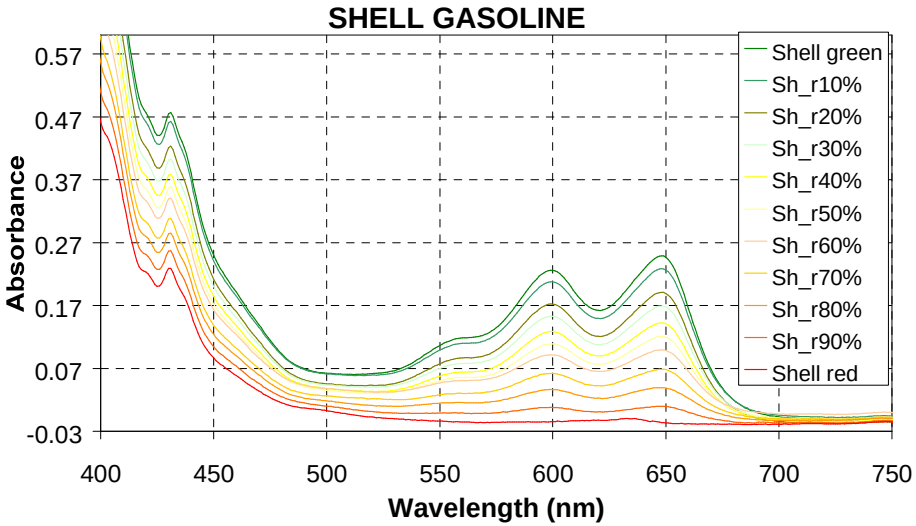
Recognition of gasoline blending transition in a pipeline





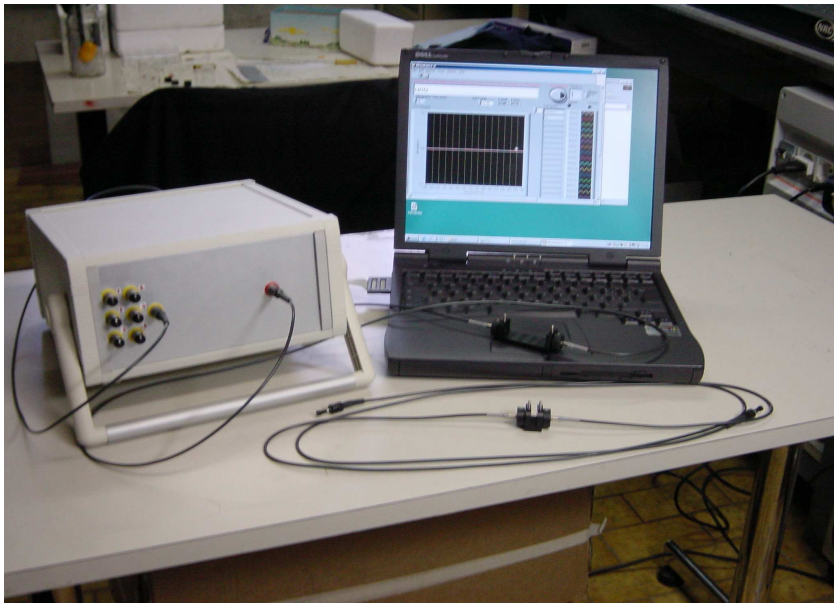
Application of absorption spectroscopy
Water color monitoring in a recycling plant

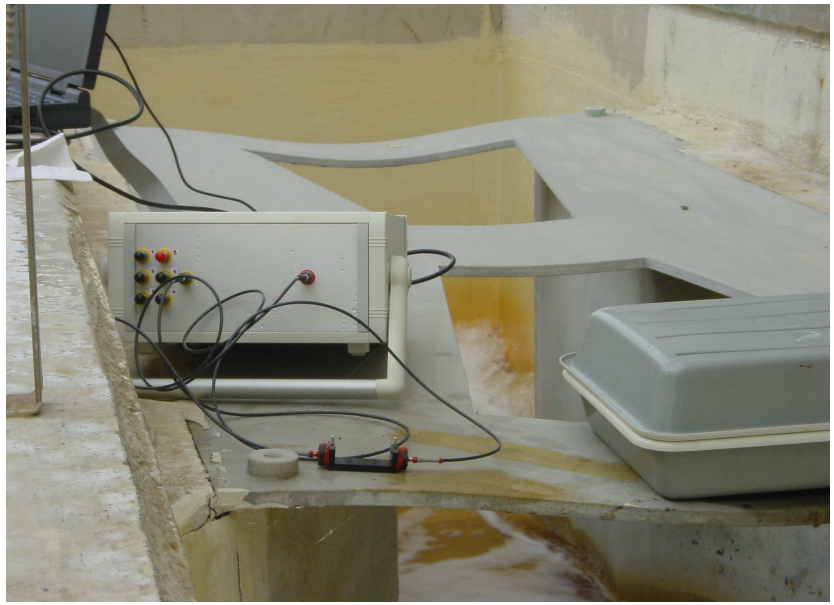
- The water recycling process at the IDRA plant in Prato makes use of reservoirs for water storage after each recycling step. At present, water samples from reservoirs are taken and analysed in the laboratory, so as to monitor the operating efficiency of the recycling process.
- A fiber optic spectrophotometer was used to perform online water color measurements, proving the feasibility of online monitoring by exploiting fiber optic technology.

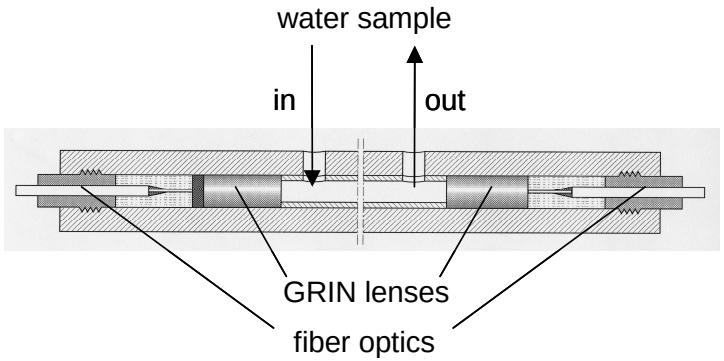
On-line absorption spectroscopy: water color monitoring in a recycling plant

On-line absorption spectroscopy: water color monitoring in a recycling plant

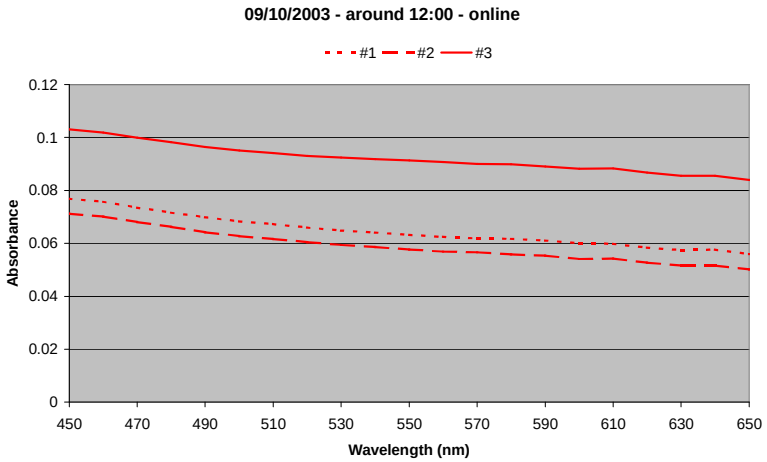
Application of absorption spectroscopy
Water color monitoring in a recycling plant

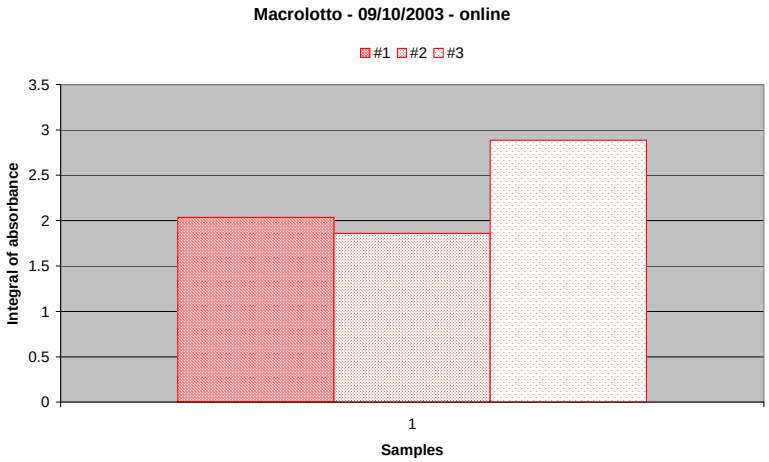




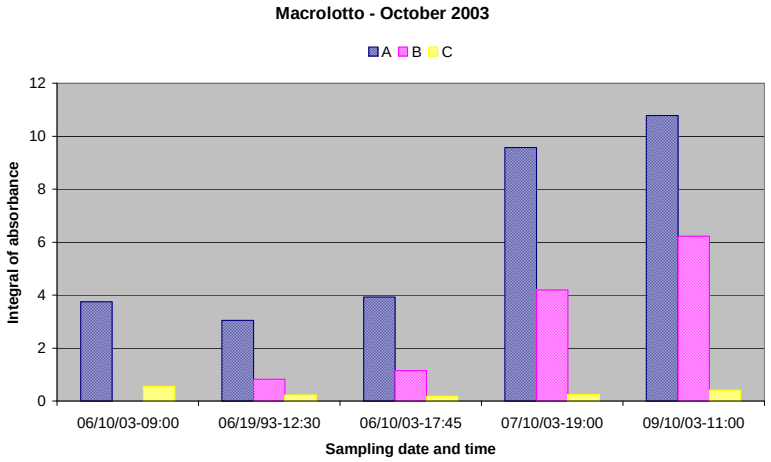


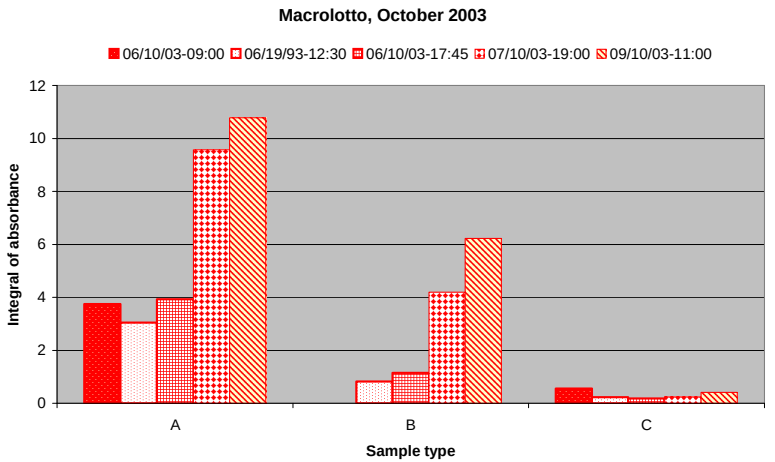
Application of absorption spectroscopy
Water color monitoring in a recycling plant





Application of absorption spectroscopy
Water color monitoring in a recycling plant





Colorimetry:

- Fiber-optic spectrophotometers for absorption and reflection spectroscopy
  - Direct:
    - Gasoline blendings
    - Water color monitoring in a recycling plant
  - Chemically-mediated:
    - Lighting monitoring in museums
    - Fiber optic multimeter for spectral interrogation of opto-chemical sensor arrays
      - Metal ions in water
      - Artificial olfactory perception of olive oil rancidity

Application of reflection spectroscopy: equivalent-light dosimetry inside museums

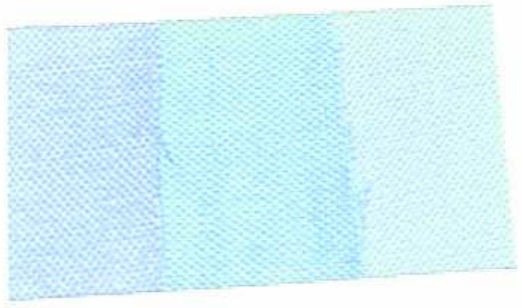
- All organic materials such as papers, textiles, resins and leathers can be damaged by excessive or unsuitable lighting, because of the light-induced photo-oxidation
- Photo-oxidation is a cumulative and irreversible effect; consequently, artistic material remains permanently damaged by the wrong lighting
- Lighting is not the only cause of color fading. The presence of pollutants and unsuitable temperature and humidity conditions can amplify and accelerate photo-alteration processes

Firenze, Italy: the Uffizi Gallery

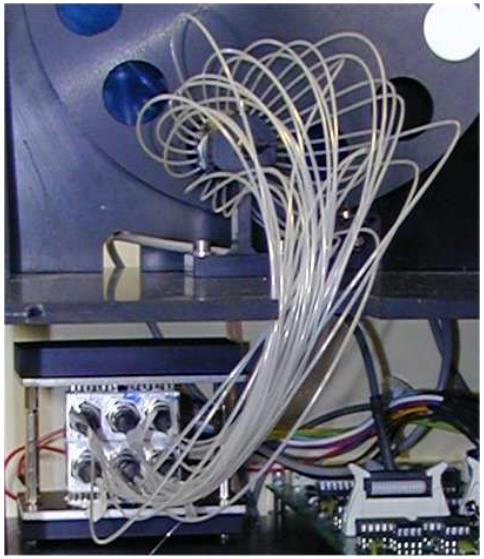
Equivalent-light dosimetry inside museums

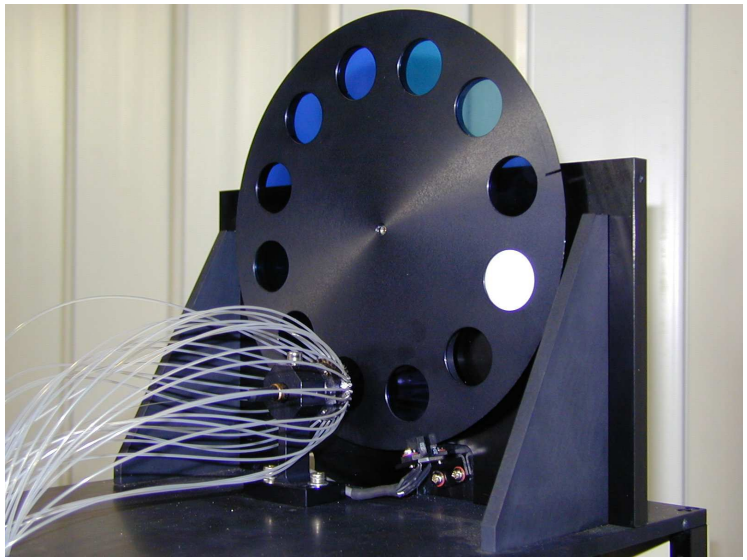
- **'Equivalent-light dose':** cumulative impact of light and environmental conditions
- Blue Wool Standard
  - Suitable for light-equivalent dosimetry since exposure to environmental conditions induces a progressive color fading

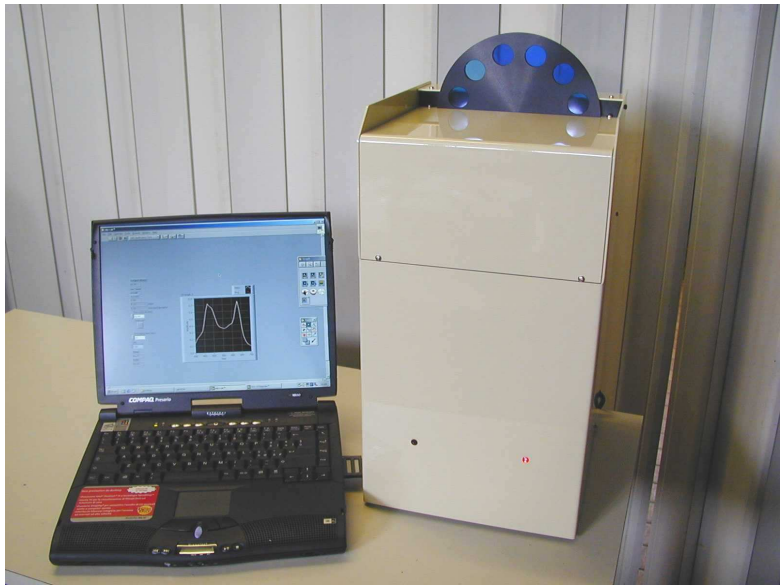
    - Two series of 'Blue-Wool Standard' samples can be used
    - one series can be exposed to environmental conditions
    - the other can be kept un-exposed
    - comparative colorimetry between exposed and un-exposed samples can be achieved by reflection spectroscopy, thus measuring the 'equivalent-light' dose

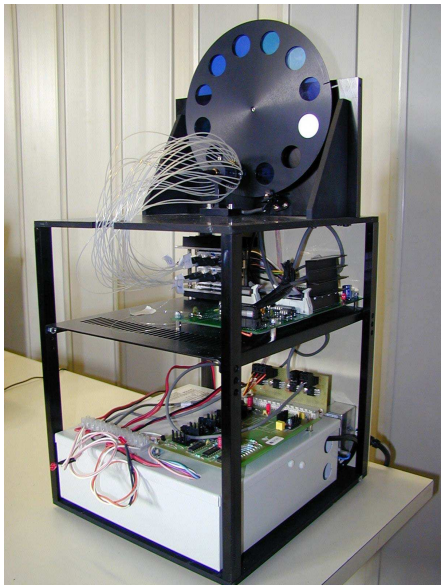


Instrumentation for indoor equivalent-light dosimetry inside museums

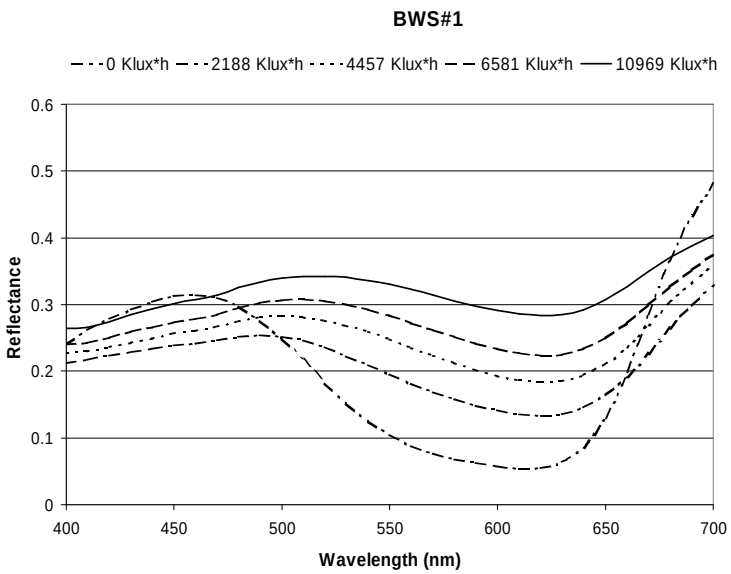


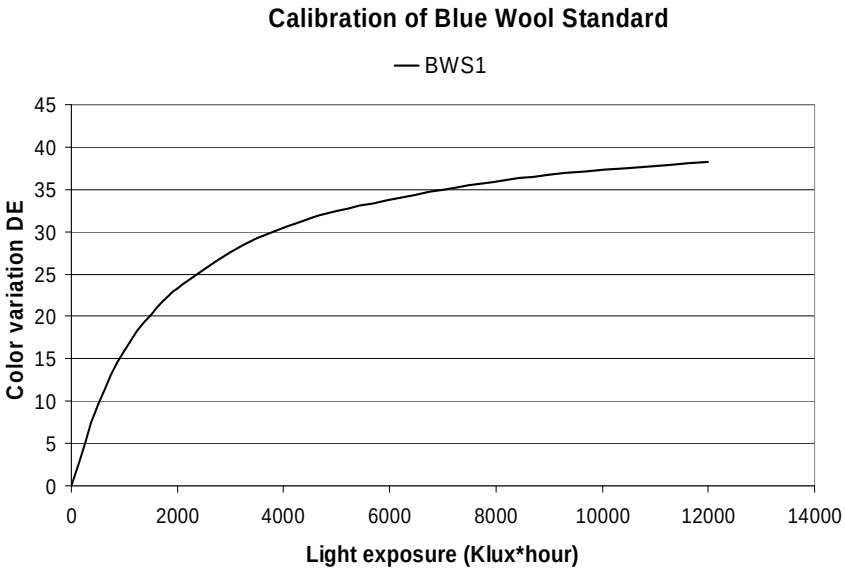






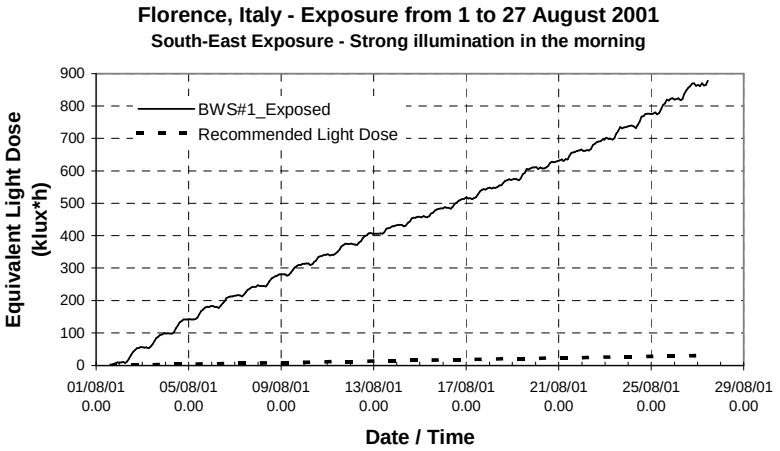
Equivalent-light dosimetry inside museums: calibration



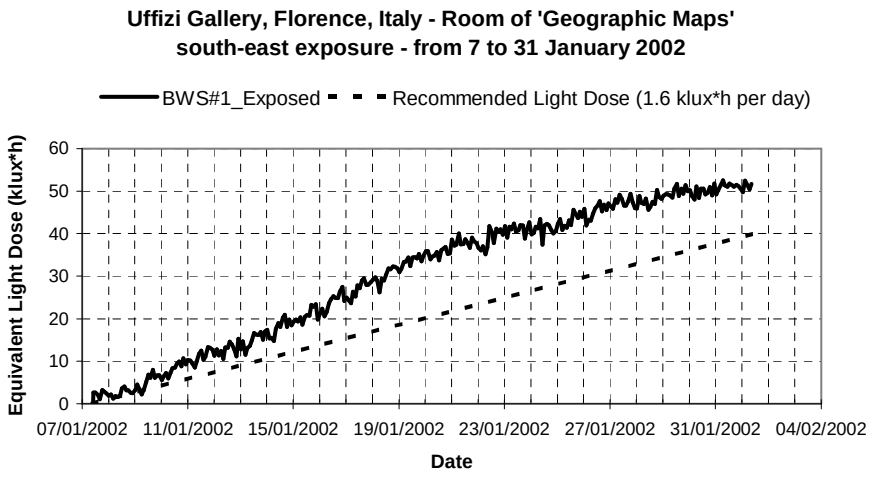


Equivalent-light dosimetry inside museums: preliminary tests

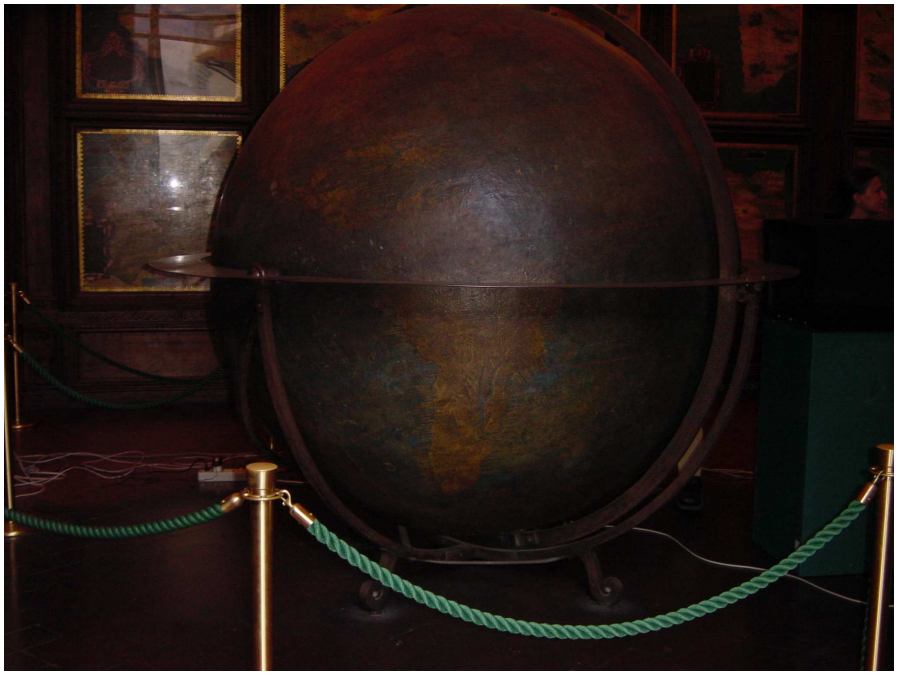
CNR-IFAC laboratory
Summer 2001

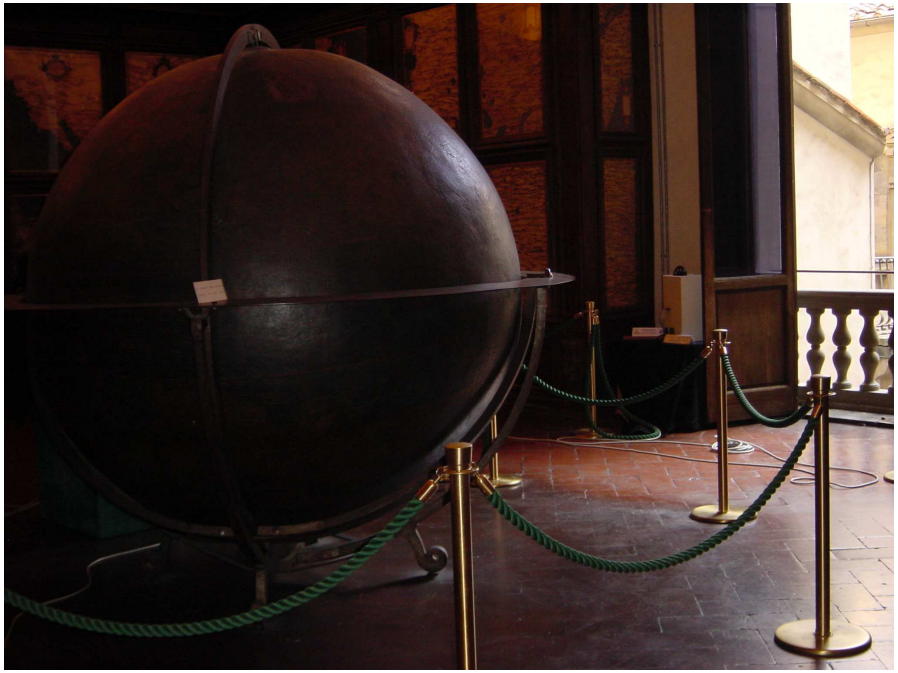


Uffizi Gallery
room of Geographic Maps
Winter 2002

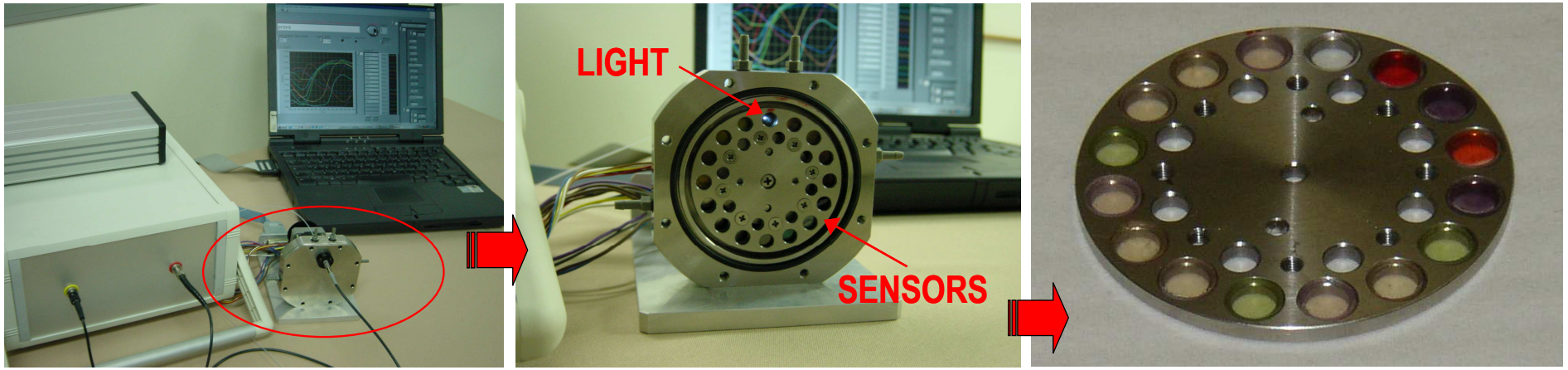


Equivalent-light dosimetry at Palazzo Vecchio, Firenze, Italy



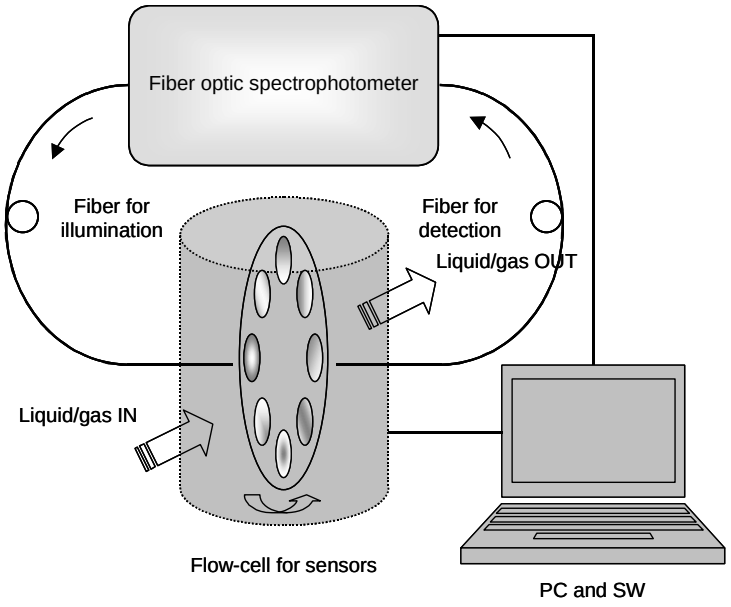


Fiber optic multimeter for spectral interrogation of an opto-chemical sensor array

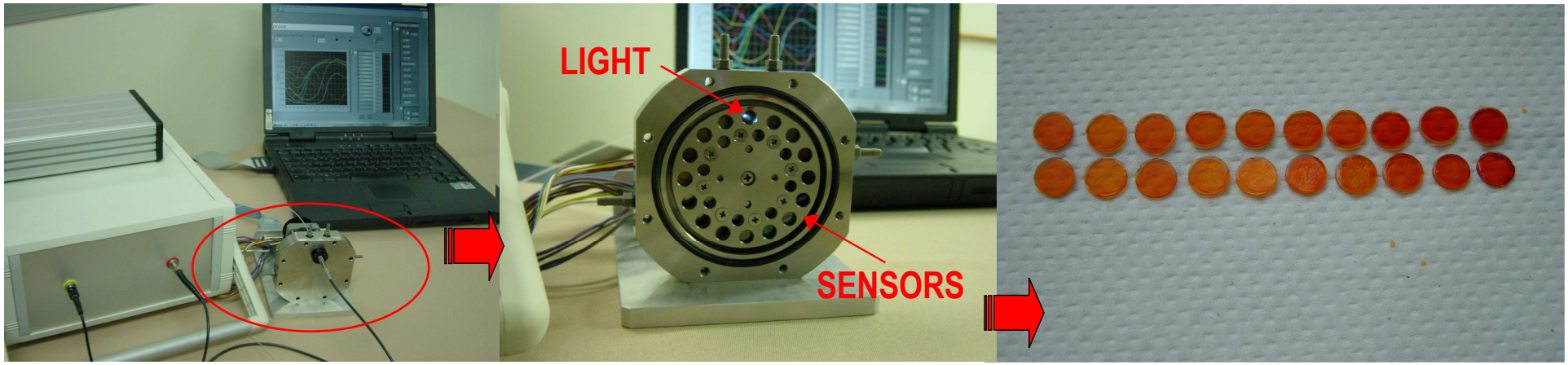


A single electro-optic unit capable of interrogating a multiplicity of sensors

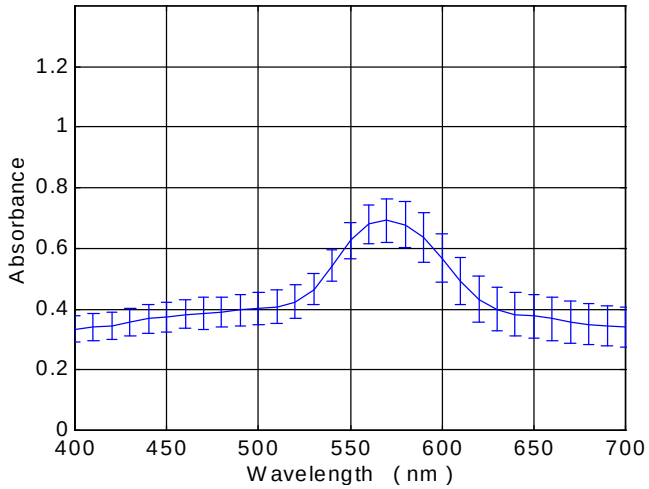
evident added value supplied by identical hardware and software at the service of a sensor array



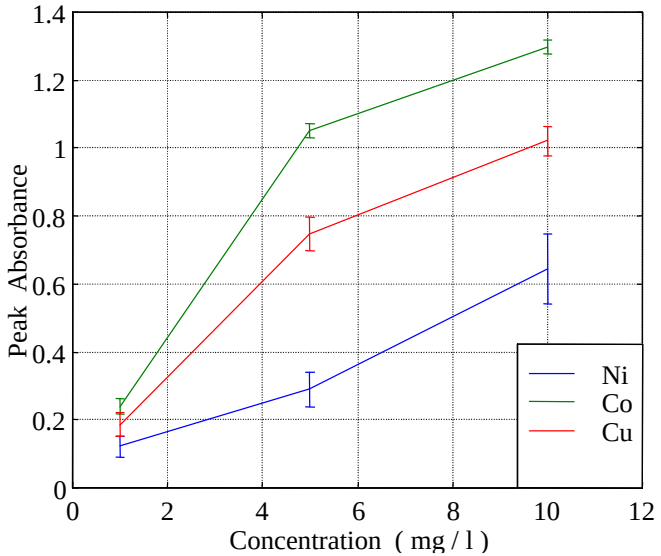
Fiber optic multimeter for spectral interrogation of an opto-chemical sensor array: validation of metal ion dosimeters

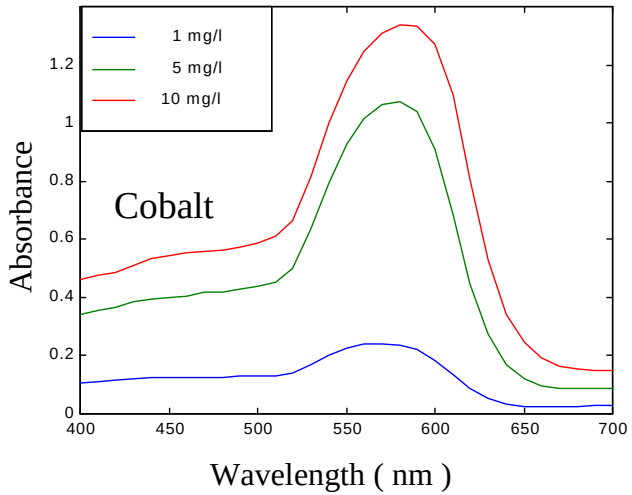


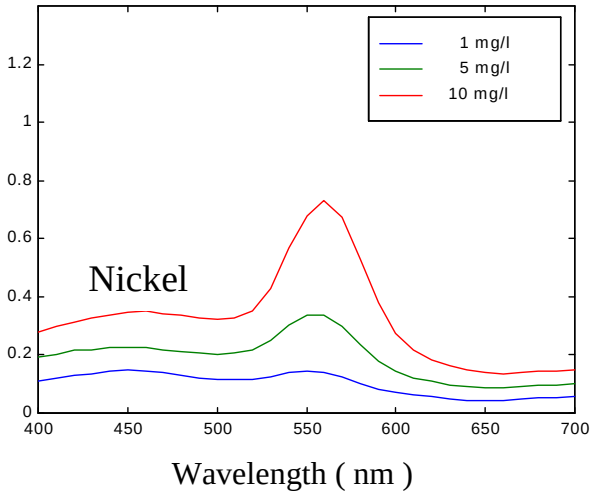
SENSORS: azo dye species, 2-(5-Bromo-2-pyridylazo)-5-diethylaminophenol (BrPADAP), together with an ionophore and plasticizer, immobilized in a PVC film and deposited onto a glass disc

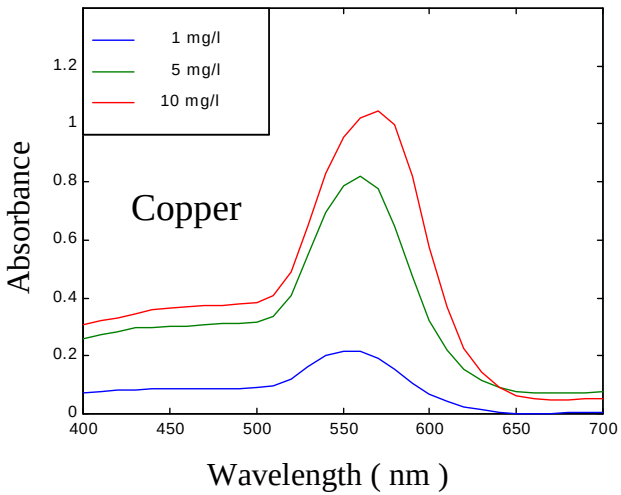


Fiber optic multimeter for spectral interrogation of an opto-chemical sensor array: validation of metal ion dosimeters

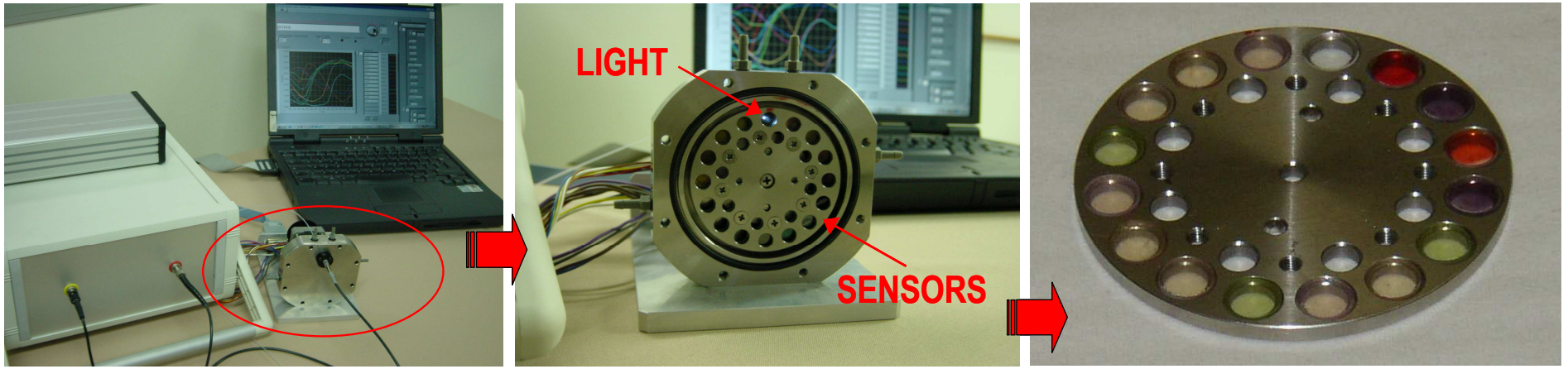






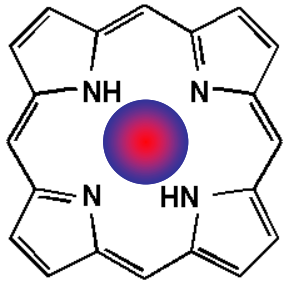


Fiber optic multimeter for spectral interrogation of an opto-chemical sensor array: artificial olfactory perception of toxic gases and vapors



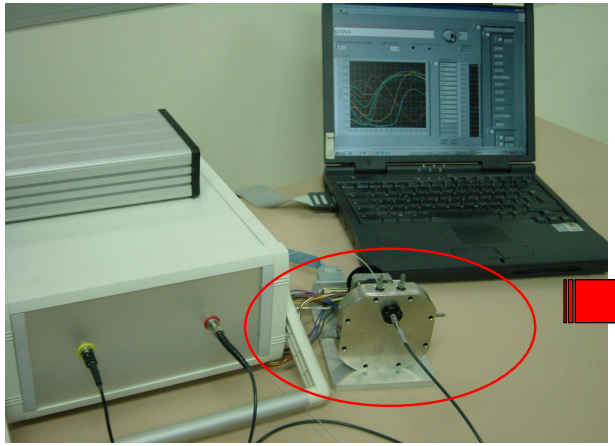
SENSORS: blend of metallo-porphyrins and metallo-fthalocyanins

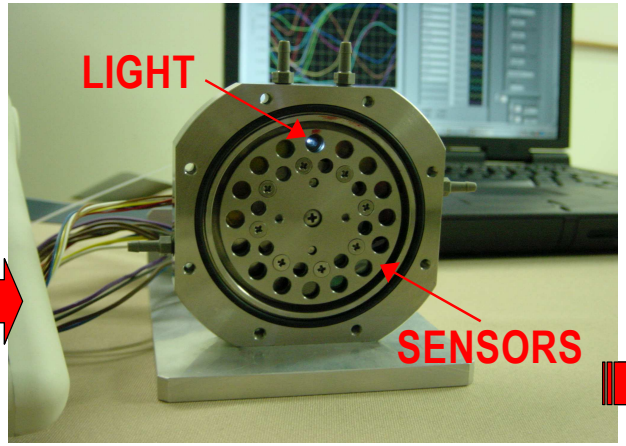
Structure name	***Acronym***	
Zinc-5,10,15,20-tetrakis (4-Heptiloxyphenyl)-Porphyrin	ZnTHEPP	(3)
Cobalt-5,10,15,20-tetrakis (4-Hexadodecyloxyphenyl)-Porphyrin	CoTEXPP	(3)
Manganese-5,10,15,20-tetrakis (4-Hexadodecyloxyphenyl)-Porphyrin	MnTEXPP	(3)
Copper--5,10,15,20-tetrakis (4-Dodecyloxyphenyl)-Porphyrin	CuTDPP	(2)
Zinc-Tetraphenyl-Porphyrin-PVC	ZnTPPPVC	(2)
Copper-TetraphenylPorphyrinPVC	CuTPPPVC	(2)



Different metals coordinated to the macrocycle

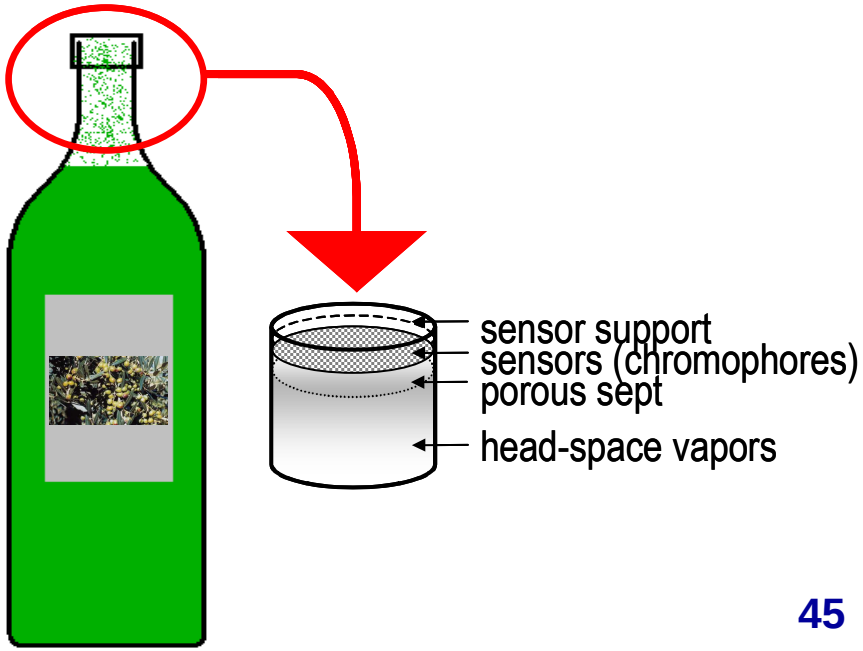
Fiber optic multimeter for spectral interrogation of an opto-chemical sensor array: artificial olfactory perception of olive oil rancidity



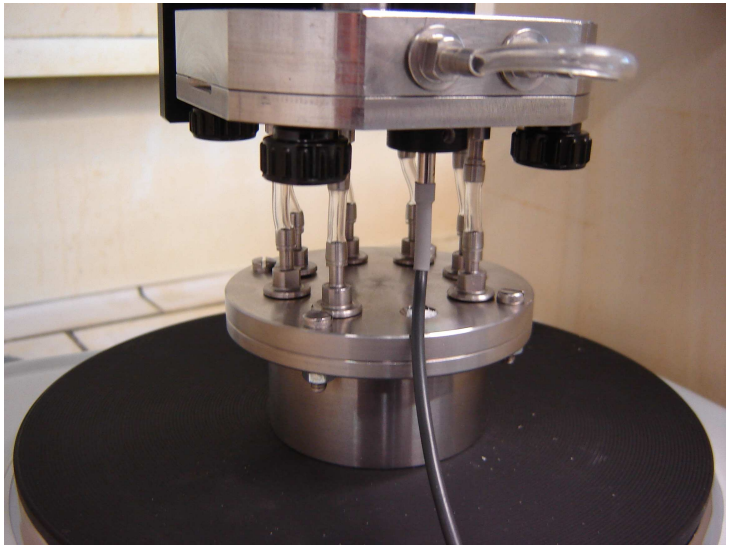


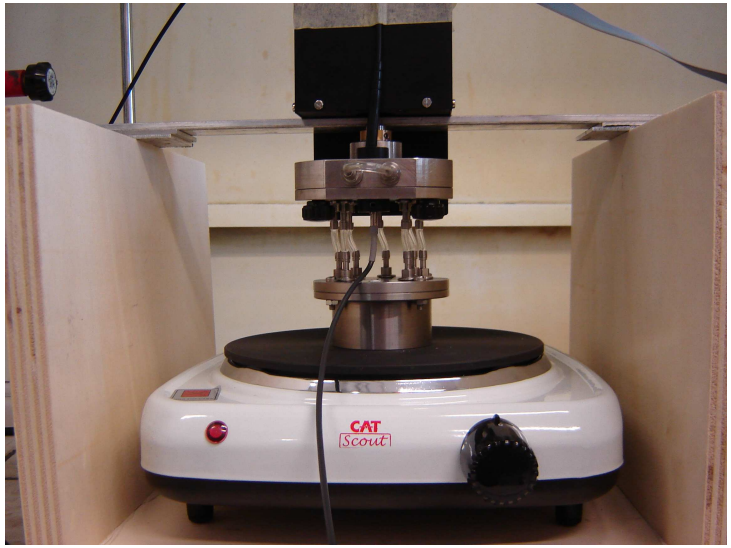
SENSORS: metallo-porphyrins

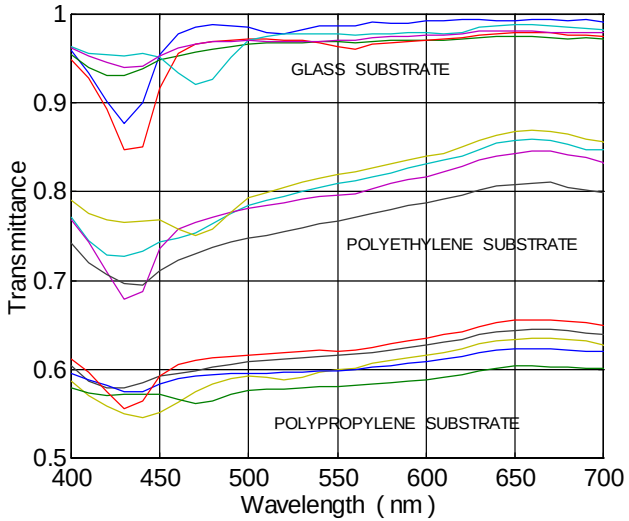
Smart cap for non-destructive testing of oil quality (rancidity) by analyzing the vapor in the bottle head-space during the shelf life

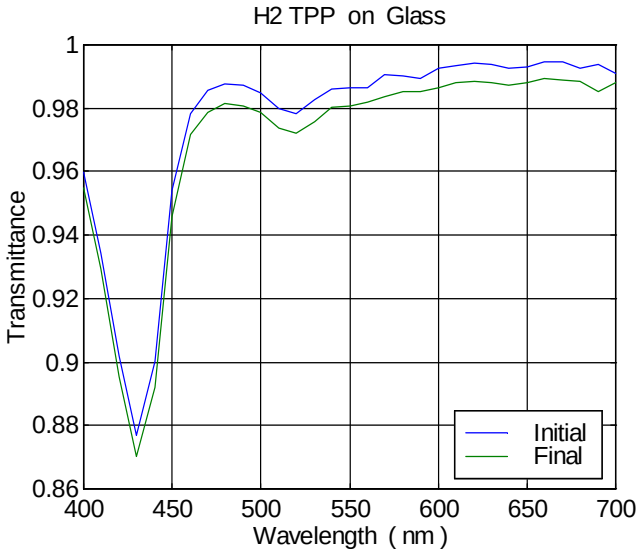


Simulation of a smart cap for artificial olfactory perception of olive oil rancidity

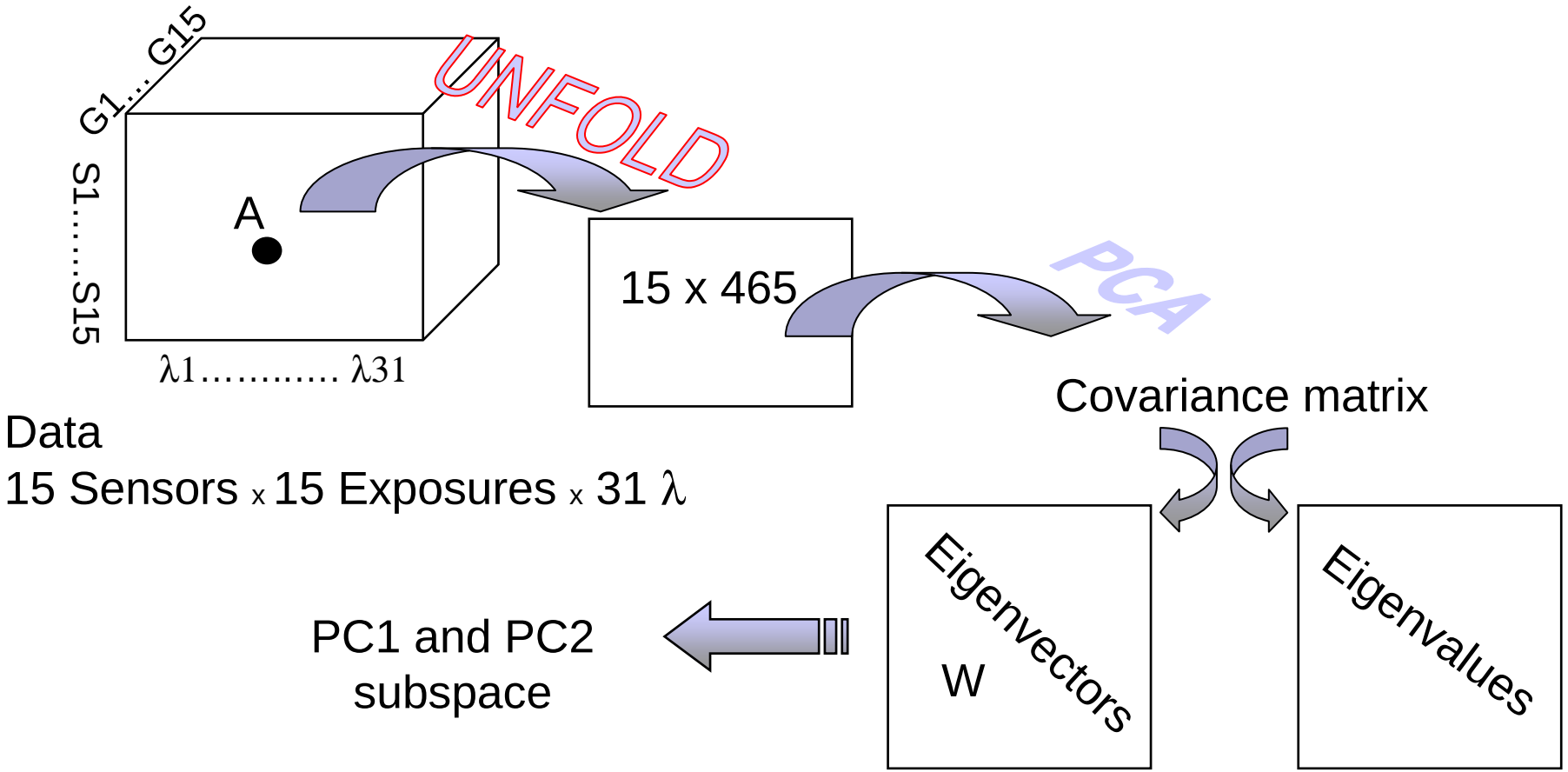








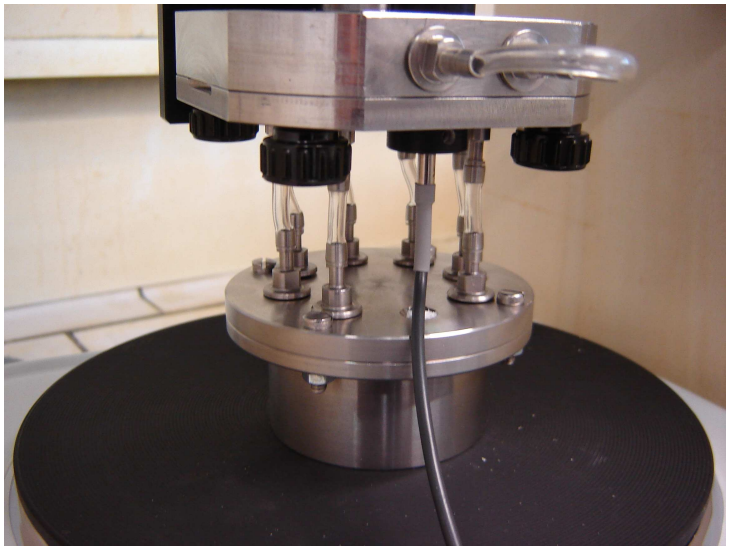
PARAFAC and PCA signal processing

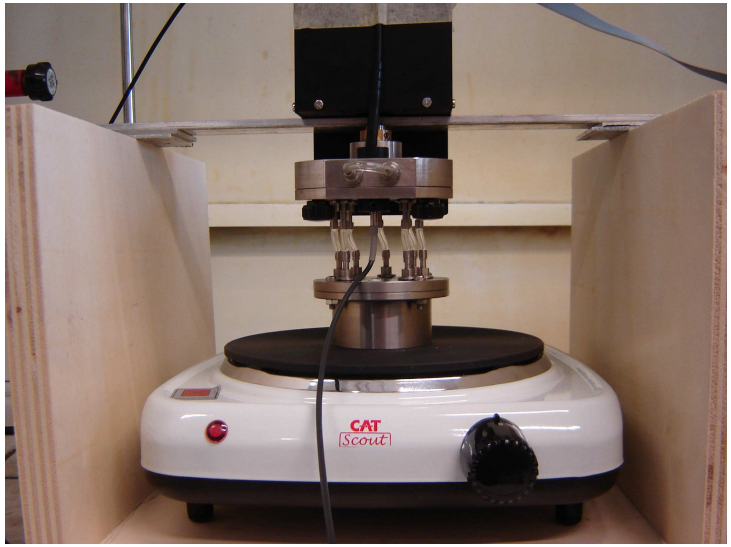


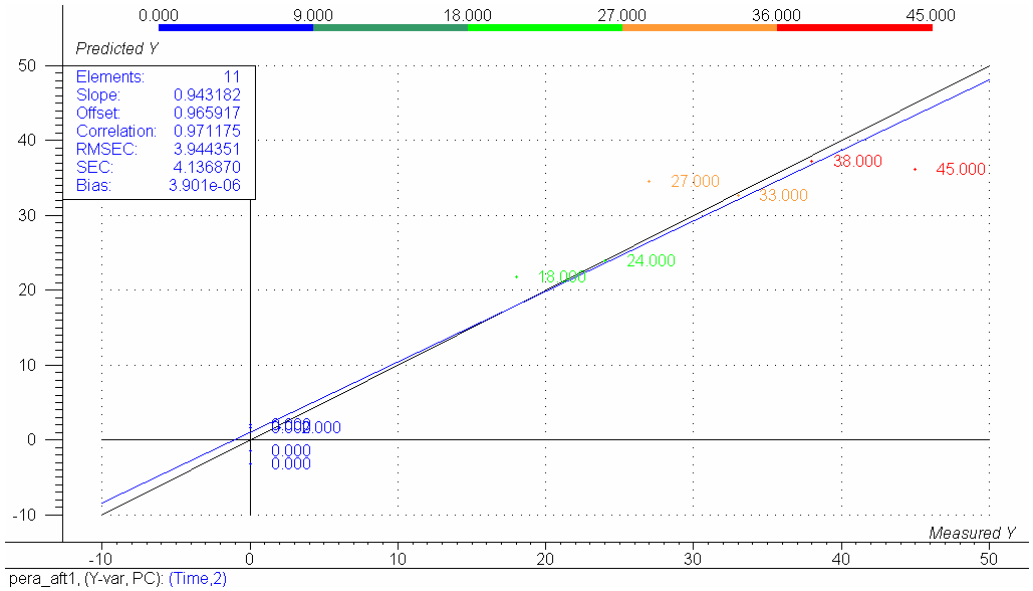
Data

15 Sensors x 15 Exposures x 31 λ

Simulation of a smart cap for artificial olfactory perception of olive oil rancidity







Outline

- **Optical fiber sensors: basics**
- **Colorimetry**
  - Absorption and reflection spectroscopy
    - Fiber optic spectrophotometers for general purpose applications – Direct / chemically-mediated
- **Scattered colorimetry**
  - Multi-λ and multi-α absorption spectroscopy
- **Hyperspectral colorimetry**
- **Fluorescence spectroscopy**

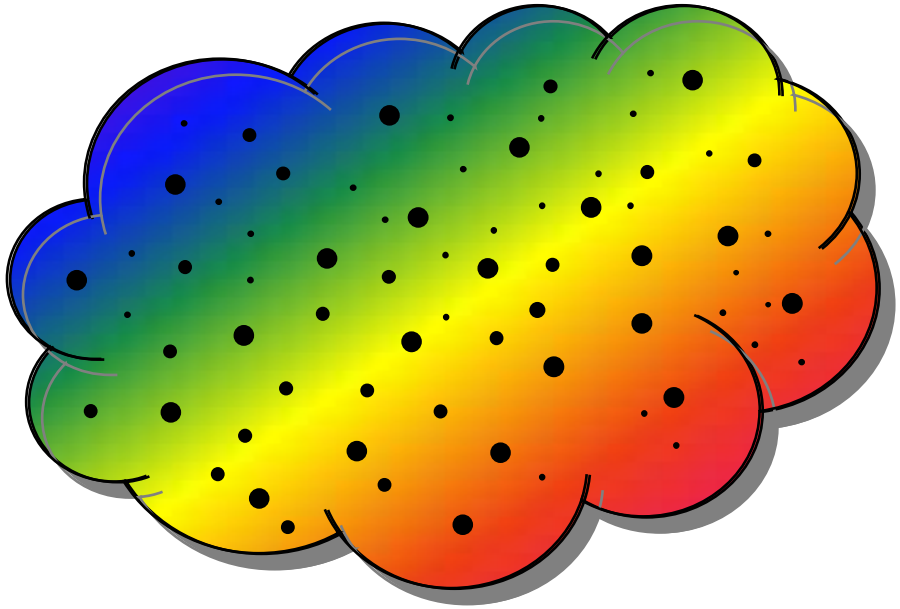
….. Liquids

- ✓ Moderately colored
- ✓ Moderately turbid

- ✓ Appearance

- ✓ Mapping
- ✓ Comparing and classifying

The appearance of a liquid:
what a liquid looks like



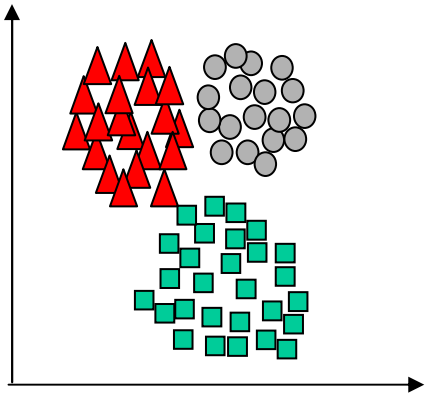
color + turbidity = visual perception

- ✓quality
- ✓mixtures: components

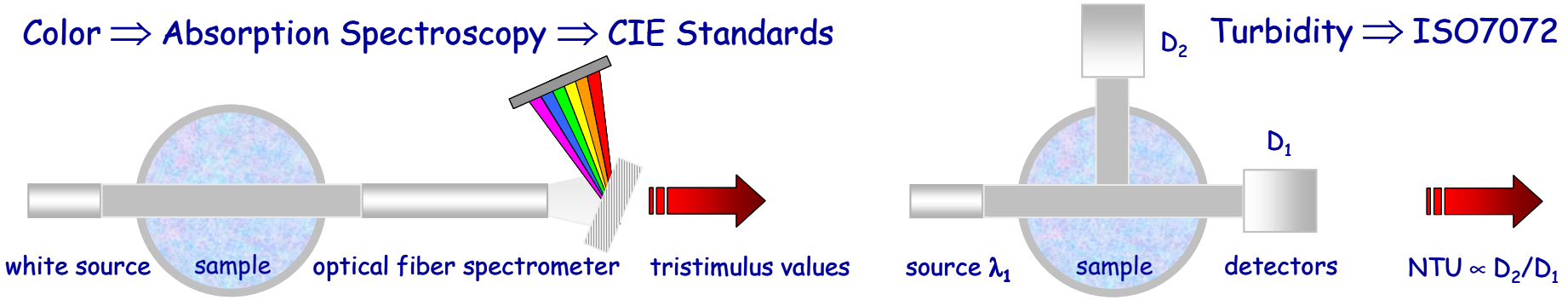
Scattered colorimetry + multivariate data processing

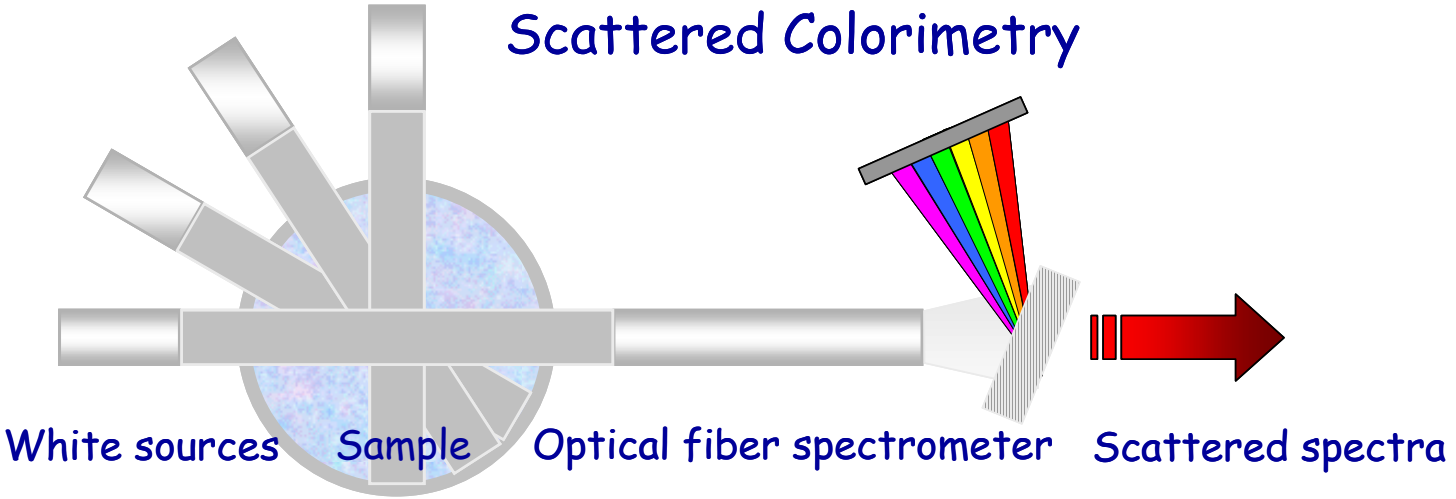
- Integrated and global measurement of the color and turbidity = appearance of liquids
- Appearance is determined objectively by means of a measuring instrument

  - Liquid mapping = digital ‘footprint’
  - Clustering



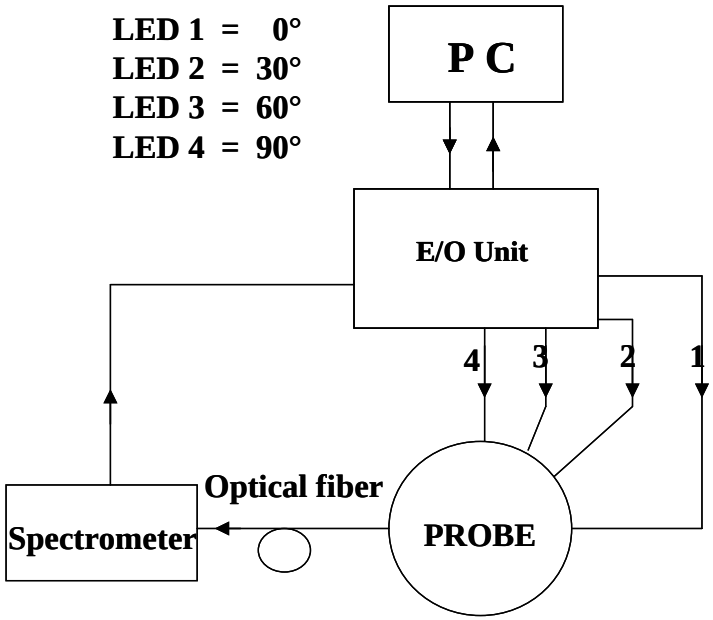
Scattered colorimetry
multi-λ and multi-α absorption spectroscopy in the visible spectral range





Instrumentation for scattered colorimetry

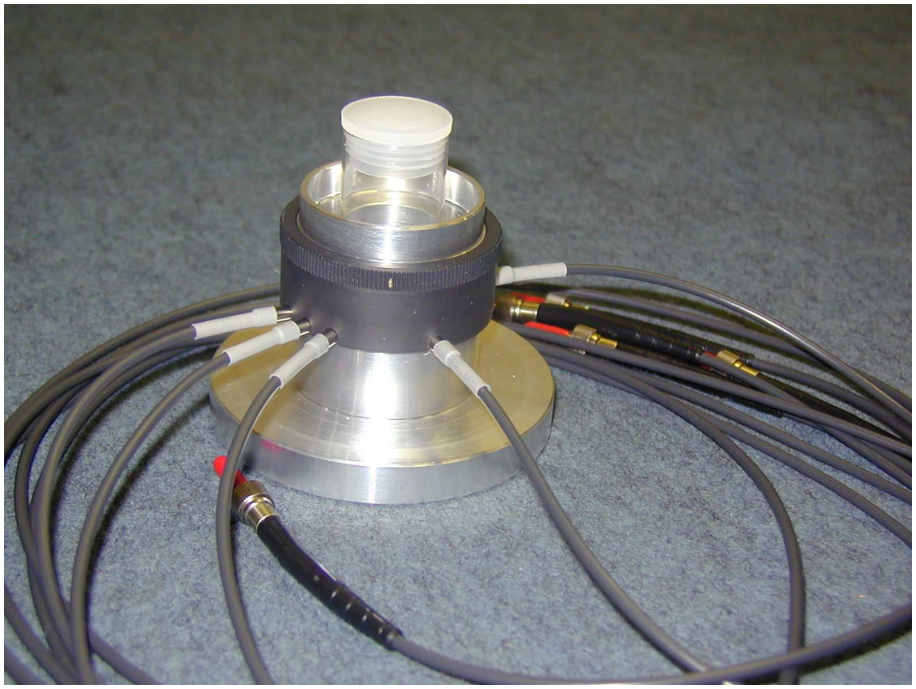
OPTIMO
Optical Technology for Intelligent Monitoring Online



Probes for scattered colorimetry

OPTIMO
Optical Technology for Intelligent Monitoring Online

without optical fibers



with optical fibers

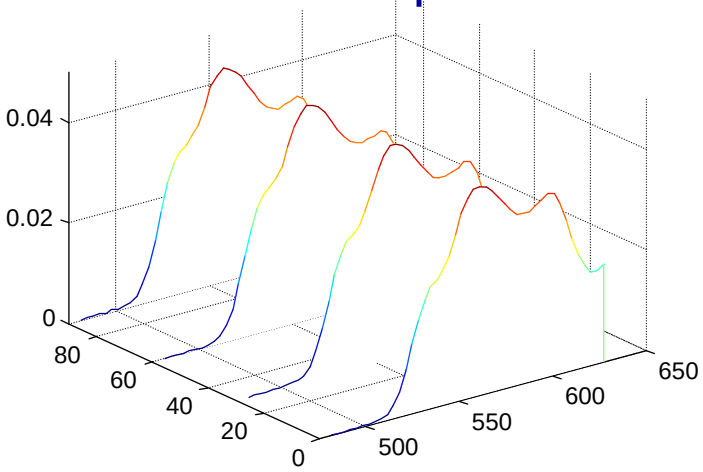
Scattered colorimetry: analysis of port wine

OPTIMO
Optical Technology for Intelligent Monitoring Online

Courtesy of Sandeman, Porto, Portugal

Scattered colorimetry: the spectral data

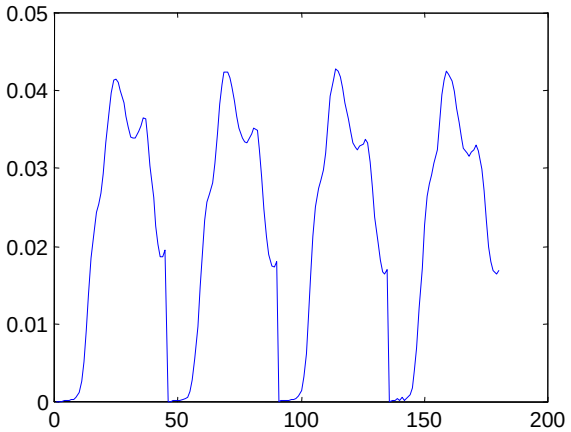
Measured Spectra



46 wavelengths x 4 angles

Unfolding

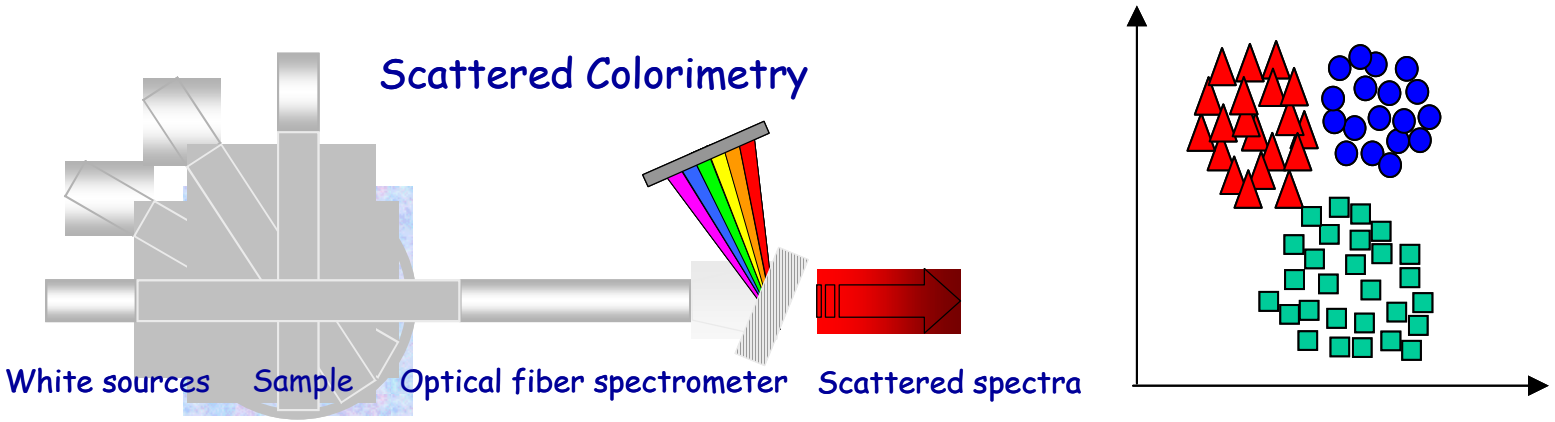
Sample Pattern



..... 184 variables .....
dimensionality reduction is needed

MULTIVARIATE DATA PROCESSING
Principal Component Analysis
Linear Discriminant Analysis

Scattered colorimetry + multivariate data processing



- Mapping
- Clustering
- Comparing

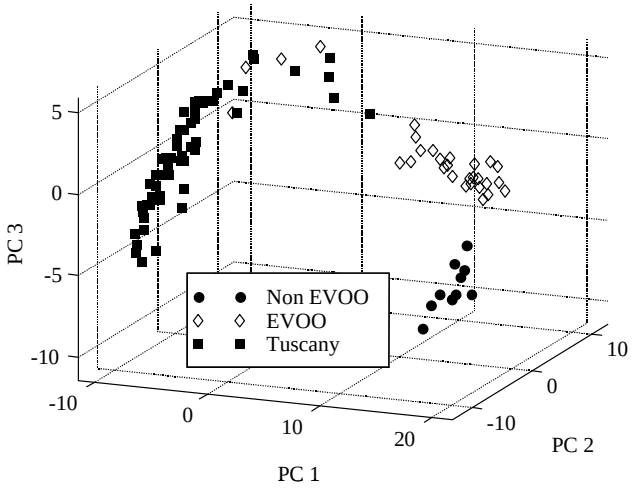
Successful applications

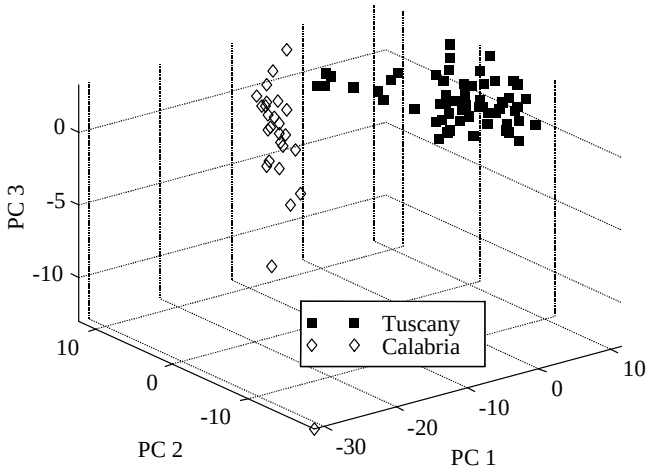
- Food
  - Mapping of extra virgin olive oils according to geographic area of origin
  - Mapping of frying oils according to degree of degradation and substance being fried
  - Mapping of beers according to types
- Non-food
  - Mapping of lubricant oils according to the degree of degradation

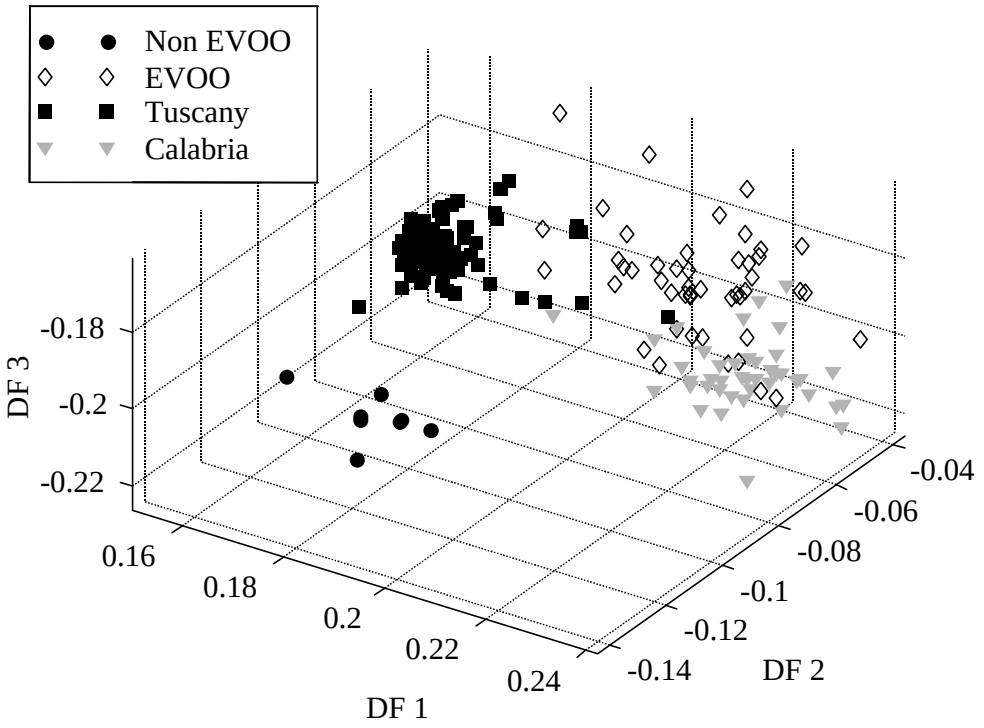
Mapping of extra virgin olive oils according to geographic area of origin

- 115 Tuscan and 53 Calabrian extra virgin olive oils produced by traditional methods
- 68 oils (58 extra virgin and 10 non extra virgin) purchased from retailers

Mapping of extra virgin olive oils according to geographic area of origin





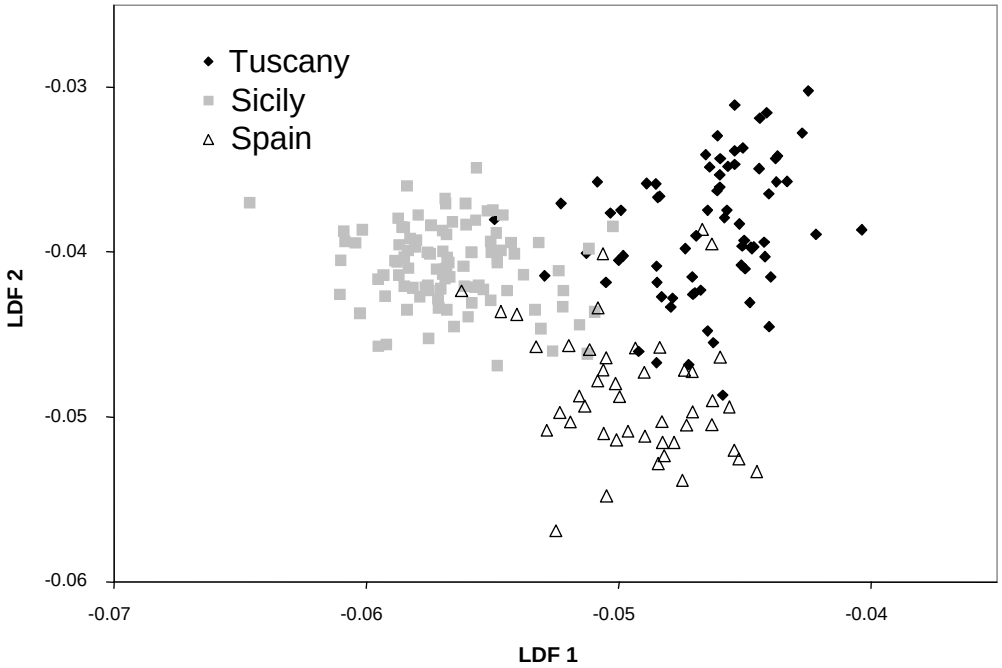


Mapping of extra virgin olive oils according to geographic area of origin

- 213 Italian oils (90 Tuscan and 123 Sicilian)
- 57 Spanish oils

- Because of the intrinsic differences due to different harvesting time (weather conditions, harvest times, etc.), a new map had to be created

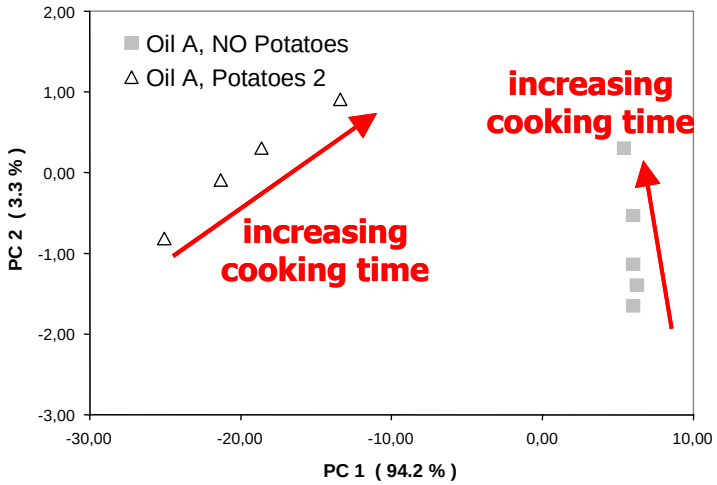
Mapping of extra virgin olive oils according to geographic area of origin

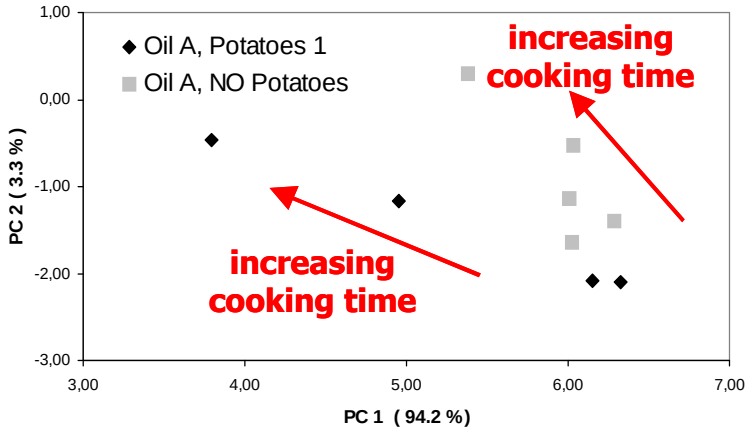


Mapping of frying oils according to degree of degradation and substance being fried

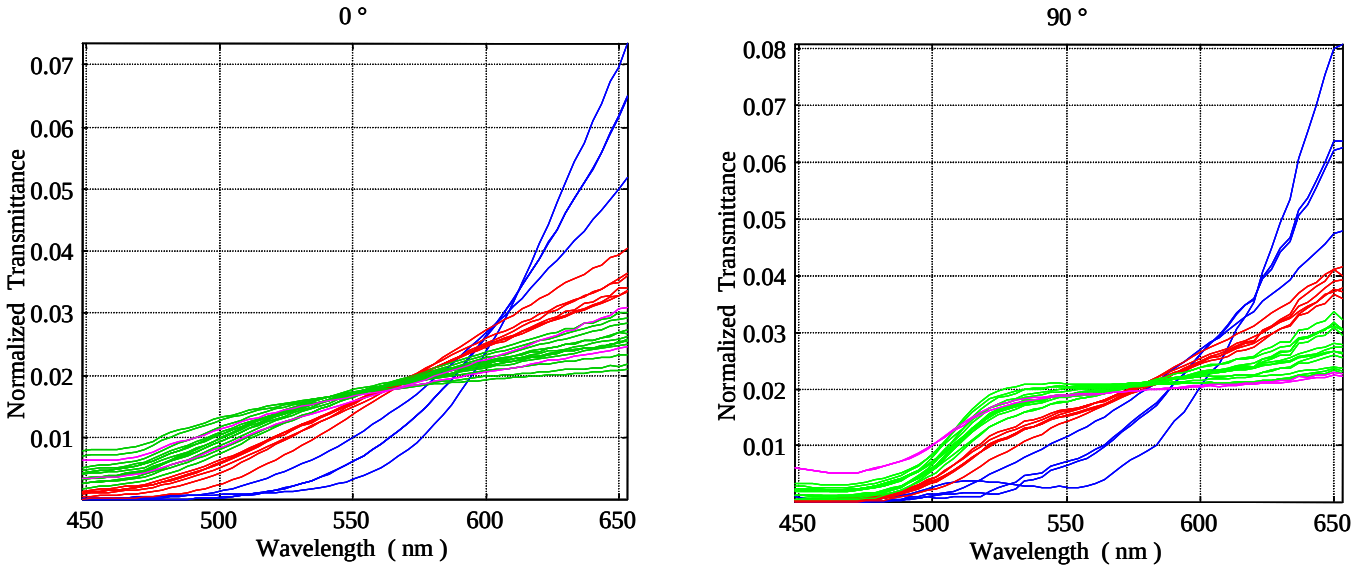
- Industrial fryers
- During frying, oil changes color, turning darker and more turbid, from the food being fried leaves residues in the oil
- Variation in color and turbidity are thus indicators of the oil's degree of degradation
  - Experiment: different types of potatoes for different cooking times ranging from 4 to 16 hours

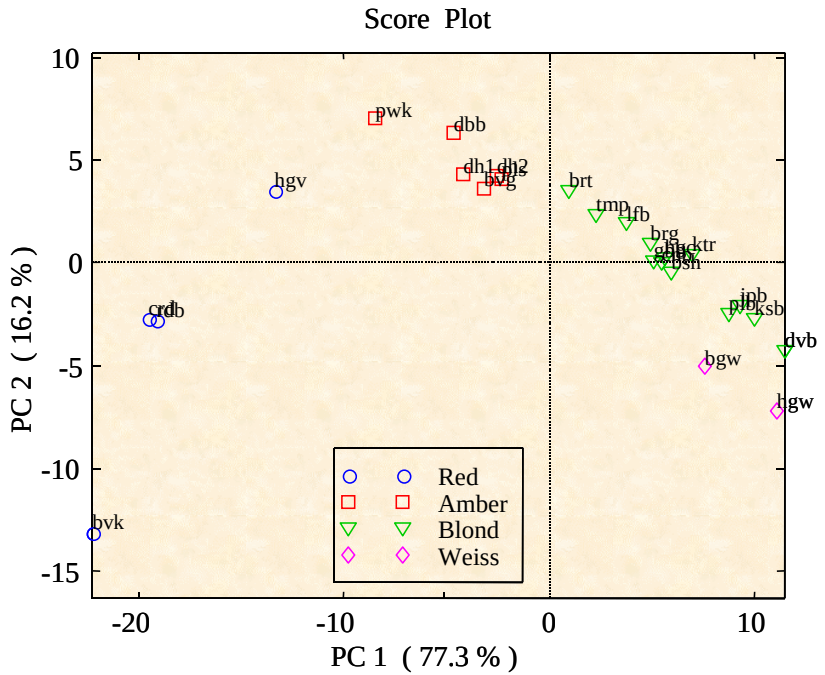
Mapping of frying oils according to degree of degradation and substance being fried





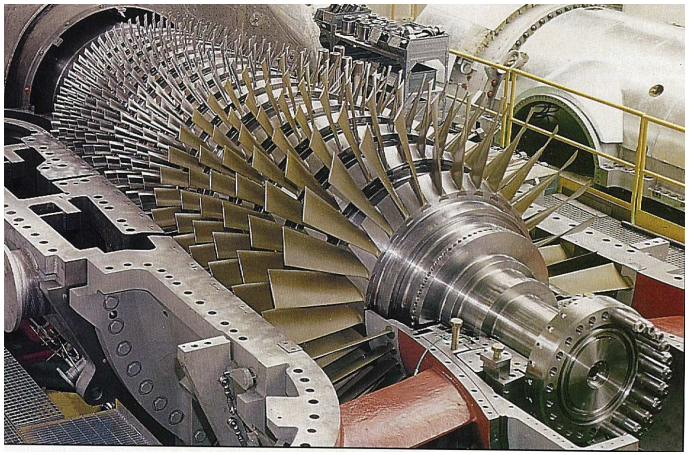
Mapping of beers according to types

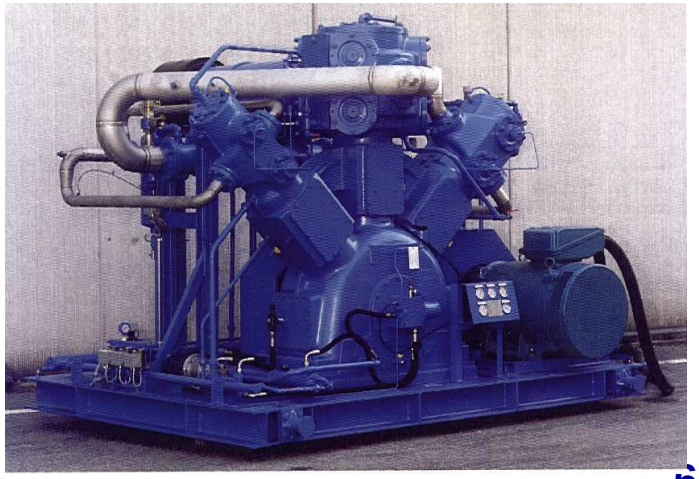




Lubricant oils: the machineries

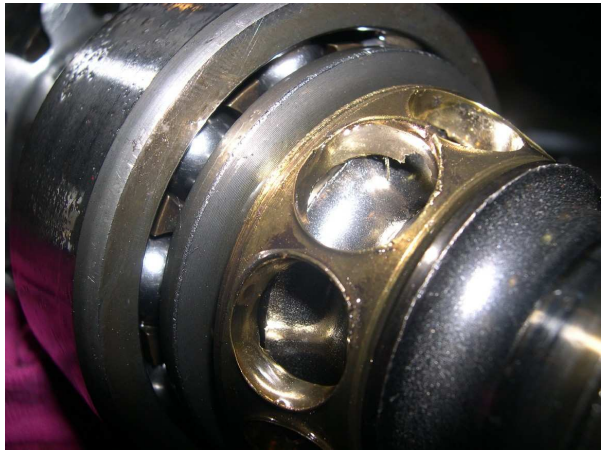
high temperature
metals
particles
dusts





oil degradation

Metals in lubricant oil
as indicators of wrong functioning



Regularly-programmed sampling and conventional laboratory analysis

MECOIL
DIAGNOSI MECCANICHE

- viscosity
- FTIR
- ferrography
- acidity

score

chemical-physical status:

- ✓ 1: good
- ✓ 2: acceptable
- ✓ 3: change suggested
- ✓ 4 and 5: change mandatory

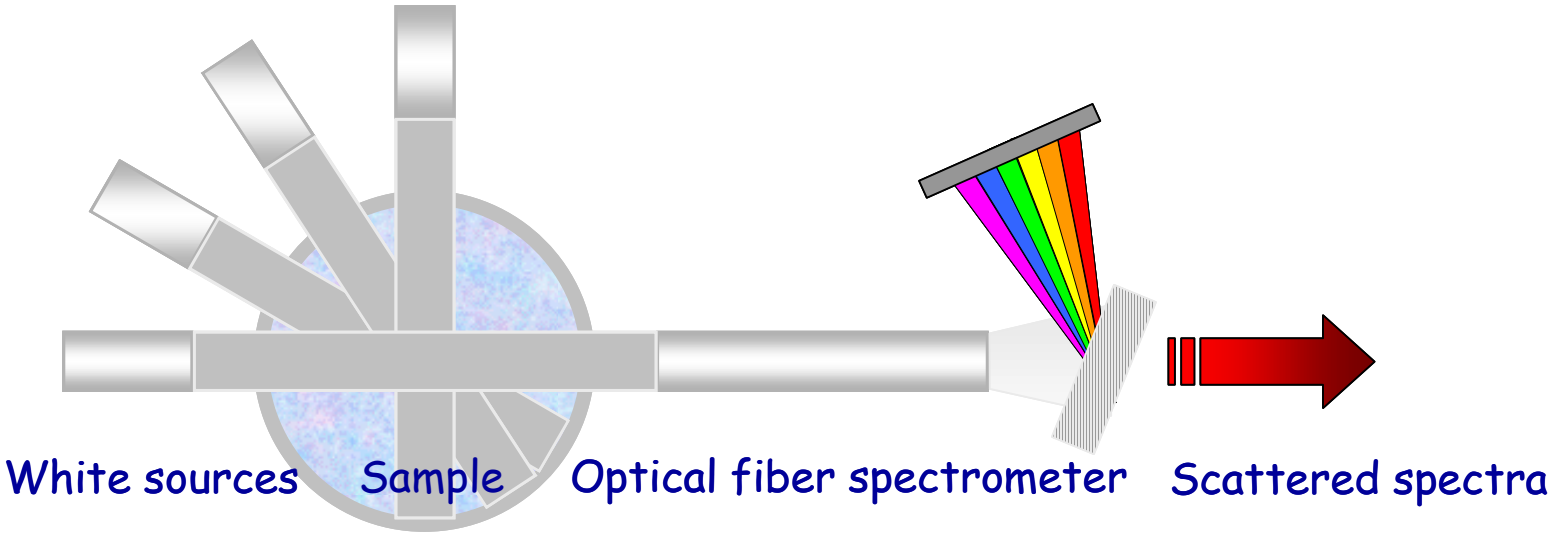
On-line diagnosis
of early wrong functioning

- Capable of distinguishing different chemical-physical status
- Low-cost system
- Immune to EMI

The lubricant oils

Degree of degradation = Different color and turbidity content

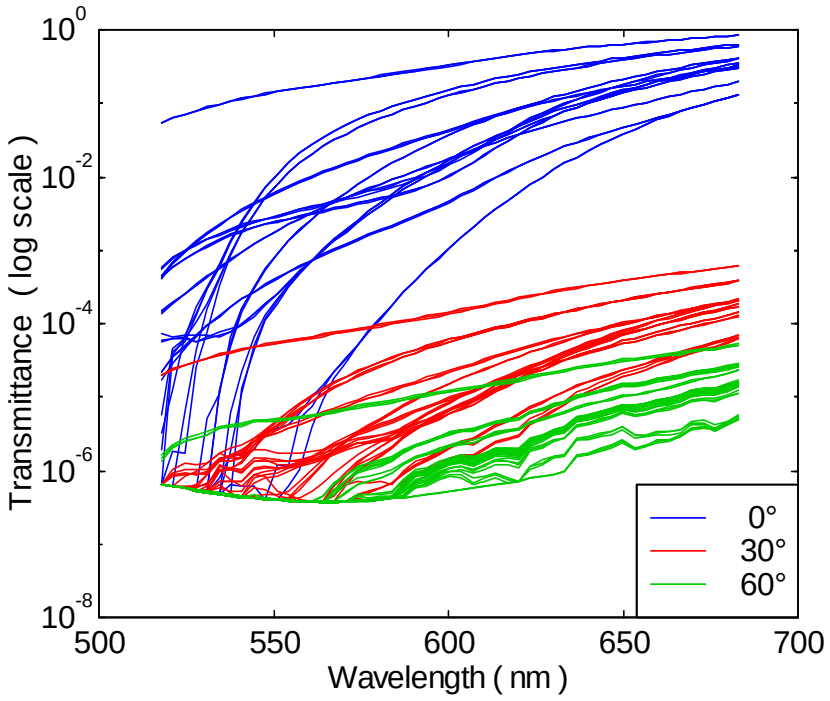
Scattered colorimetry
multi-α and multi-λ absorption spectroscopy

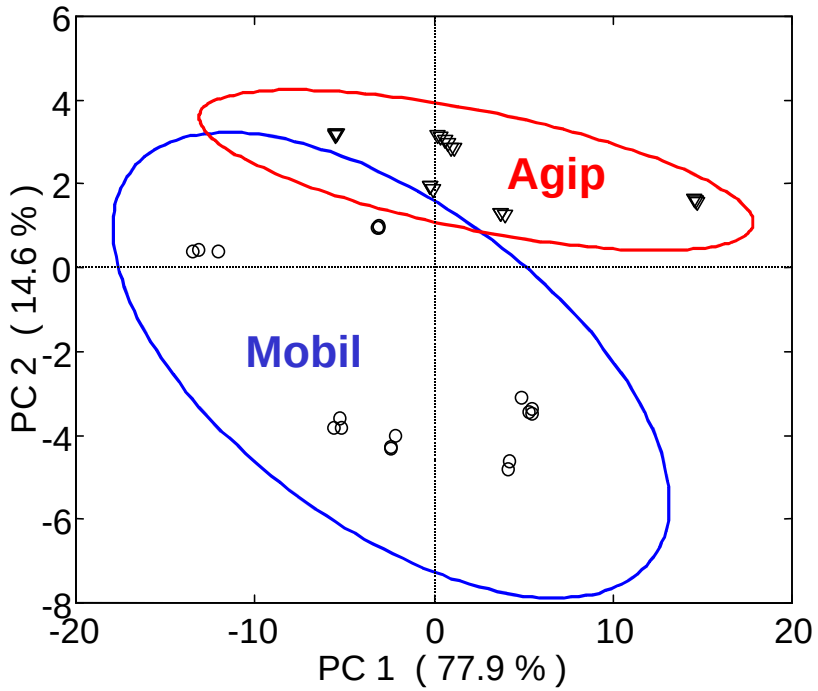


- 184 spectral data for each sample
- Multivariate data analysis (PCA-PLS) for dimensionality reduction and sample classification

Lubricant oils: Experimental results

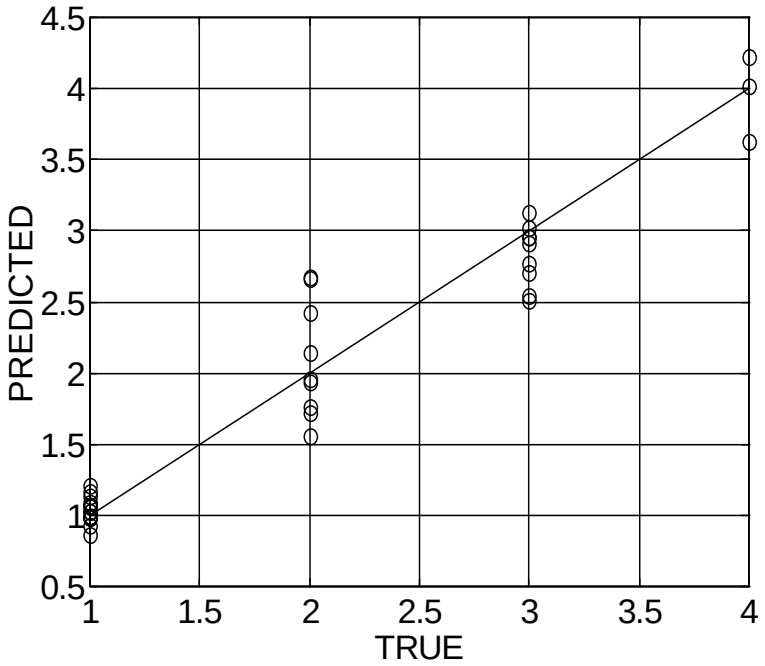
- Mobil Jet II polyester-synthetic oil from a gas turbine
- Agip OTE 46 mineral-paraffin oil from a steam turbine





Lubricant oils: Experimental results

Correlation between the spectral data and the chemical-physical status of the lubricant oil (score 1-4)



RMSECV = 0.35 R = 0.967

Outline

- **Optical fiber sensors: basics**
- **Colorimetry**
  - Absorption and reflection spectroscopy
    - Fiber optic spectrophotometers for general purpose applications – Direct / chemically-mediated
- **Scattered colorimetry**
  - Multi-λ and multi-α absorption spectroscopy
- **Hyperspectral colorimetry**
- **Fluorescence spectroscopy**

Hyperspectral colorimetry as an optical fingerprint - optical signature -

UV-VIS-NIR absorption spectroscopy
(200-1700 nm)

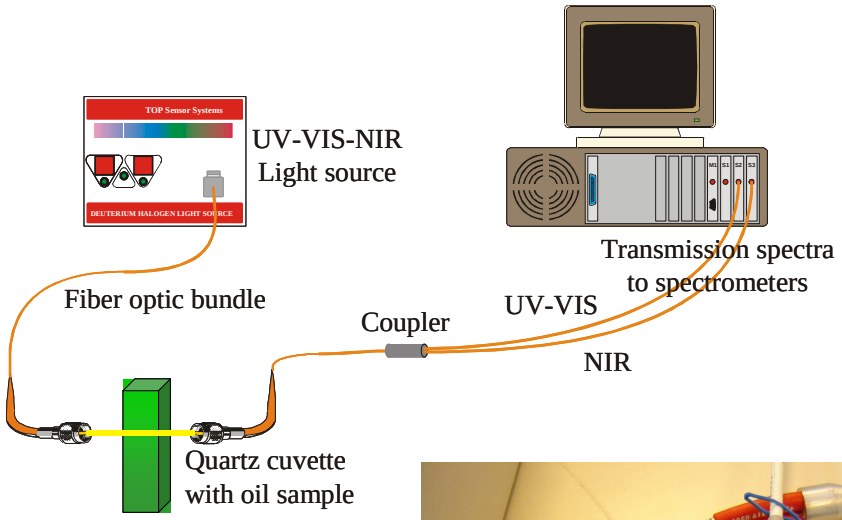
+

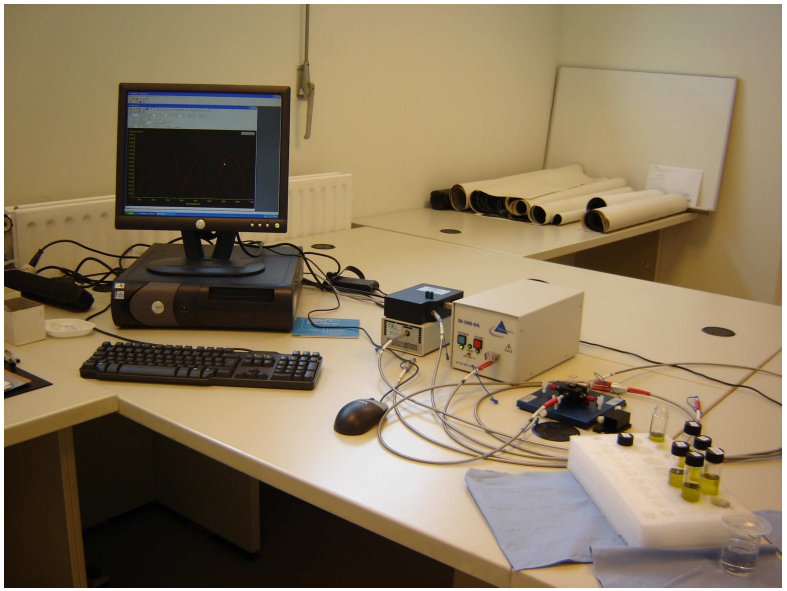
Multivariate data processing and classification
(PCA, LDA, PLS, KNN)

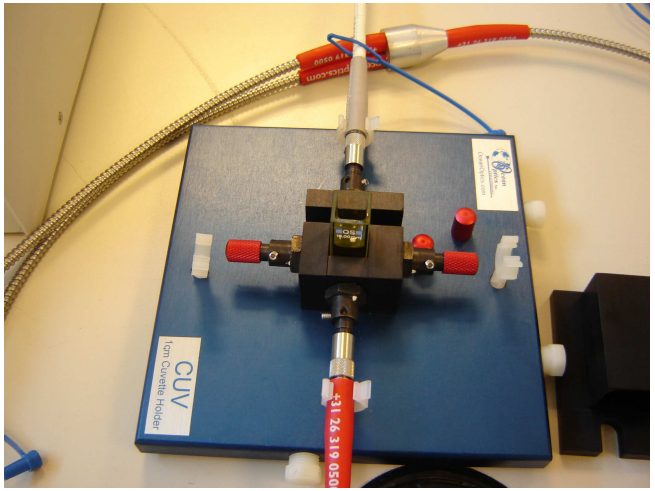
=

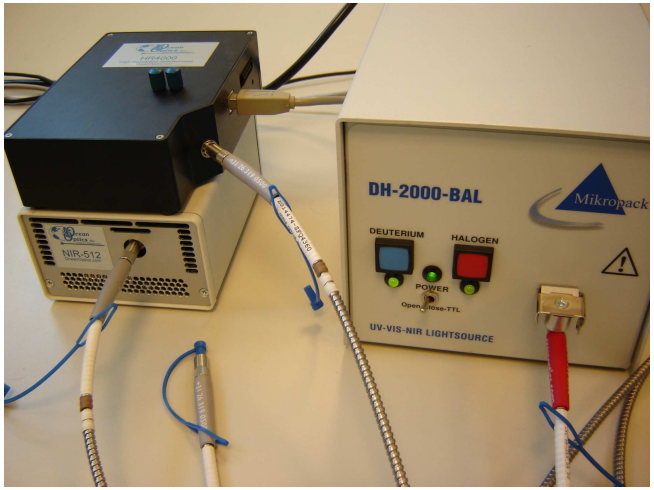
- 2D map clustering the oils according to similarities
- Correlation of optical parameters with chemical characteristics (fatty acid content)

The instrumentation for optical fingerprint







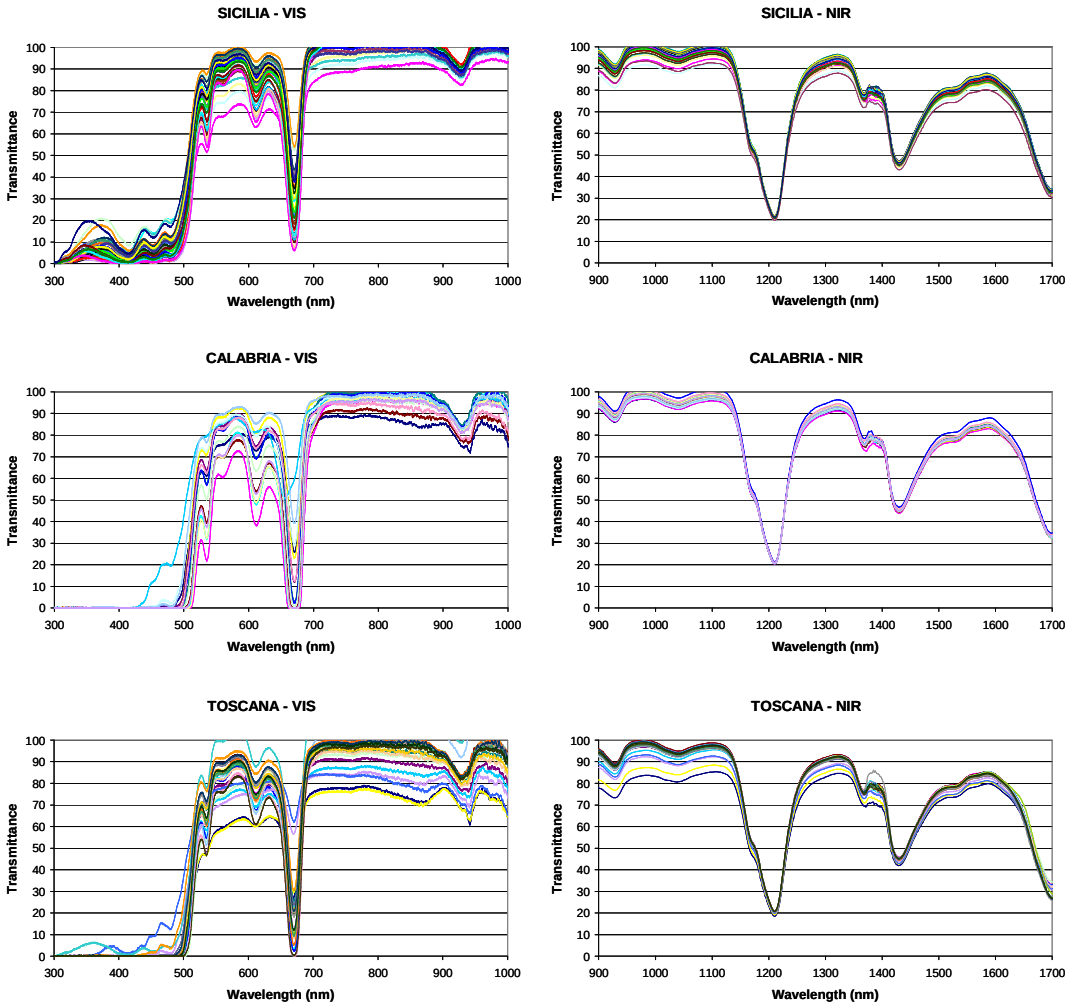


Extra virgin olive oils
- The library: 85 samples -

- 28 samples from Toscana
- 15 samples from Calabria
- 42 samples from Sicilia

- ✓ Different cultivar
- ✓ Different weather conditions
- ✓ Different harvesting time
- ✓ Different production systems
- ✓ All artesanally produced

The measured spectra
- The optical signature -

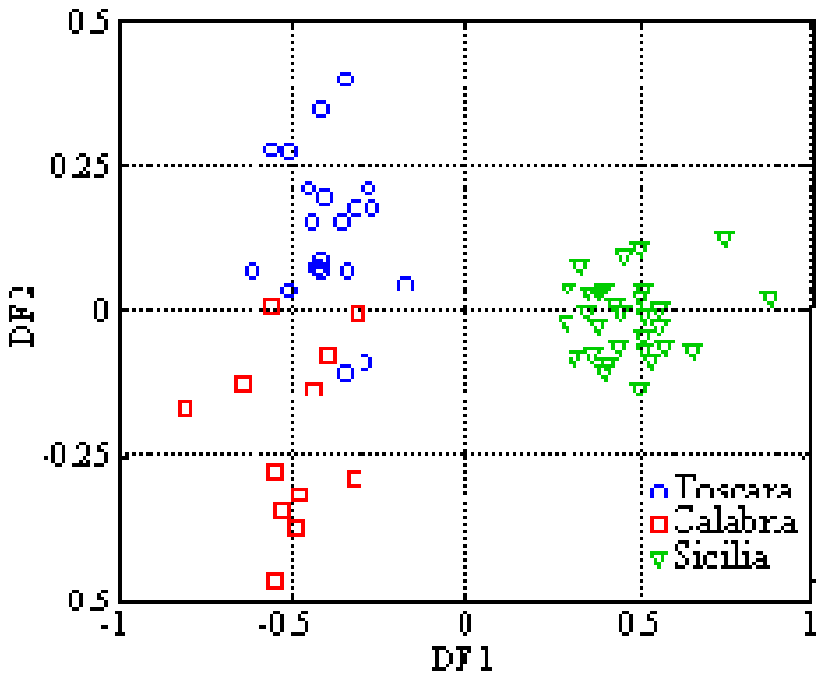


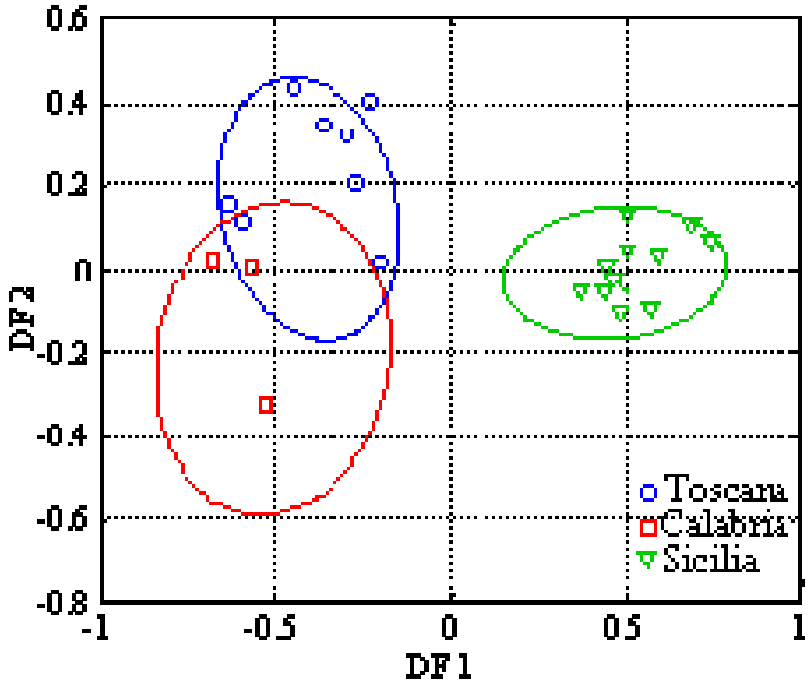
UV-VIS: 200-1100 nm
Dl: 0.23 nm

NIR: 900-1700 nm
Dl: 1.7 nm

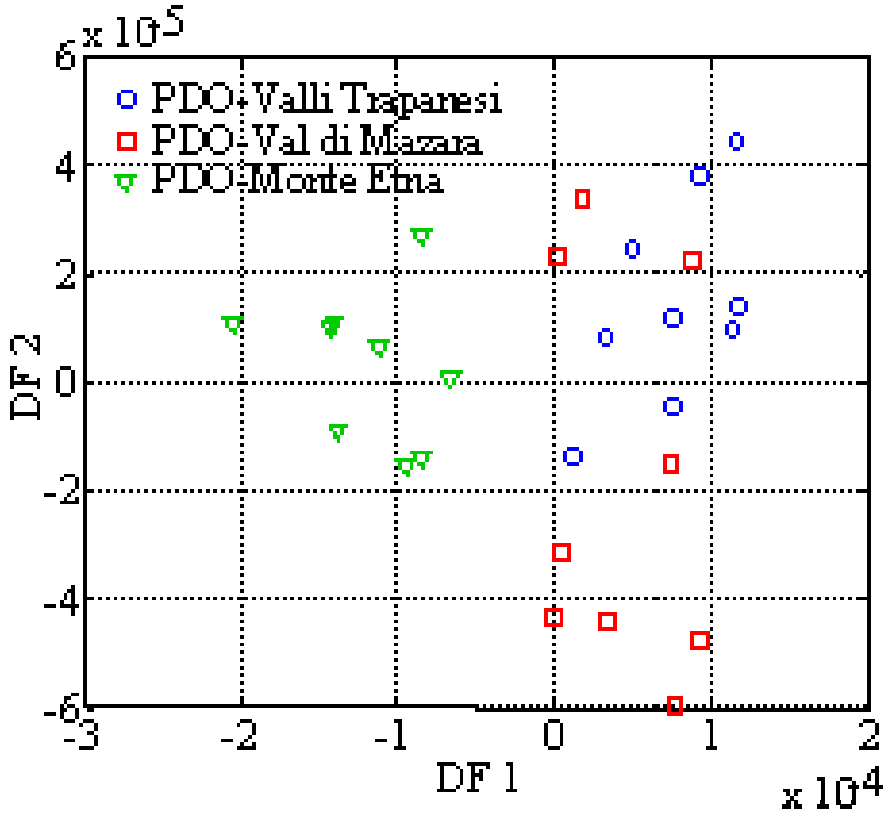
Each sample
4160 spectral data

Discrimination of extra virgin olive oils from Sicilia, Calabria, and Toscana

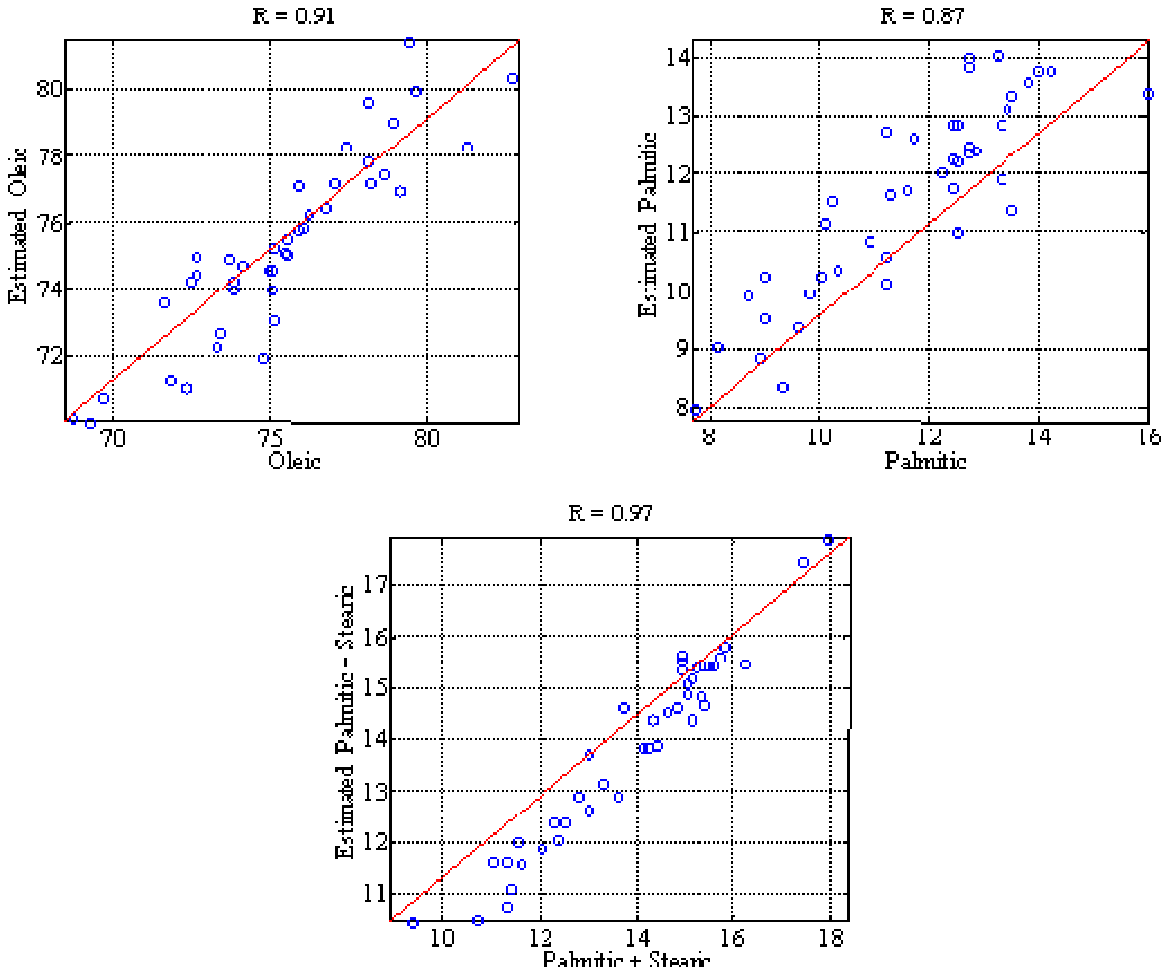




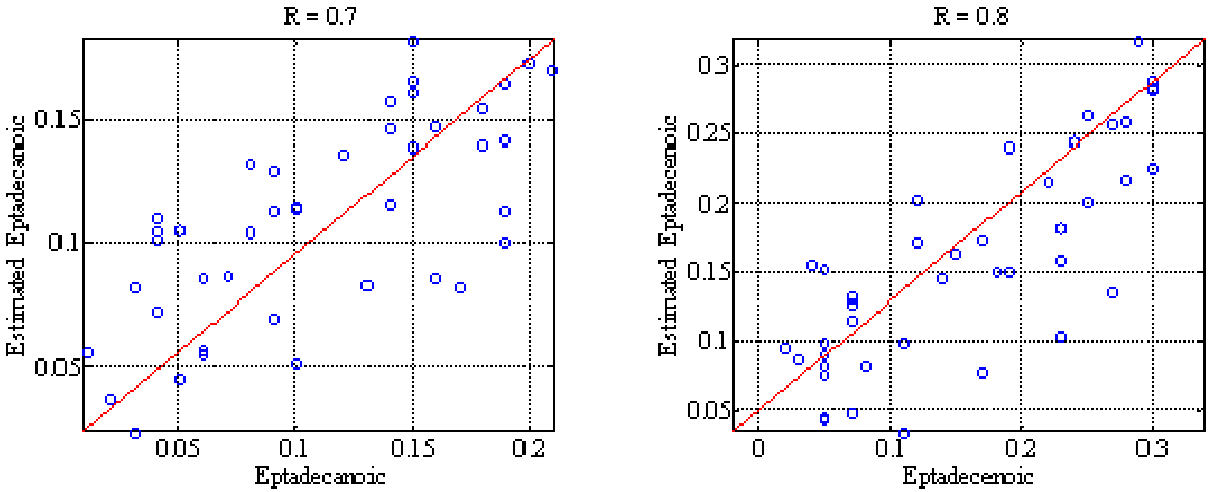
More thorough analysis of extra virgin olive oils from Sicilia: - Discrimination according to PDO -



More thorough analysis of extra virgin olive oils from Sicilia: - Spectral data and fatty acids -



More thorough analysis of extra virgin olive oils from Sicilia: - Spectral data and fatty acids -



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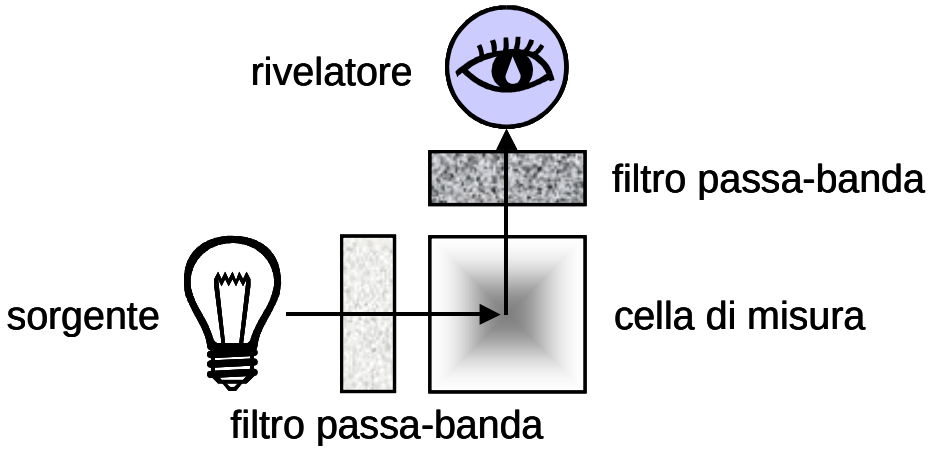
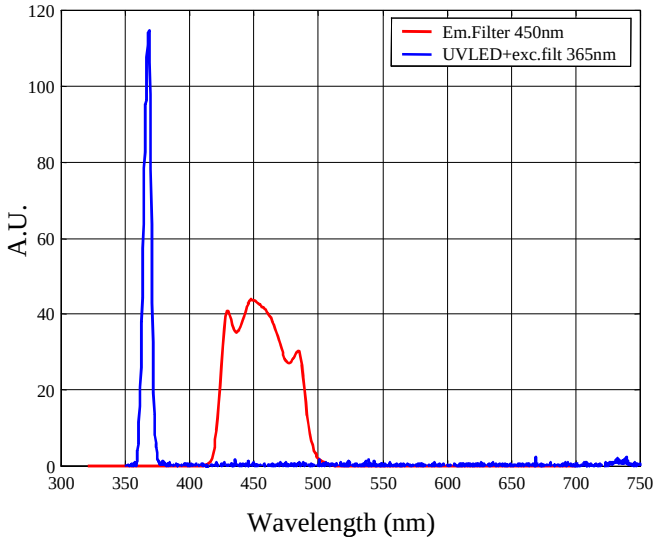
  - Multi-λ and multi-α absorption spectroscopy
- **Hyperspectral colorimetry**
- **Fluorescence spectroscopy**
  - **M1 aflatoxin monitoring**

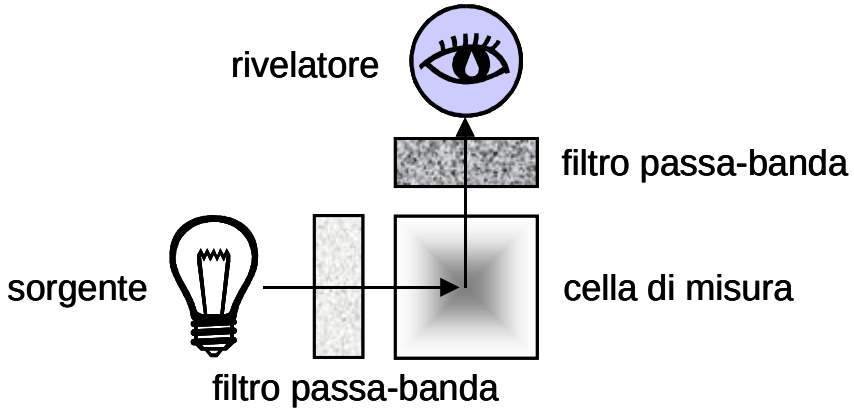
Fluorescence spectroscopy for M1 aflatoxin detection

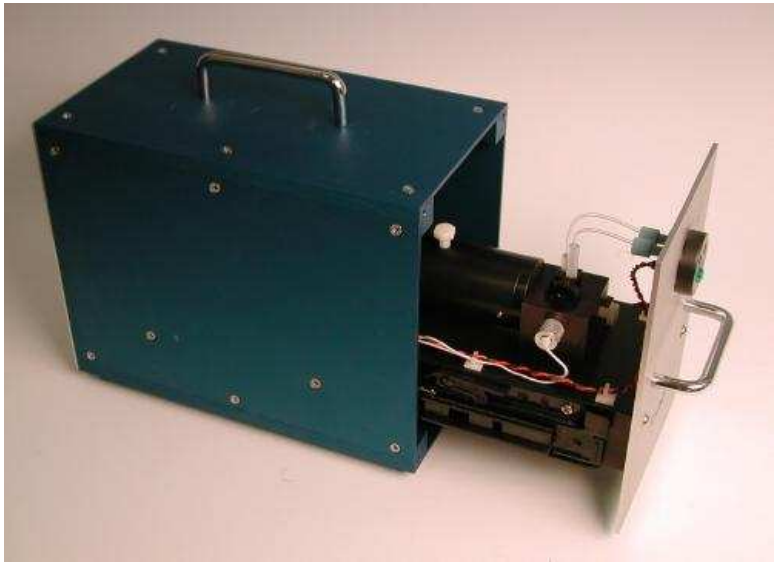
- LED: Roithner Lasertechnik, UVLED365-10 (l=365 nm) and high-sensitivity photomultiplier
- Band-pass filters
- Micro-cells

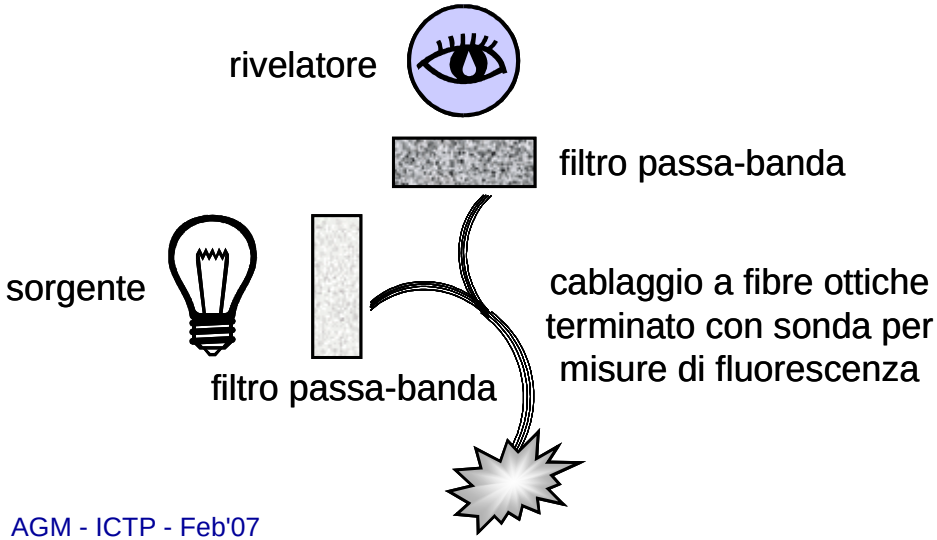


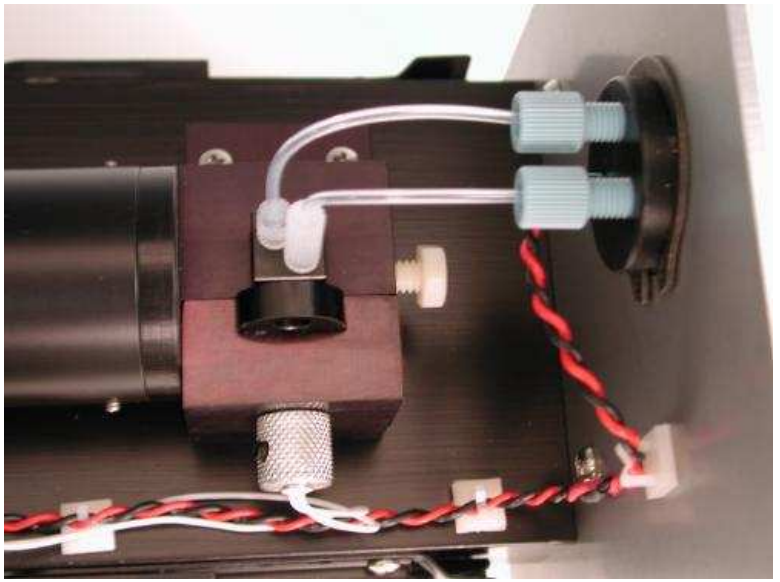


Fluorescence spectroscopy for M1 aflatoxin detection – the instrumentation

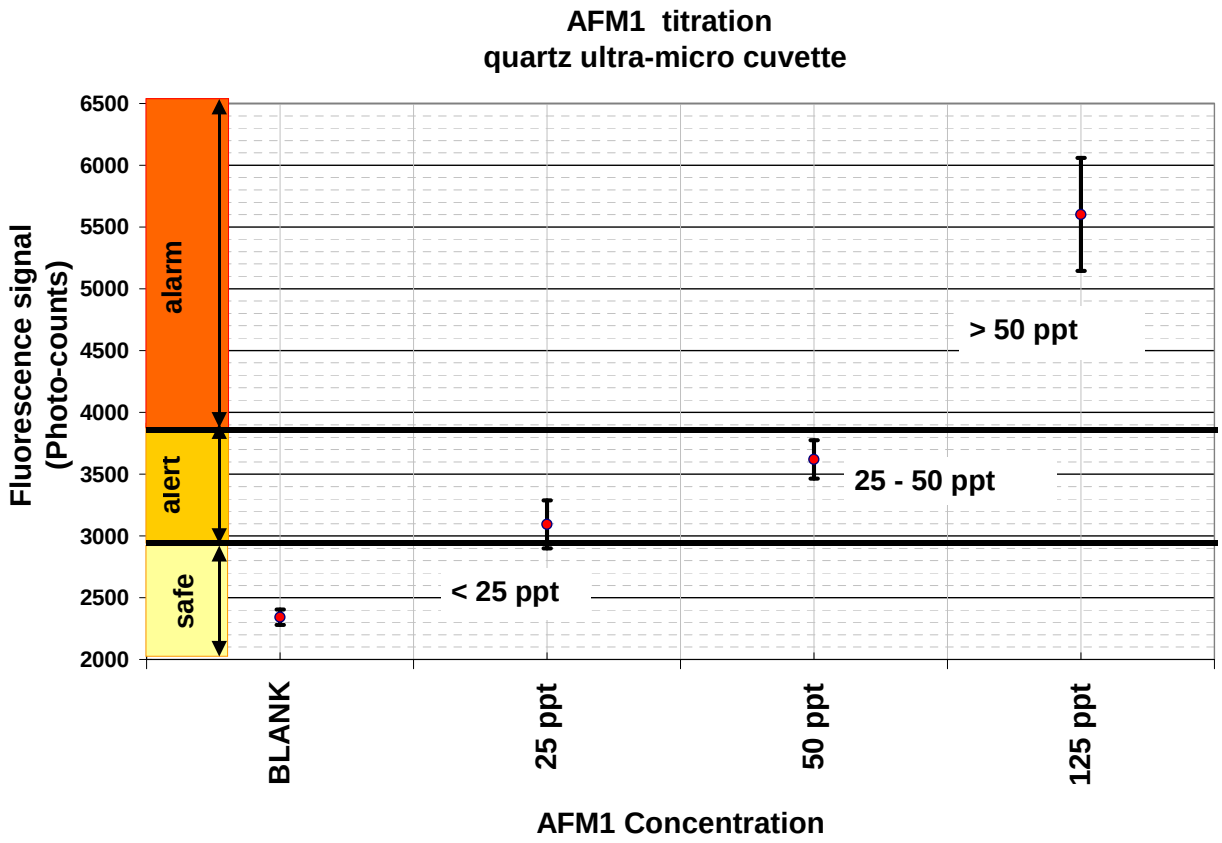




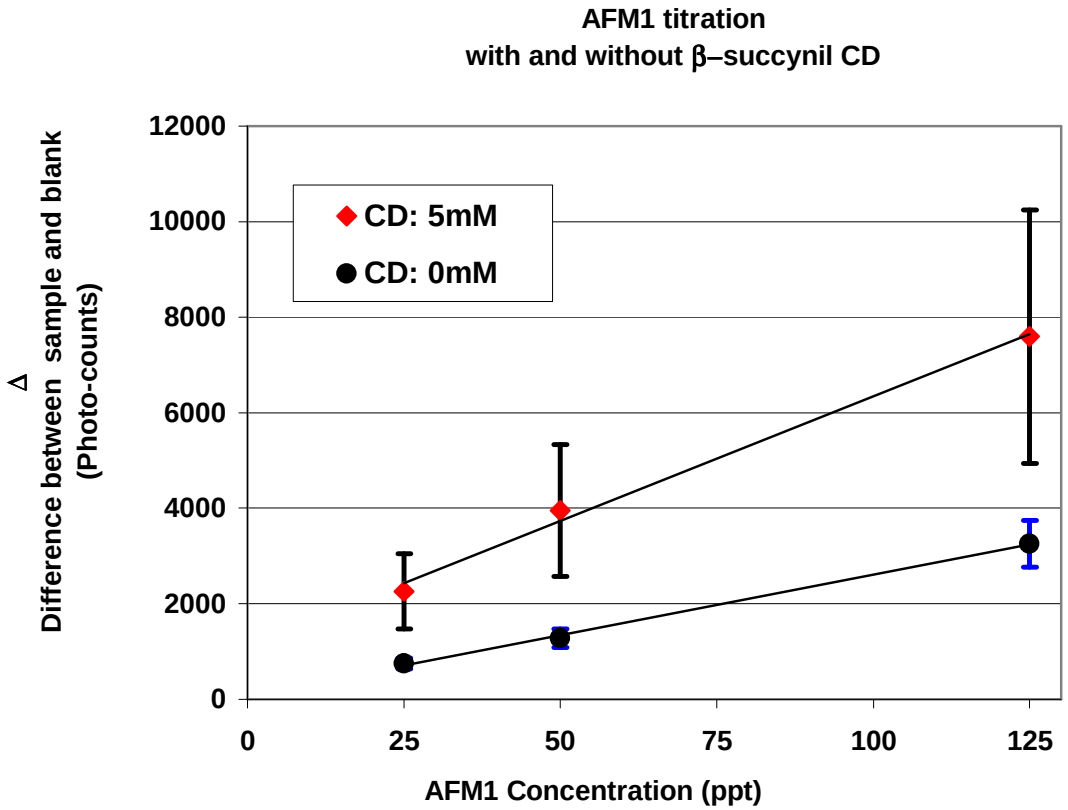




Fluorescence spectroscopy for M1 aflatoxin detection – the results



Fluorescence spectroscopy for M1 aflatoxin detection – the results



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- ✓ European Commission: ‘RAMFLAB’ project (contract #ERBIC18CT970171)
- ✓ European Commission: ‘OPTIMO’ project (contract #ERBIC18CT970171)
- ✓ European Commission: Network of Excellence on Micro-Optics
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