Compact Optical Spectroscopy: The Future of Food Analytics in Your Pocket

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shrinking, shrinking, shrinking
spectroscopy in wonderland

CNR – Institute of Applied Physics ‘Nello Carrara’

Sesto Fiorentino, Firenze – Italy http://www.ifac.cnr.it/

- Space, Aerospace and Earth Observation
- Health, Nanomedicine and Safety
- Environment and Food Quality
- Cultural heritage

Our main expertise from 2000

- Spectroscopy VIS+NIR
  - Absorption, reflection
  - Fluorescence
  - Raman @ 1064 nm
- Chemometrics - Multivariate data processing

Multi-analytics:

single spectroscopic measurement + math

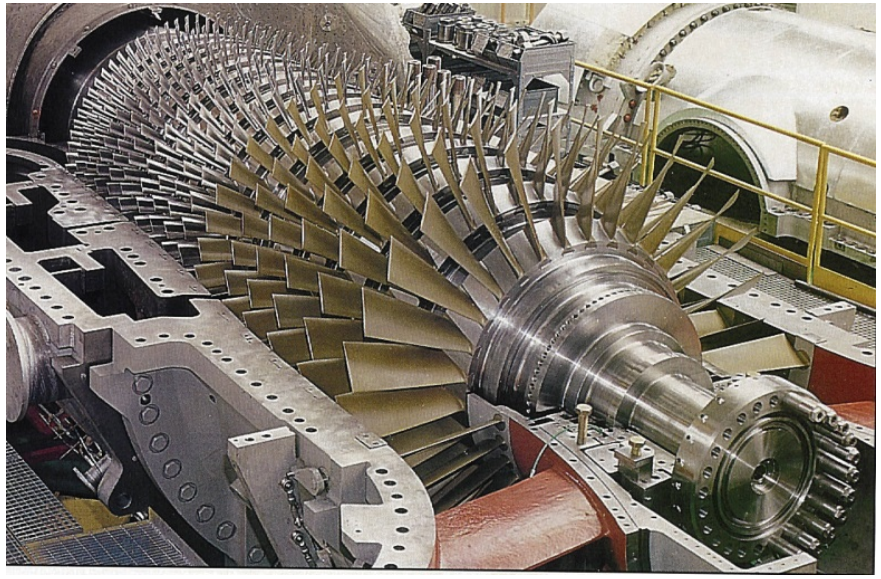
On-line absorption spectroscopy

water quality monitoring in recycling plants

Sensors&Actuators B, 2007, vol.121(1), p.231
SPIE Proc. 2000, vol.4185, p.444
SPIE Proc. 2004, vol.5459, p.281

On-line fluorescence spectroscopy

lubricant oil condition monitoring



IoP-MS&T, 2009, vol.20(3), p.34011
IoP-JMM 2010, vol.20, p.105018
IoP-MS&T 2016, vol.27, p.15004

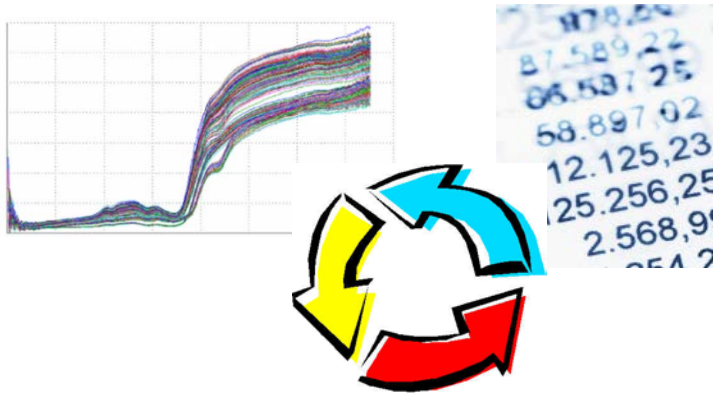
Colorimetry of Port wine

OPTIMO
Optical Technology for Intelligent Monitoring Online

Courtesy of Sandeman, Porto, Portugal

Probing food by light
optical spectroscopy – a photonic tasting

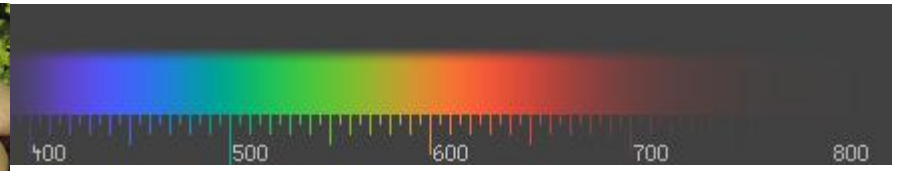
'green' analytical technique without chemicals and discharge



Shine light, get the spectrum, and use math:

- ✓ Multicomponent analysis
- ✓ Quality, authenticity & safety indicators

Spectroscopy & food



NIR

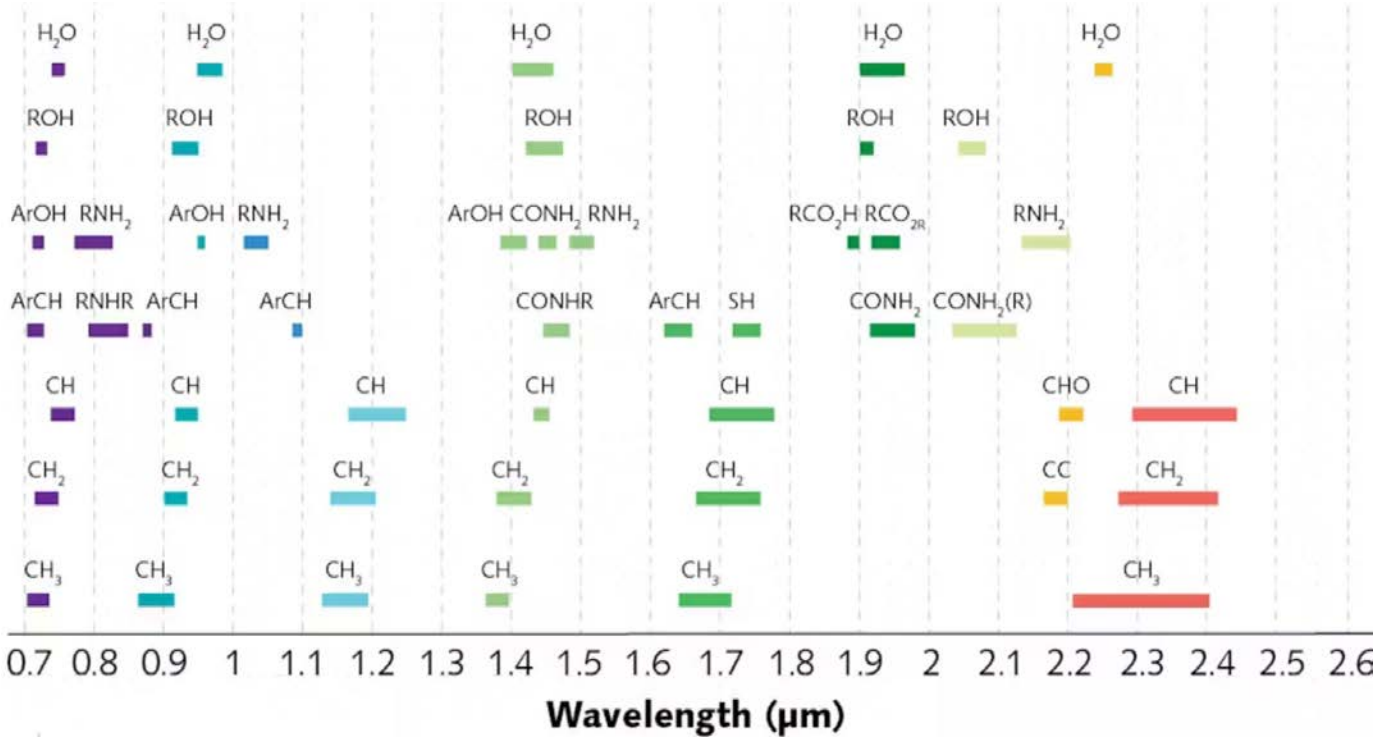
C-H O-H N-H
overtones/combinations

VIS: dyes-pigments

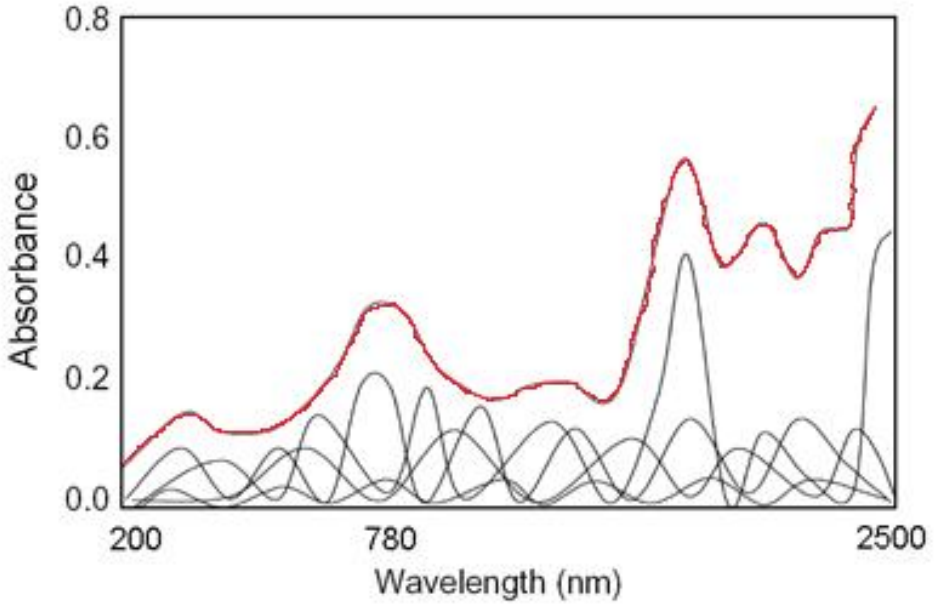
- Phenol derivatives
  flavonoids: 500, 545 nm
  b-cyanines: 480, 536 nm
- Carotenoids
  Carotene: 463 nm
  Lycopene: 473 nm
  Lutein: 445 nm
- Chlorophylls
  - A: 430, 662 nm
  - B: 453, 642 nm

Near Infrared up to 2500 nm

Proteins, Carbohydrates, Oils, Water, Cellulose, Sugars



VIS-NIR absorption spectroscopy

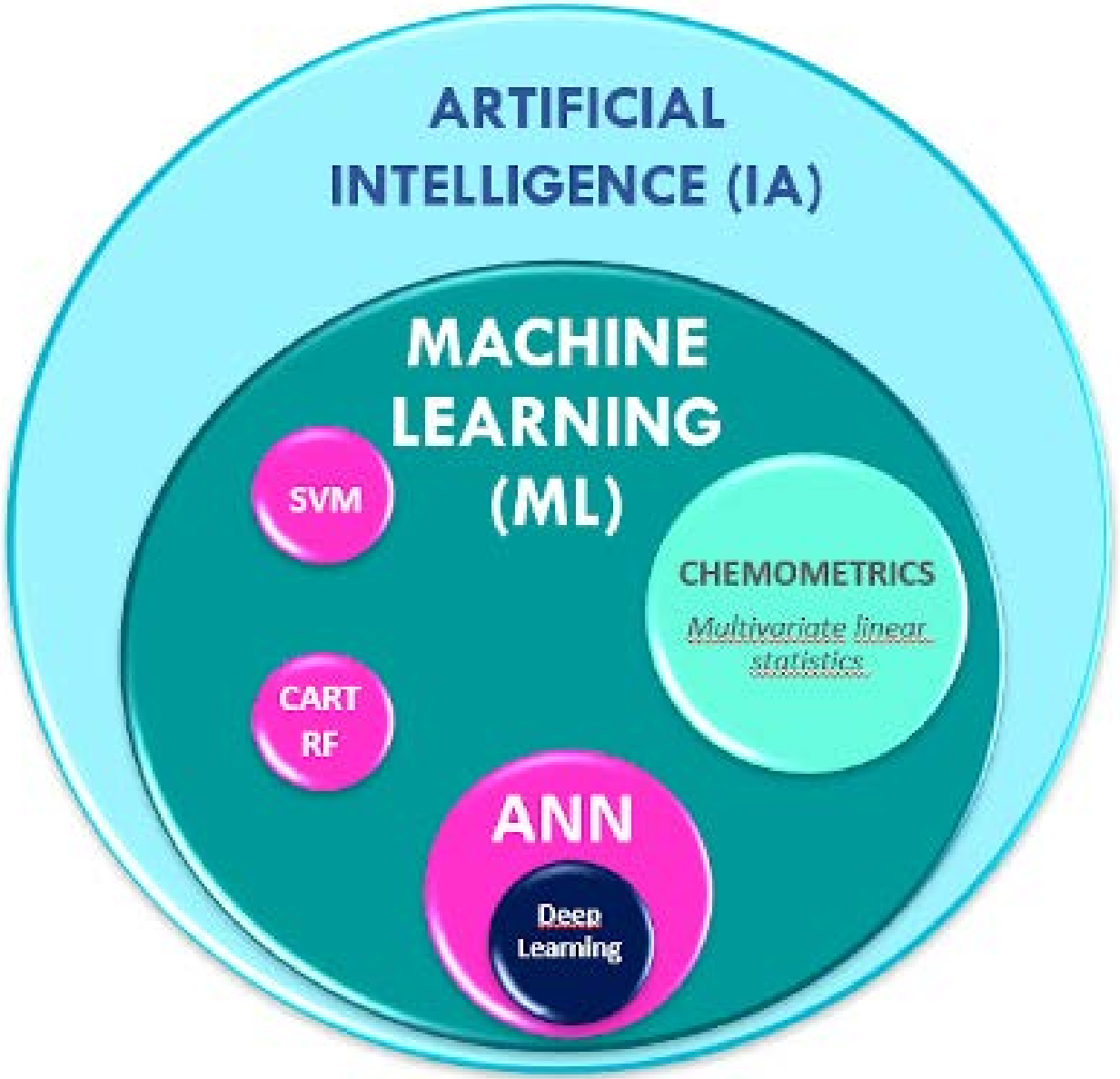


VIS-NIR spectrum – product signature/fingerprint

Lack of selectivity

https://onlinelibrary.wiley.com/doi/10.1002/9780470027318.a1018

Which Math ??

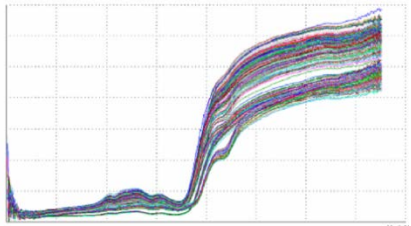

ARTIFICIAL INTELLIGENCE (IA)
MACHINE LEARNING (ML)
SVM
CART
RF
CHEMOMETRICS
Multivariate linear statistics
ANN
Deep Learning

Data processing by chemometrics

extraction of qualitative and quantitative info from spectra

Selected reference samples

Measured spectra

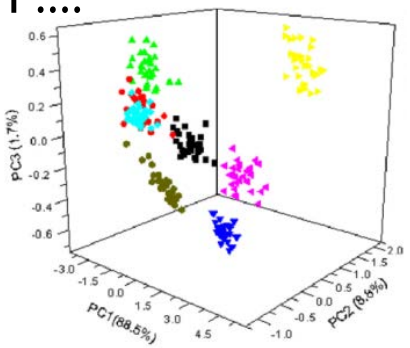


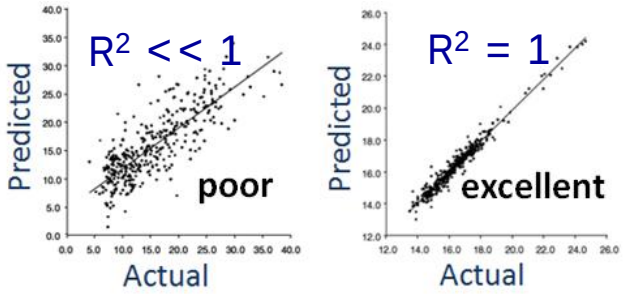
Analytical data

Qualitative:
class identification, thresholds, authentication ....

PROCESSING

Quantative:
concentration detection
multi-component analysis



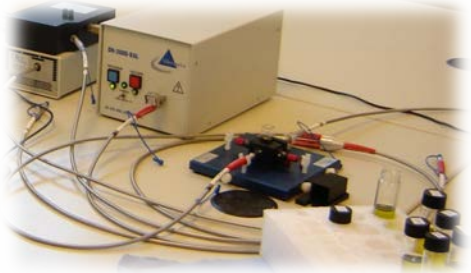


1) Data dimensionality reduction and clustering according to peculiar features

2) Calibration and predictive model building for evaluation of quality indicators

3) Validation

The route of spectroscopy



>2000

>2010

spectrometers in wonderland:
shrinking, shrinking, shrinking

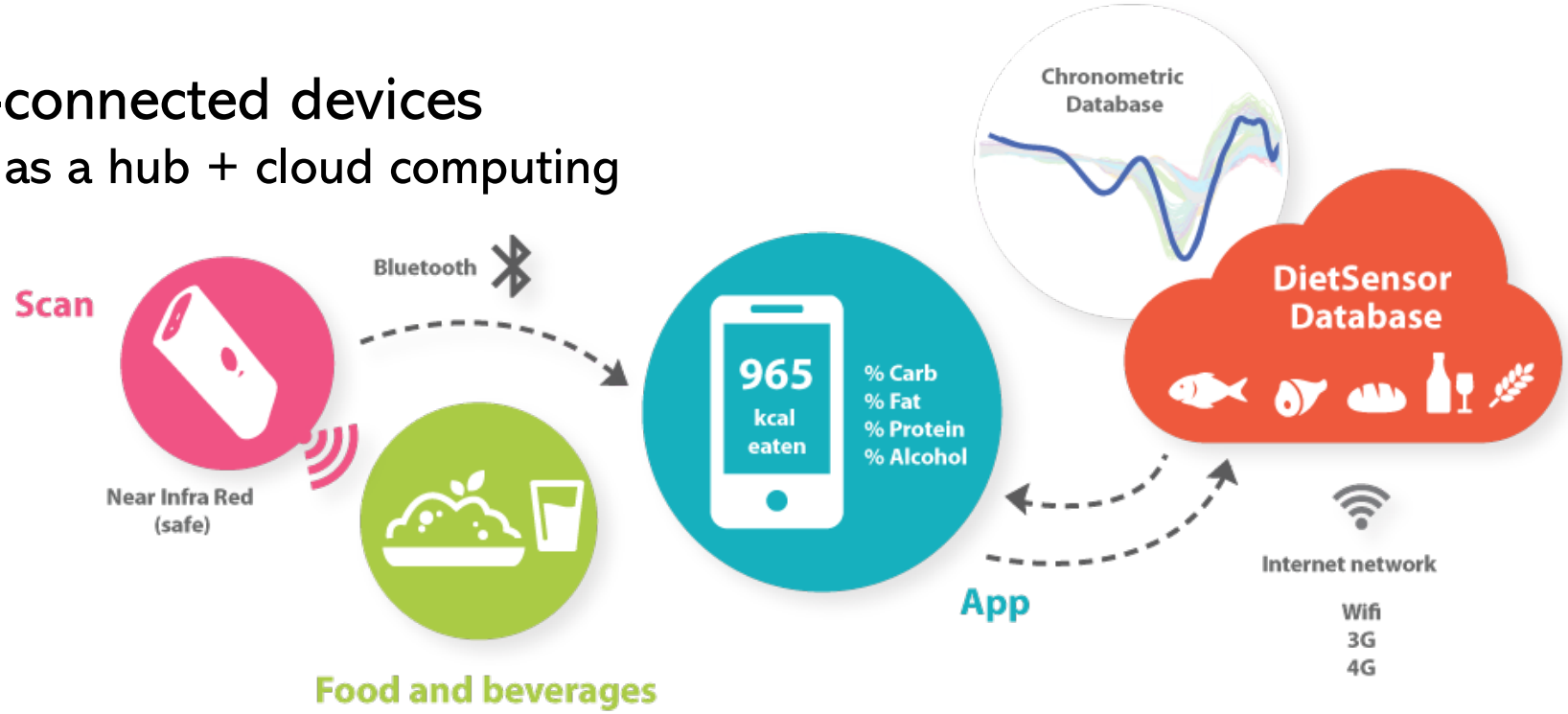
SCOPUS: near infrared spectroscopy (title)
17789 records
17563 from 1990
8790 from 2015

https://www.spectroscopyonline.com/view/spectrometers-in-wonderland-shrinking-shrinking-shrinking

Smartphone
?? an analytical lab in everyone's pocket ??

- Camera+light: poor spectroscopic resolution
- Clip-on gratings, covers: not practical – phone models change
- ?? THE FUTURE AHEAD - spectrometers integrated into smartphones as an additional camera ??

- Bluetooth-connected devices
  smartphone as a hub + cloud computing

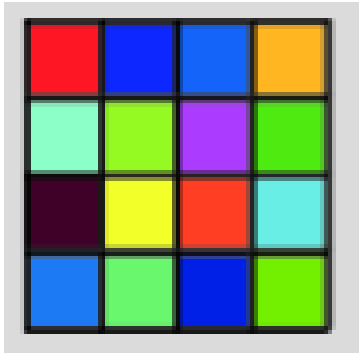


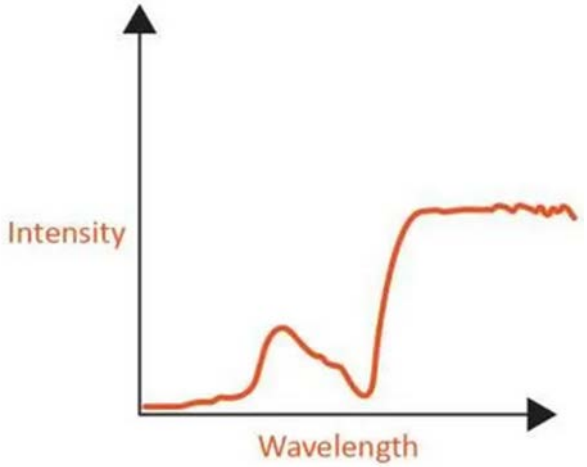
Many pocket-sized spectrometers available
OEM and turn-key

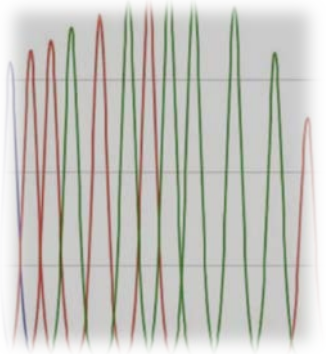
- Ams-OSRAM: https://ams.com/en/as7421#tab/description
- TrinamiX: https://trinamixsensing.com/
- Tellspec: https://tellspec.com/
- Si-Ware NeoSpectra: https://www.si-ware.com/
- Spectral engines: https://spectralengines.com/
- AB Vista: https://www.abvista.com/
- Viavi: https://www.viavisolutions.com/pt-br/node/122119
- Hamamatsu: https://www.hamamatsu.com/us/en/product/optical-sensors/spectrometers/mini-spectrometer.html
- Avantes: https://www.avantes.com/
- Ocean Optics: https://www.oceanoptics.com/
- BaySpec: https://www.bayspec.com/
- Texas Instruments DLP-NIRScan: https://www.ti.com/lit/ug/dlpu030g/dlpu030g.pdf
- …….. Many more
- ..... Review NIR spectroscopy: https://dl.acm.org/doi/10.1145/3652596
- ..... Review food spectroscopy: https://www.mdpi.com/2304-8158/13/21/3501
- SCiO: https://www.scionir.com/
- SpectraPod: https://mantispectra.com/

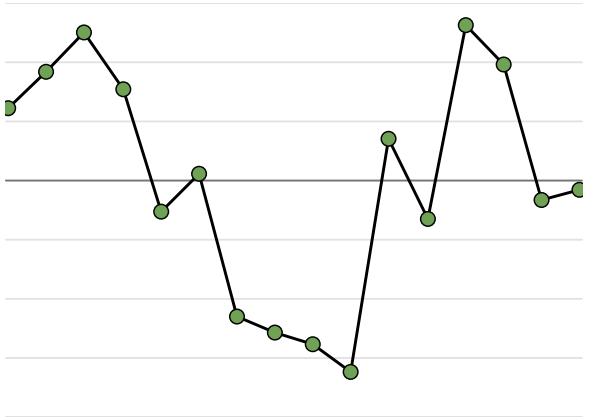
Spectroscopy by multi-spectral sensing

- from dispersive gratings to filters -









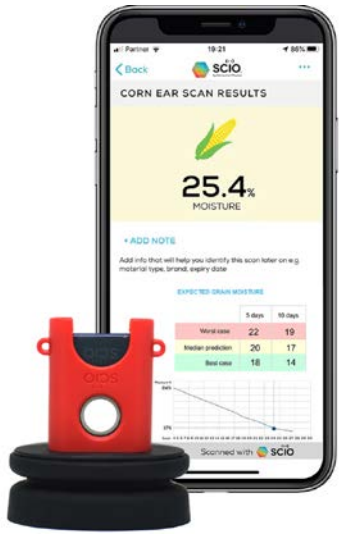
SCiO – 740-1070nm 12 channels

https://www.scionir.com/ (formerly http://www.consumerphysics.com)

https://learn.sparkfun.com/tutorials/scio-pocket-molecular-scanner-teardown-/all

SCiO Apps available

https://www.scionir.com/ (formerly https://shop.consumerphysics.com/)



SCiO most recent literature

- Beer fermentation: https://www.sciencedirect.com/science/article/pii/S1386142524012927
- Honey: https://www.sciencedirect.com/science/article/pii/S0308814624003613
- Cheese: https://www.journalofdairyscience.org/article/S0022-0302(24)00031-6/fulltext
- Milk: https://www.sciencedirect.com/science/article/pii/S0022030224000316
- Coffee: https://www.mdpi.com/2227-9717/11/4/1140
- Fish: https://www.sciencedirect.com/science/article/pii/S2352513423004015
- Meat: https://pubmed.ncbi.nlm.nih.gov/20416766/
- Ham: https://pmc.ncbi.nlm.nih.gov/articles/PMC10825327/
- Halal meat authenticity: https://edepot.wur.nl/544019
- Flour: https://www.nature.com/articles/s41598-024-67299-w

…. >130 records in Scopus

SCiO for olive oil applications – motivation

Olive growing in Tuscany – frame (2022 data)

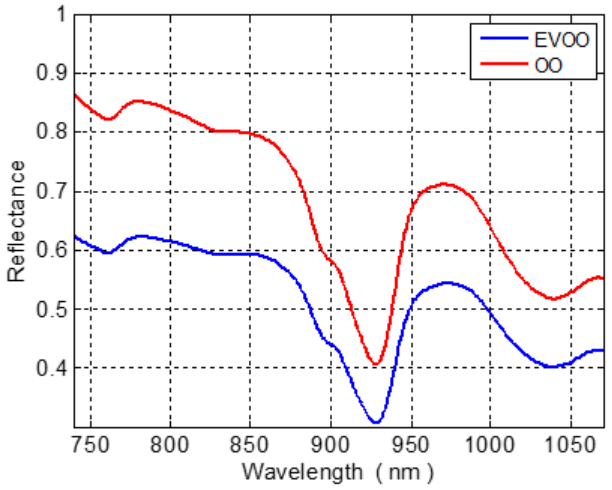
https://www.regione.toscana.it/produzioni-vegetali/olio-di-oliva

- 15 Million plants – 80 varieties
- 36.000 farms, most of them SME or family-based
- 400 mills
- 150.000 quintals of olive oil (7% of Italy)
- 5 DOP / PGI

SCiO for olive oil

116 samples:

80 EVOO, 36 OO (including pomace and lampante)

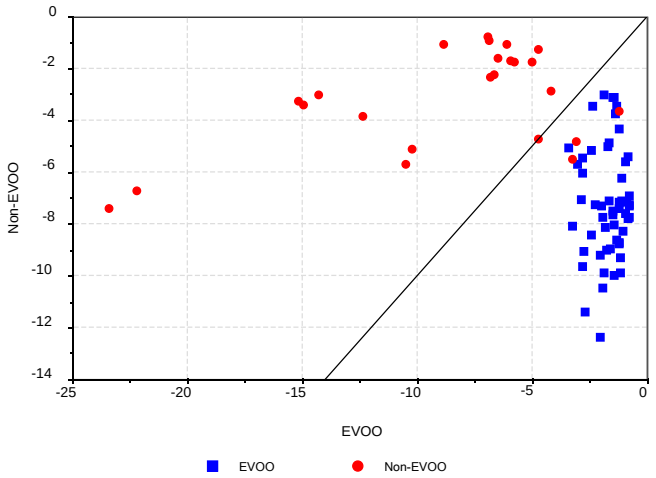


https://doi.org/10.3390/foods11152265

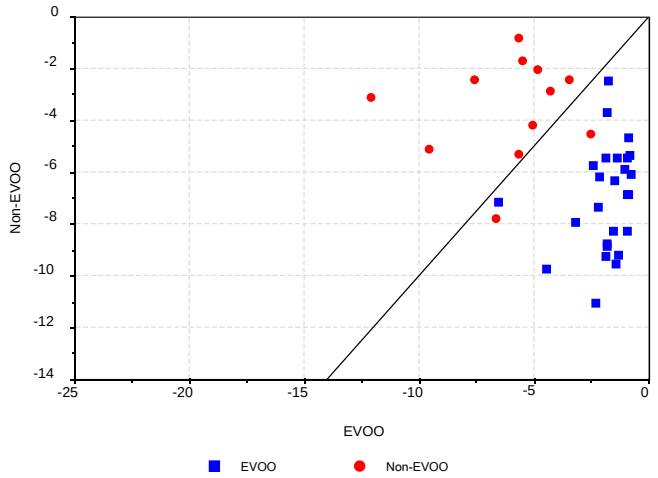
SCiO for olive oil EVOO vs OO

chemometric processing of spec data

Calibration set



Validation set



Training set: 78 samples (54 EVOO, 24 OO)

Accuracy = 96%

Sensitivity = 100%

Specificity = 88%

Training	Actual	
Predicted	EVOO	Non-EVOO
EVOO	54	3
Non-EVOO	0	21

Test set: 38 samples (26 EVOO, 12 OO)

Accuracy = 95%

Sensitivity = 100%

Specificity = 83%

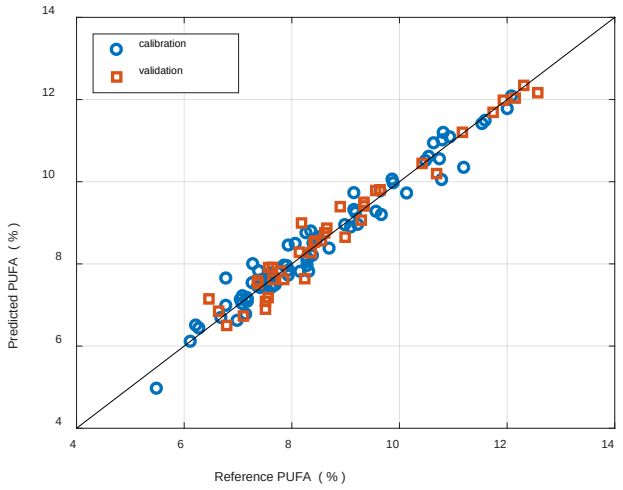
Test	Actual	
Predicted	EVOO	Non-EVOO
EVOO	38	2
Non-EVOO	0	10

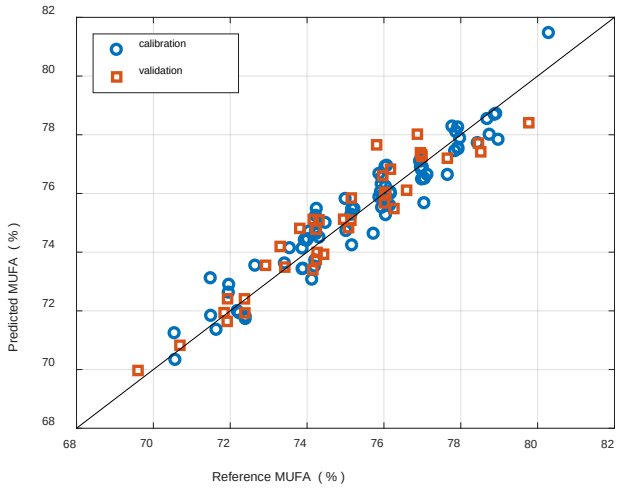
SCiO for olive oil – multi-analysis

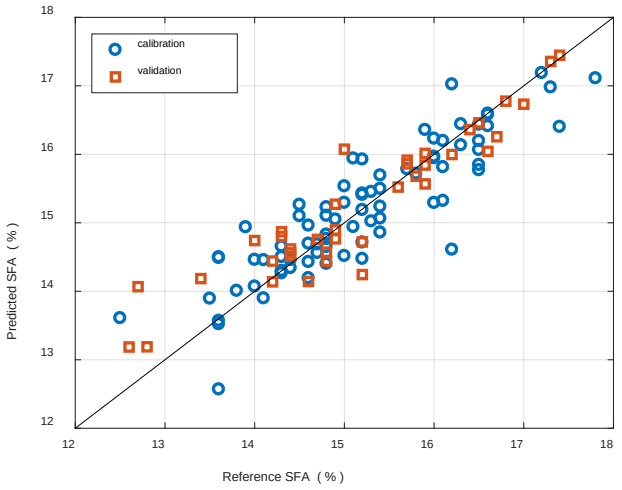
labelling nutraceutic indicators (fatty acids)

PUFA: linoleic (w3) + linolenic (w6) MUFA: oleic (w9) + palmitoleic

SFA: palmitic + stearic

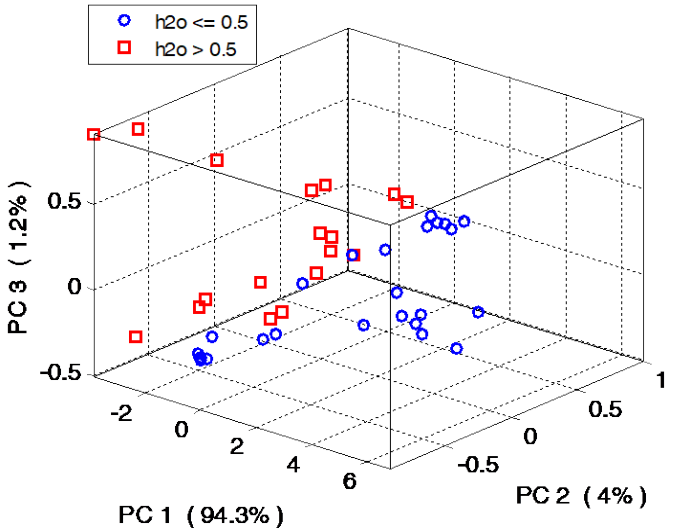


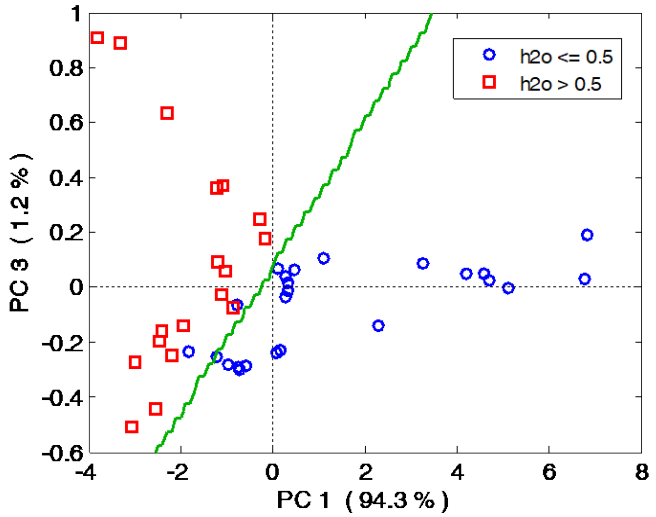




		SFA	MUFA	PUFA
Calibration	RMSECV	0.51%	0.74%	0.37%
	R^2 (cal.)	**0.780**	**0.895**	**0.950**
Validation	RMSEP	0.55%	0.74%	0.39%
	R^2 (val.)	**0.764**	**0.872**	**0.921**

SCiO for olive oil – %water in oil
threshold 0.5% v/v

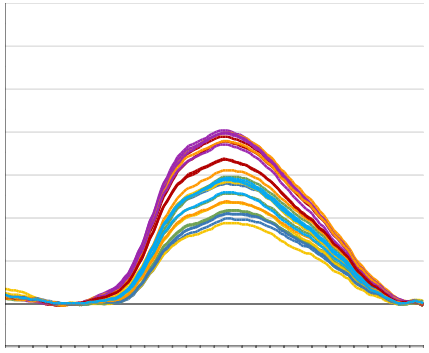


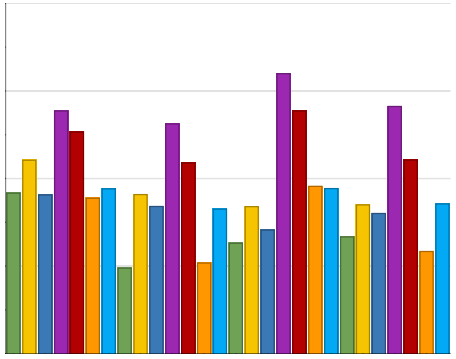


LDA accuracy & confusion matrix			
PC used:	3	**Accuracy:**	93%
	Actual class →	H_2O <= 0.5	H_2O > 0.5
Predicted Class	H_2O <= 0.5	21	0
	H_2O > 0.5	3	18

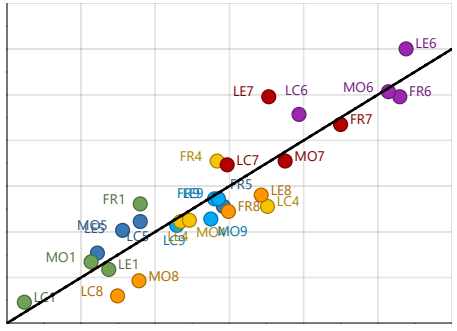
https://doi.org/10.1117/12.2540041

SCiO for plant analytics
mesuring the water stress of olive trees

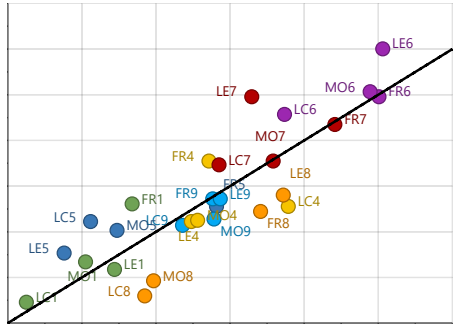




Observed vs. Predicted (Calibration)



Observed vs. Predicted (Cross-validation)



OPLS Regression Statistics		
LV	Number of OPLS components: predicting + orthogonal	1 + 2
R^2	Determination coefficient of calibration	0.844
Q^2	Determination coefficient of cross-validation	0.723
RMSEC (mg/Kg)	Root Mean Square Error of Calibration	1.2
RMSECV (mg/Kg)	Root Mean Square Error of Cross-Validation	1.5

https://spie.org/photonics-west/presentation/Near-infrared-spectroscopy-for-olive-cultivation--tracking-water-content/13357-22

SCiO for plant analytics
to be – measuring the effect of watering

SCiO for plant health assessment

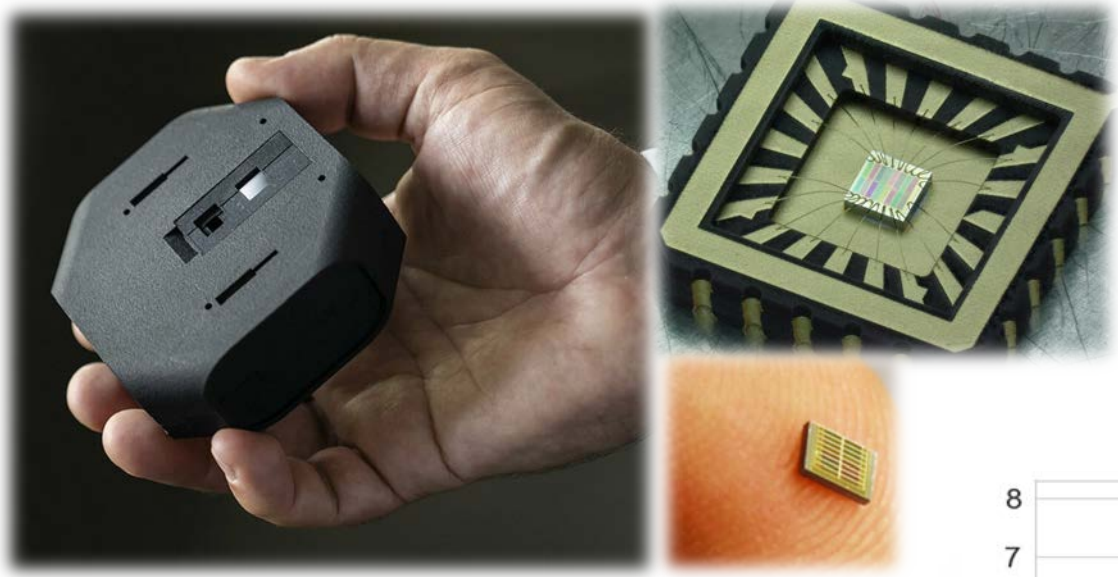
non-destructive assessment of plant infection by fungi – in progress

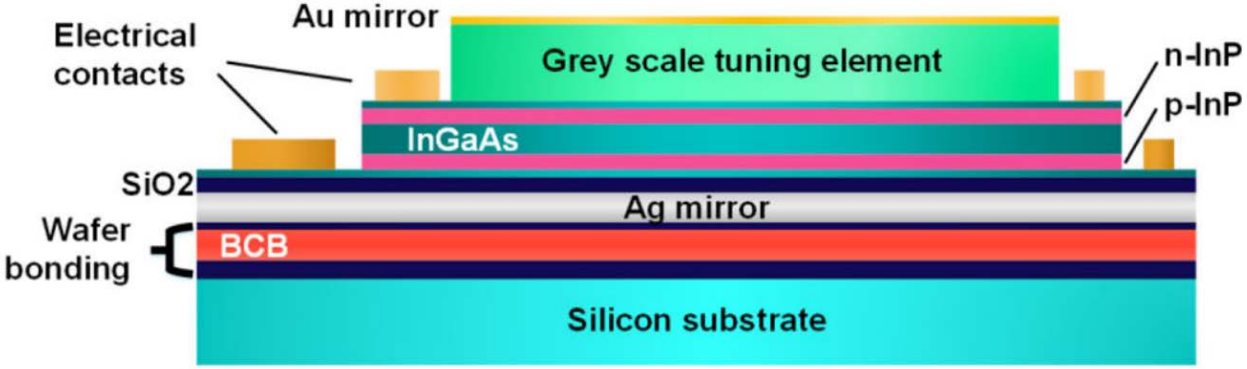
Data Processing in progress
Expected overall accuracy 87-90%

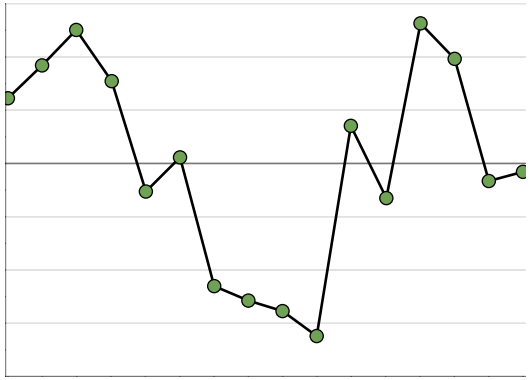
Nature Comm. 2022, 13:103
APL Photon. 22023, 8:041302

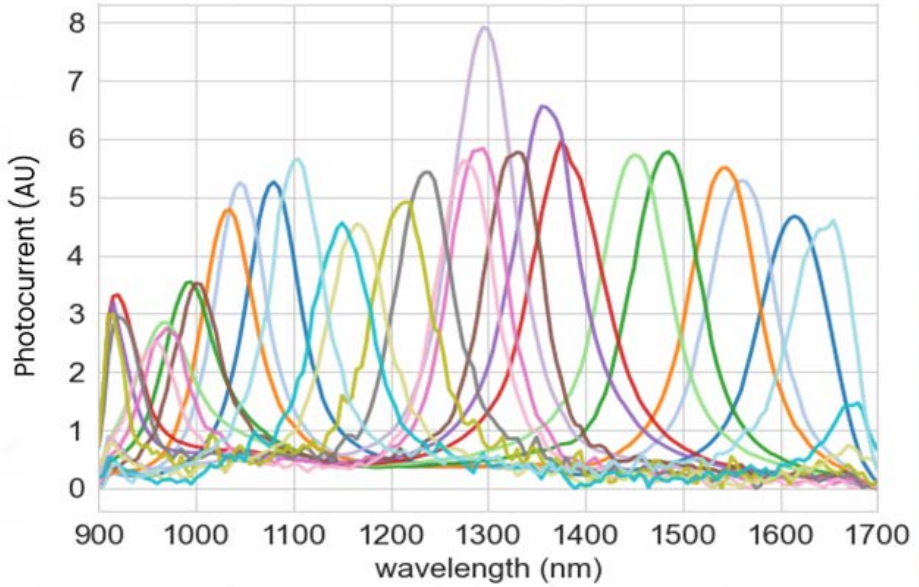
SpectraPod – 850-1700nm 16 channels

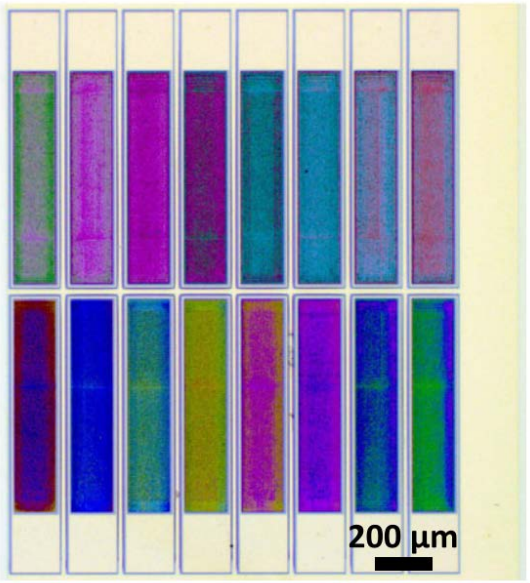
https://www.mantispectra.com/





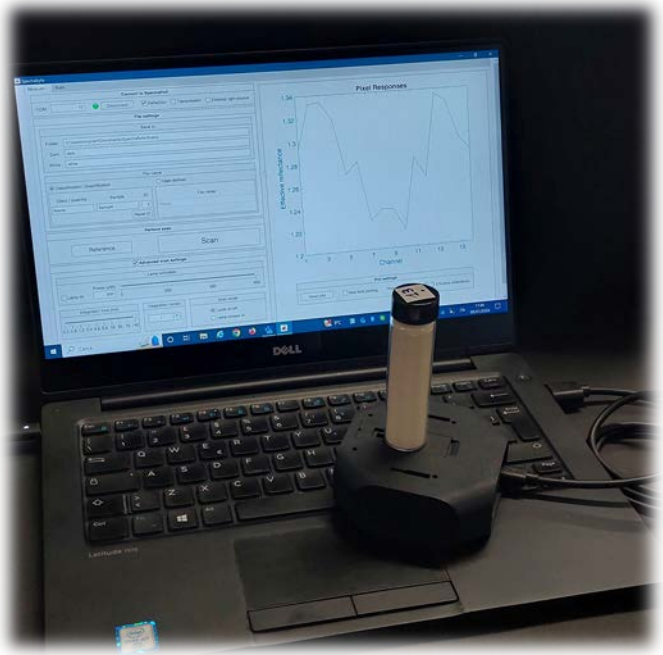


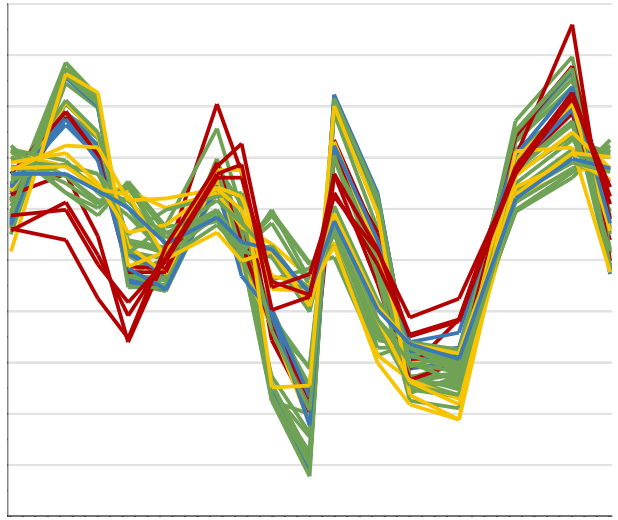




SpectraPod for flours

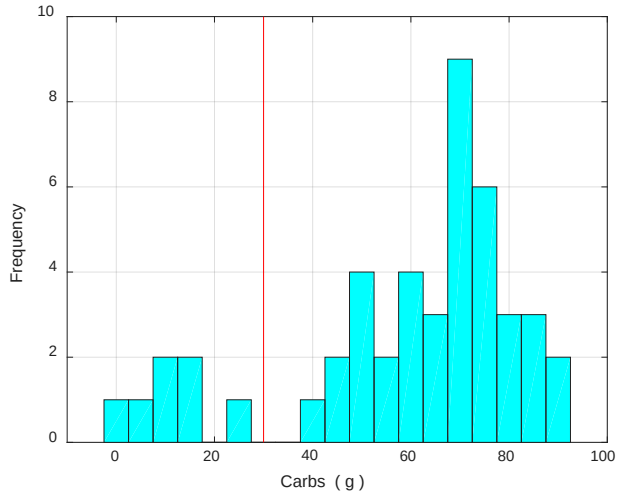
cereals, legumes, tubers, others

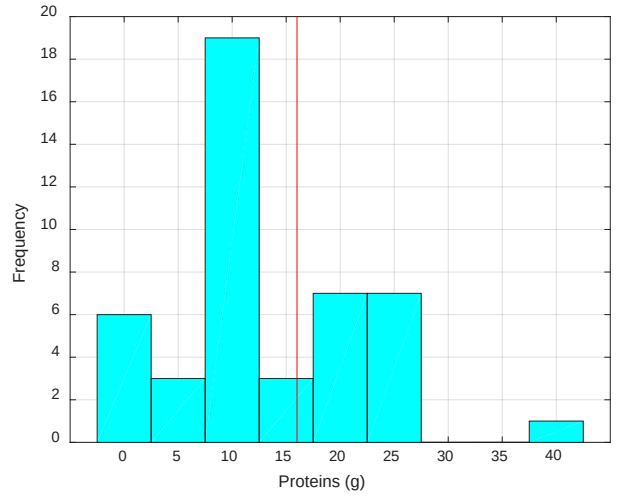


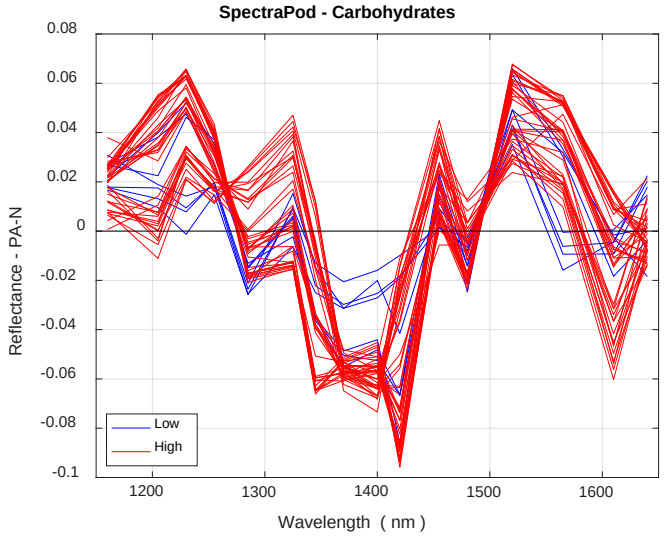


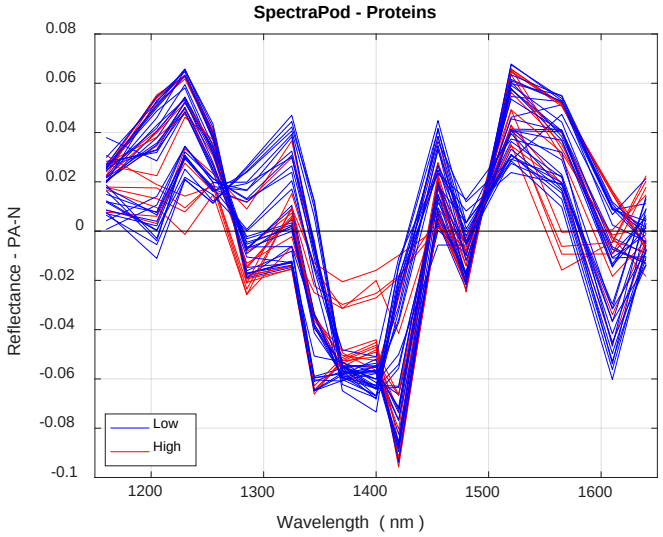
SpectraPod for flours

cereals, legumes, tubers, others





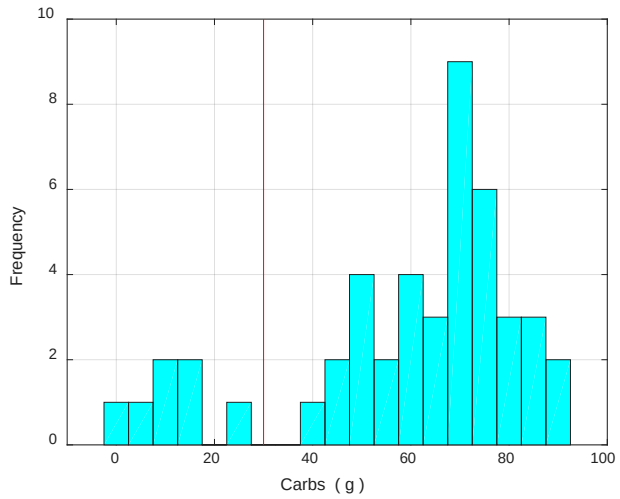


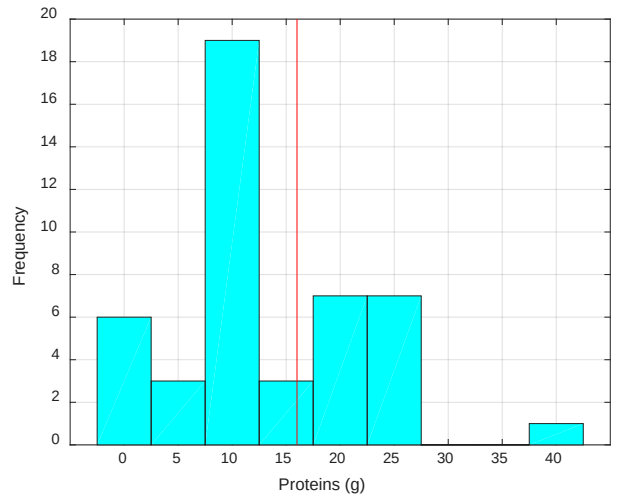


https://doi.org/10.1117/12.3021793

SpectraPod for flours

cereals, legumes, tubers, others





Carbs confusion matrix			
Predicted class		Low	High
True class	Low	4	3
	High	0	39

Predictors: PC2-PC3
Accuracy : 93.5%
False-High: 11, 24, 26
False-Low: none

Prots confusion matrix			
Predicted class		Low	High
True class	Low	27	4
	High	4	11

Predictors: PC2-PC3
Accuracy : 82.6%
False-High: 4, 6, 23, 36
False-Low: 12, 14, 35, 43

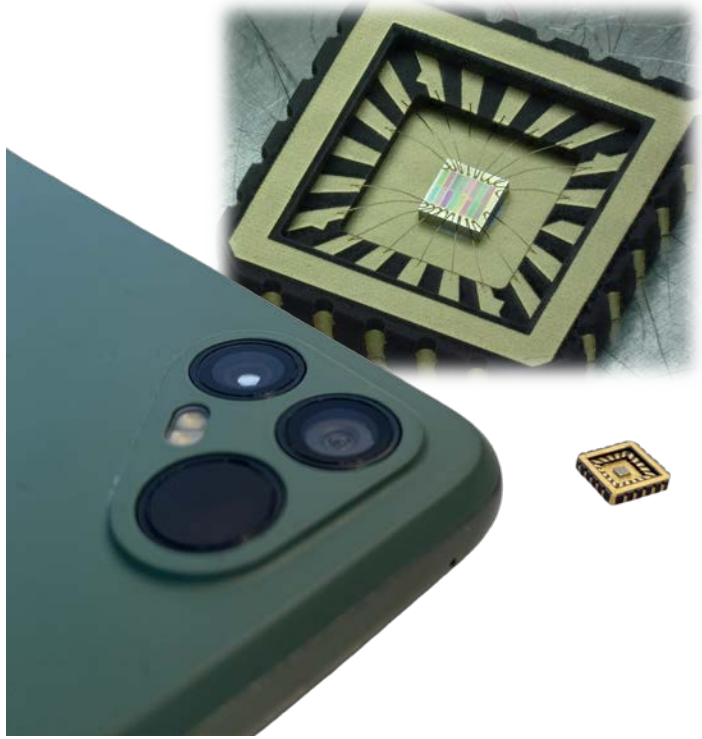
https://doi.org/10.1117/12.3021793

Smartphone-integrated SpectraPod
@ SPIE-Photonics West 2025

Protoype – Stellarnet: https://www.stellarnet.us/
Contact: David Parrino, DParrino@StellarNet.us

Concepts of smartphone-integrated spectroscopy

https://spectrum.ieee.org/israeli-startup-consumer-physics-says-its-scio-food-analyzer-is-finally-ready-for-prime-timeso-we-took-it-grocery-shopping
https://www.youtube.com/watch?v=CPPfatkXx74



https://epic-photonics.com/wp-content/uploads/2022/09/Kaylee-Hakkel-Mantispectra.pdf

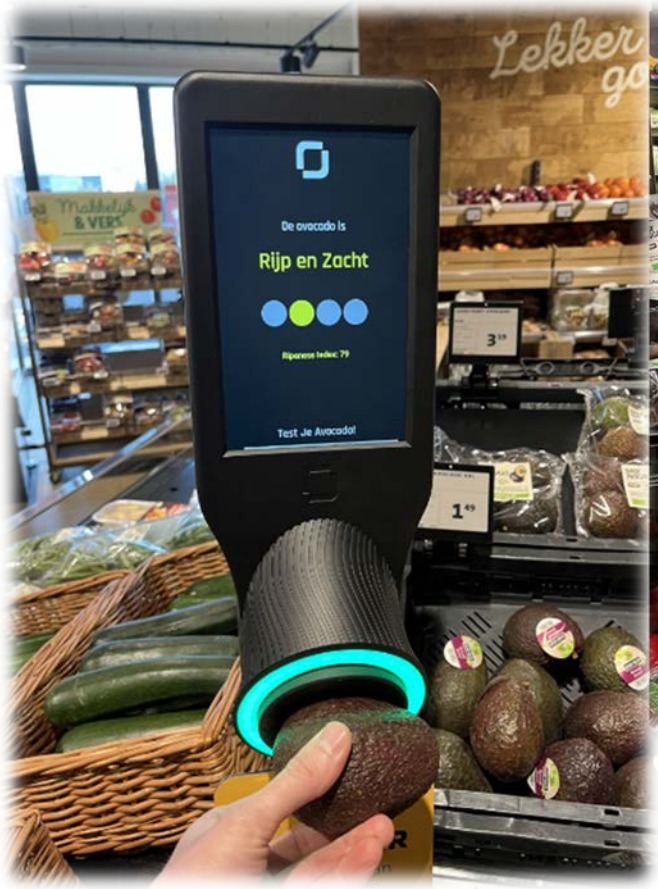
https://trinamixsensing.com/consumer-spectroscopy/consumer-spectroscopy-overview/

Consumer electronics is pushing the development of miniaturized spectral sensors

https://mantispectra.com/

http://koreabizwire.com/from-ai-to-iot-home-appliances-get-tech-treatment/99404

Consumer electronics already available



https://onethird.io/

Consumer electronics already available @ SPIE-Photonics West 2025

Protoype – BaySpec: https://www.bayspec.com/

Contact: William Yang, Wyang@bayspec.com

Combining robotics and spectroscopy for Agriculture 5.0

Free initial assessment by top experts for European companies

Strongly

SUBSIDISED PROJECTS

TRL 3-4: PROTOTYPE LEVEL

Small-Medium Enterprises (SMEs):
First €30k of innovation project budget fully subsidised;
75% of total budget subsidised thereafter*

Large-Scale Companies (LSCs):
50% of total budget subsidised*

* Up to a maximum subsidised amount of €100k per prototyping project.

Illustrative examples:	Total innovation project budget		Subsidised for company		Cash contribution of company
SMEs	€ 50k	▷	€ 45k	✚	€ 5k
	€ 100k	▷	€ 82.5k	✚	€ 17.5k
LSCs	€ 50k	▷	€ 25k	✚	€ 25k
	€ 100k	▷	€ 50k	✚	€ 50k

TRL 5-6: UPSCALING LEVEL

SMEs: 85% of total budget subsidised**

LSCs: 50% of total budget subsidised**

** Up to a maximum subsidised amount of €250k per upscaling project.

Illustrative examples:	Total innovation project budget		Subsidised for company		Cash contribution of company
SMEs	€ 100k	▷	€ 85k	✚	€ 15k
	€ 220k	▷	€ 187k	✚	€ 33k
LSCs	€ 100k	▷	€ 50k	✚	€ 50k
	€ 220k	▷	€ 110k	✚	€ 110k

CUSTOMISED BENEFITS TO YOUR COMPANY

ONE-STOP-SHOP
Full supply chain of cutting-edge photonics platforms

TOP EXPERTS
We select the partners that can best serve your technology needs

SEAMLESS SUPPORT
All the way from concept to manufacturing (TLR3-8) through multiple follow-on projects

CONCRETE RESULT
TRL advancement of 1 to 2 TRL levels

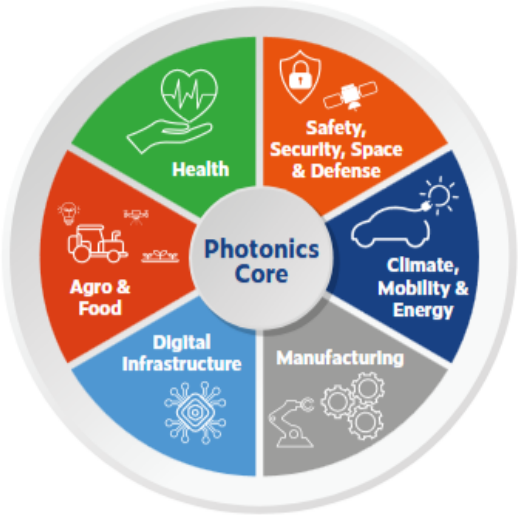
FASTER TO MARKET
Duration of project: 6-9 months

BUSINESS ACCELERATION
Customised business and IP coaching to support strategic development

SCALING FOCUS
Scaling Club dedicated to guidance on upscaling

GET STARTED!
PHOTONHUB.EU

Photonics
Driving innovation across all industry domains



Start your photonics innovation journey with our support

PhotonHub™ Europe

Version: Autumn 2024

Thank you !!

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