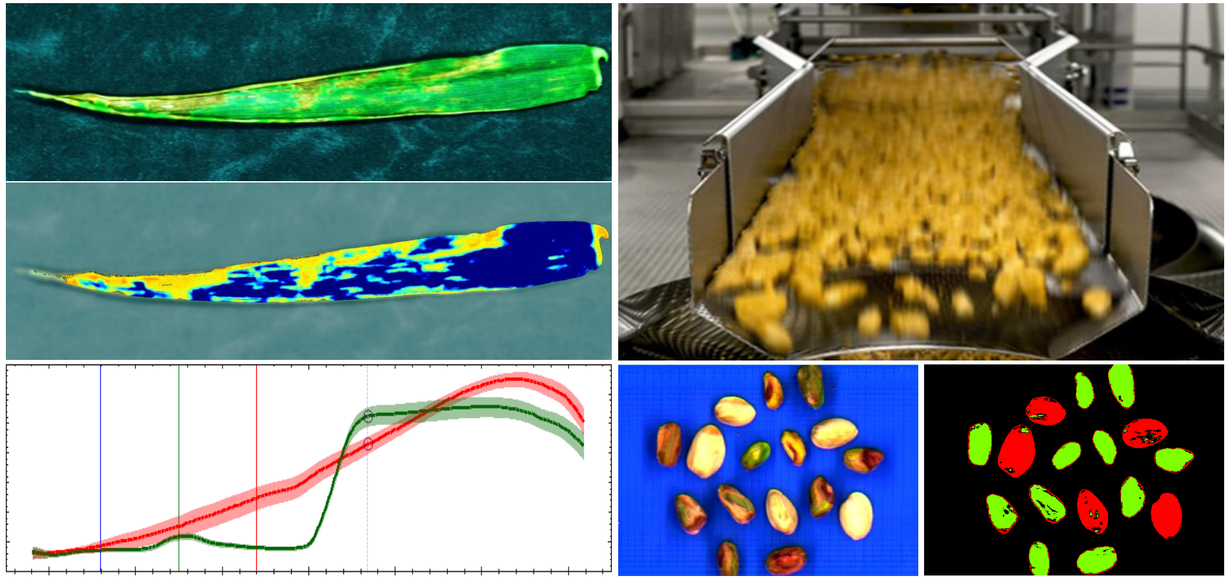
EPIC Technology Meeting on Photonics for the AgriFood Industry
Enlightening the Future at DigiFoods
24-25 April 2024 ; Oslo, Norway

Advances in AgriFood-Relevant Photonics Solutions

A Focus on Spectral Imaging



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Photonics in the AgriFood Market

Photonics are key technologies for the modernization of agriculture and the food industry

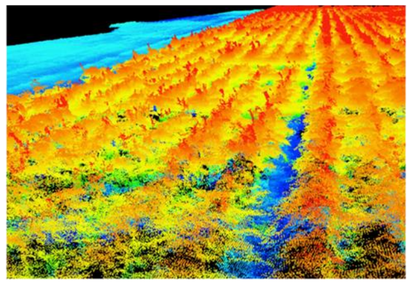
→ non-destructive, contactless, polyvalent (in terms of both gathered information and integration)

Photonics in agriculture

A technological revolution already initiated several decades ago.

→ non-invasive, harmless, fast, allows avoiding lab costs

- **Lighting systems** for optimized plant growth in vertical farming
- **LIDAR** to monitor culture growth in the field
- Ground based **NIR spectroscopy** to detect plant diseases
- Airborne **multispectral / hyperspectral imaging** for nitrogen mapping

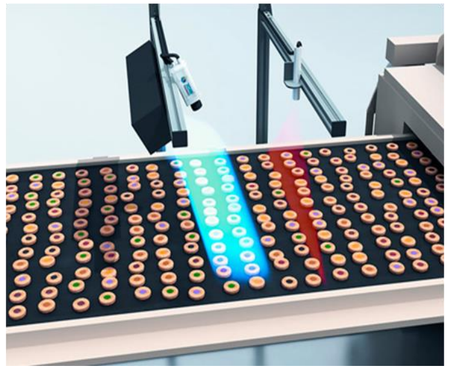



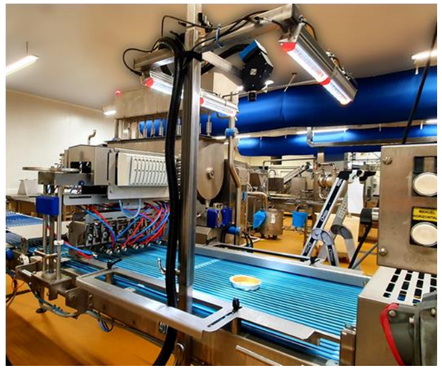
Photonics in the food industry

Later and slower evolution than in agriculture.

→ online, faster and more reliable quality inspection or production optimization

- **RGB machine vision** for food sorting, food and packaging quality inspection
- **Point spectroscopy** for composition monitoring of homogeneous food products
- **Multispectral / hyperspectral imaging** expands point spectroscopy capabilities and slowly starts complementing machine vision (infancy…)





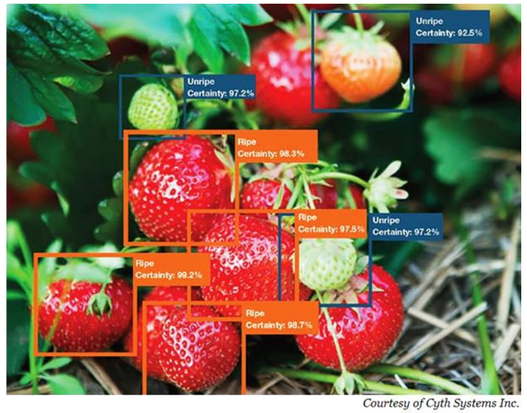
RGB Computer Vision in the AgriFood Market

RGB computer vision solution: *automated monitoring of visual characteristics (color, dimensions, shape, surface features…) of products.*

RGB computer vision in agriculture*: application examples*

- Automated harvesting / counting of fruits and vegetables
- Color-based estimation of internal quality parameters (ripeness, sweetness…)
- Detection of surface defects
- Geometry analysis for volume and weight estimation
- …

Noah Thomas / OPB



Courtesy of Cyth Systems Inc.

RGB computer vision in the food industry*: application examples*

- Online detection of foreign objects based on color or geometry
- Online detection of surface defects
- Online monitoring of food product parameters compliance (color, size/geometry)
- Vision-guided pick-and-place robotics
- …

[VISIONIFY]

Source: Soft Robotics

Optical Spectroscopy in the AgriFood Market

Optical spectroscopy solution:
- *automated monitoring of spectral characteristics (composition, chemical degradations…) of products.*
- *different applications depending on the spectral range (UV-VIS, NIR, SWIR, fluorescence…)*

Optical spectroscopy in agriculture*: application examples*

- Quantitative analysis of fertilizers (nitrogen, phosphate…)
- Culture growth monitoring (leaf spectroscopy…)
- Drought management (hydric stress monitoring)
- Diseases / toxin detection
- Maturity evaluation (if not visible)
- Post-harvest quality control (ripeness, ethylene effect…)
- …

Optical spectroscopy in the food industry

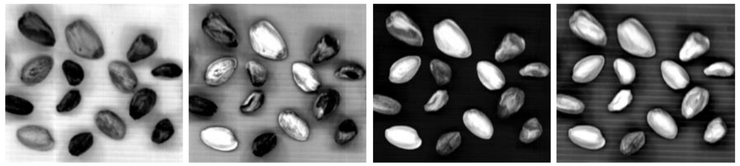
- Monitoring food quality / composition (carbohydrates, proteins, fat…)
- Quantitative monitoring of ingredients in processed food
- Moisture monitoring / detection
- Monitoring / detecting food oxidation
- Detecting food contamination (bacteria colonies…)
- …

Spectral Imaging basics

Spectral imaging: ▪ combined acquisition of an image and spectral data spatially correlated to this image
▪ acquisition of an enriched image embedding spectral data within each of the image pixel (≠ sensor pixel)

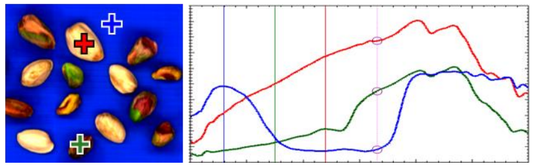
Multispectral (MSI) vs. **Hyperspectral** (HSI) imaging → discrete vs. continuous distribution of analyzed spectral bands.

MSI:



A few **discrete spectral bands**
→ stack of images
→ acquisition strategy often based on camera + band filters

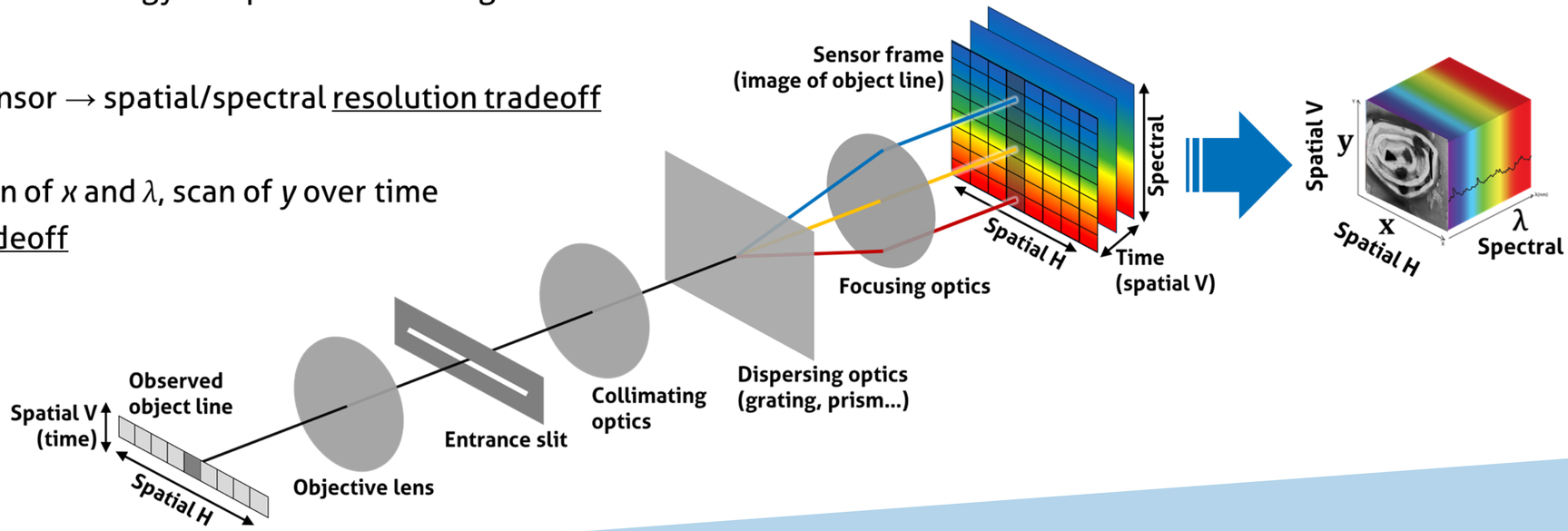
HSI:



Optical data on a **continuous spectral range**, only discretized by the sensor pixels
→ one spectrum per image pixel → datacube (x, y, λ)
→ acquisition strategy : snapshot or scanning HSI

Snapshot HSI: "folding" a 3D datacube on a 2D sensor → spatial/spectral resolution tradeoff

Scanning HSI: "push-broom" → instant acquisition of x and λ, scan of y over time
→ no resolution tradeoff



Spectral Imaging for Agriculture

Main applicative markets: airborne monitoring of nitrogen related indices (NDVI, GNDVI, RVI…), hydric stress mapping, early detection of plant diseases

Reliably detects what human / computer vision can hardly see:

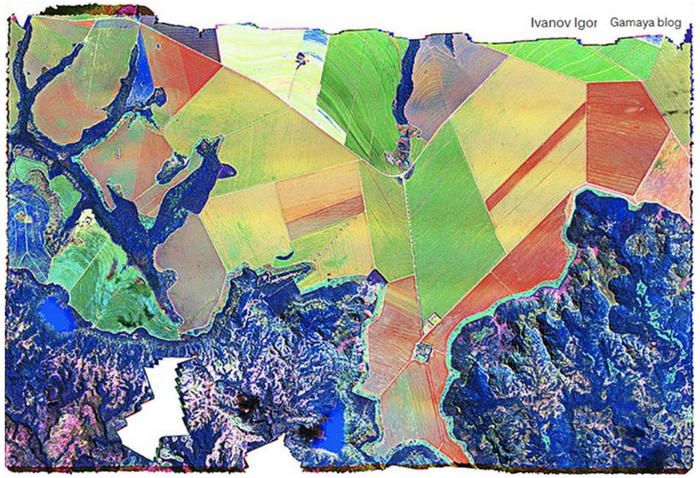
- more precise large-scale monitoring of crops growth and health
- quantitative mapping of hydric stress or nutrient deficiencies
- large-scale mapping of different vegetation types (crop varieties…)
- detecting early symptoms of plant diseases on leaves (mildew, oidium, septoria…)

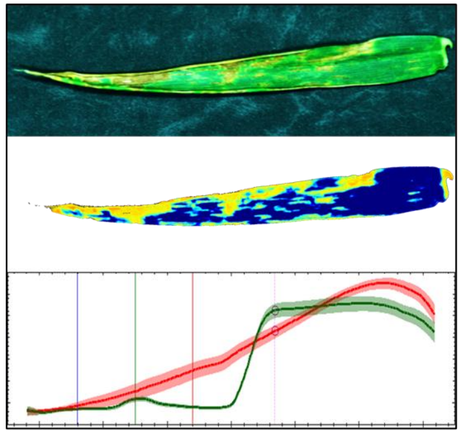
…and even for applications covered by human / computer vision:

spectra = more interpretation criteria than RGB

→ First used in airborne remote sensing systems

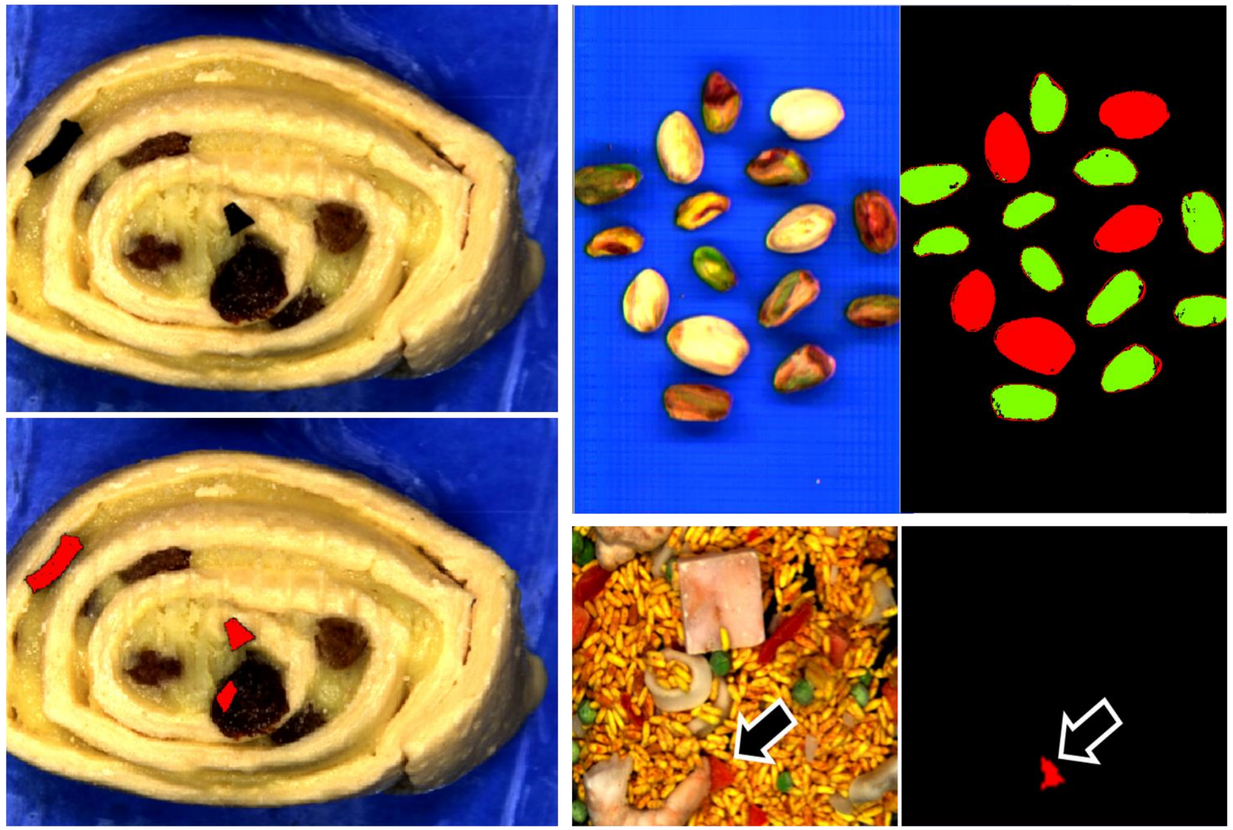
→ More and more ground-based applications (when high resolution is required)

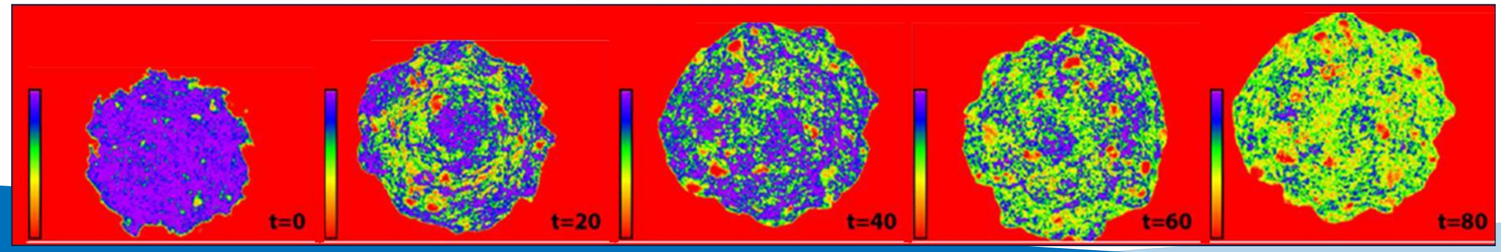




Spectral Imaging for the Food Industry

Main applicative markets: foreign object detection, sorting, composition (water, protein, fat...) monitoring in heterogenous products





Reliably detects what human / computer vision monitoring can hardly see:

- detecting stacked objects with same visible color
- sorting similar and visually heterogeneous object in a more reliable way
- detecting foreign objects with very few visual recognition criteria
- mapping and quantifying ingredients

...and even for applications covered by computer vision:

spectra = more interpretation criteria than RGB

Advances in Spectral Imaging for New AgriFood Solutions

AgriFood industry : increasing interest in HSI → <u>one</u> solution for **both spectral (composition) and spatial (inhomogeneities) monitoring**

Main obstacles : available **wavelength ranges** (monitoring application range), limited **acquisition speed** (fast conveyors), **cost, integration** capabilities.

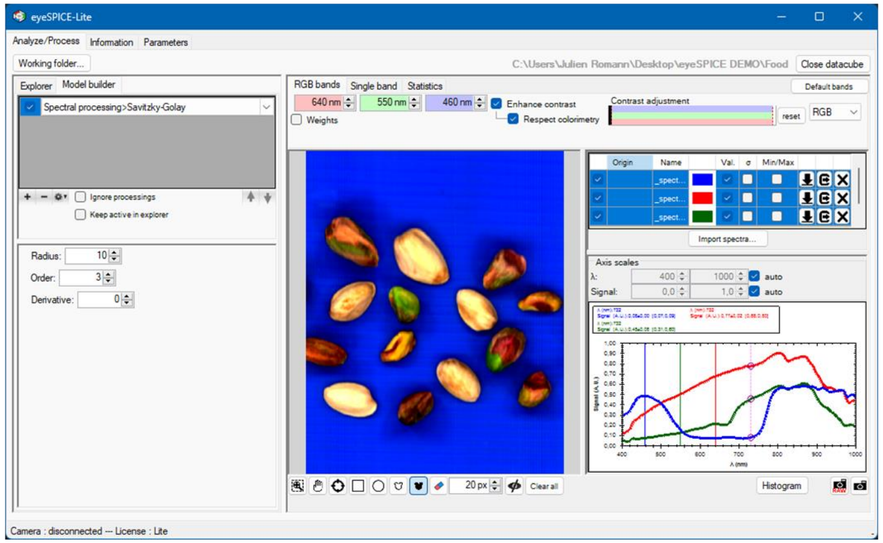
HSI compressive sensing

PRO-PIX camera
Actionable measurements and embedded decision-making for phenotyping needs
Low-cost solution (<< most solutions on the market)

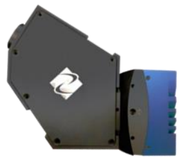
Innovative HSI software platforms

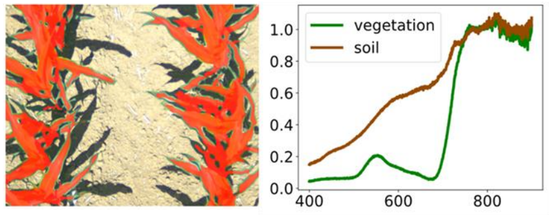
Headwall perClass Mira → IA based interpretation models

Photon Lines eyeSPICE → "hardware open" (multiple camera brands)
→ model building + online monitoring



First **high speed** (**3kHz**) HSI camera



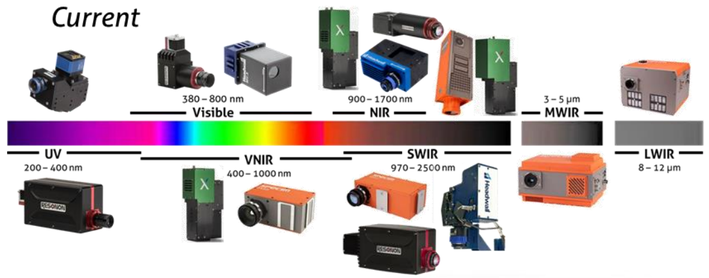


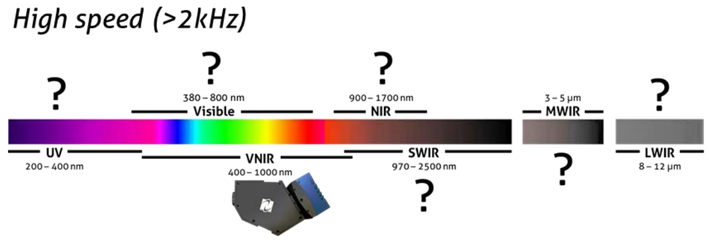
This project has received funding from the European Union's H2020 research and innovation programme under grant agreement No. 824769-S3FOOD.

Spectral Imaging Perspectives for Future New AgriFood Solutions

Monitoring speed

Generalization of high speed (>2kHz) spectral imaging cameras
→ enables the increased diffusion of SI in the food industry



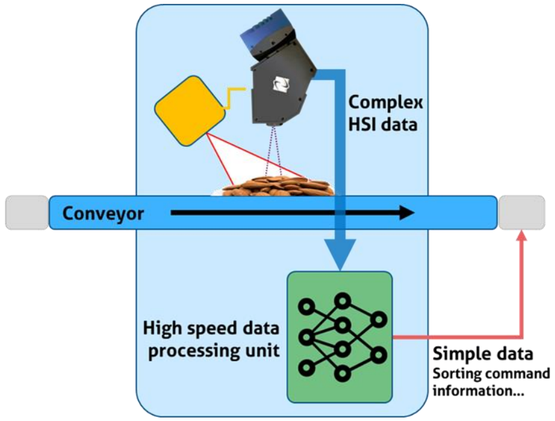


High performance processing units for real time SI interpretation at high speed (>2kHz)
→ GPU/multi-GPU based systems, new optimized AI engines...

Applicability

Native integration of spectral imaging devices in global systems suitable for the end-user environment (field, food processing industry plant).

From the sensor... *to the full Agri / Food Industry solution*



Photonics Perspectives for Future New AgriFood Solutions

Photonics will remain key technologies for the modernization of agriculture and the food industry
→ non-destructive, contactless, polyvalent (in terms of both gathered information and integration)

Photonics perspectives in agriculture

Already present in many agricultural applications, photonics are bound to further expand:
- generalization of **integrated computer vision and spectroscopy solutions** in the field (more applications "solved")
- expansion of **spectral imaging: new ground-based solutions for high precision monitoring**
- photonics solutions with **increased ROI / cost ratio**: new innovative low-cost photonics strategies
- beyond photonics sensors: **real-time photonics-based decision support systems (DSS)**

Photonics perspectives in the food industry

Many food industry markets to conquer: online, real-time, robust, reliable, food-grade integrated solutions
- smarter and more polyvalent **computer vision solutions making use of new AI processing tools**
- generalization of already mature **NIR spectroscopy solutions** for composition monitoring of homogeneous products
- new food-grade spectroscopy solutions with a **wider choice of wavelength ranges** to tackle more applications
- expansion of **spectral imaging: new online, real-time, food-grade integrated solutions**
- photonics solutions with **increased ROI / cost ratio**: new innovative low-cost photonics strategies

PHOTONLINES
Optical solutions

Tusen takk !

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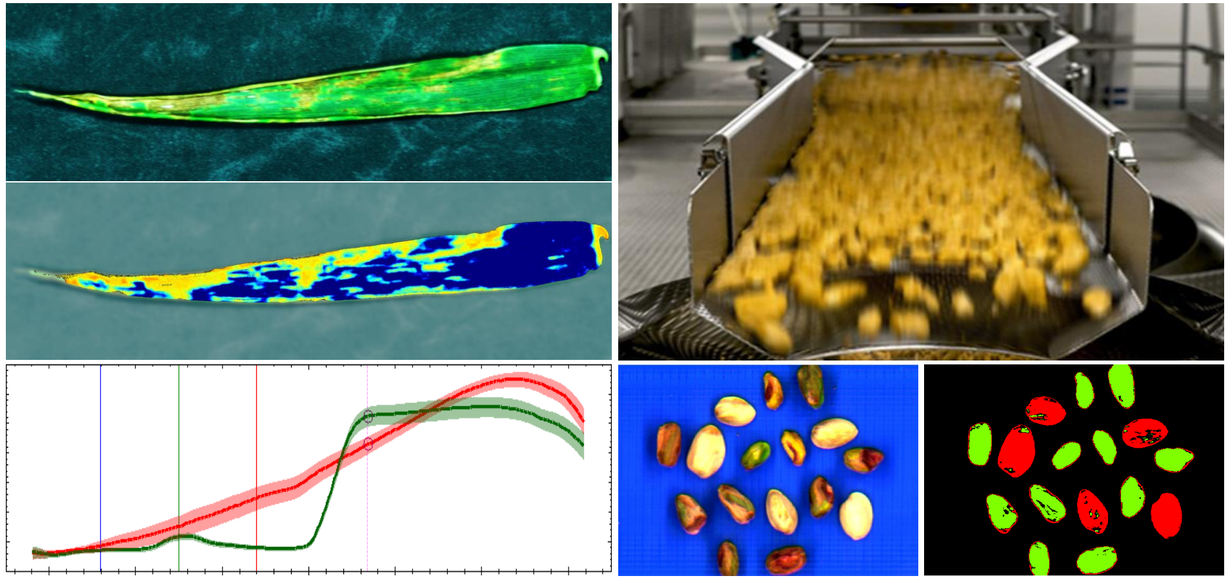

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