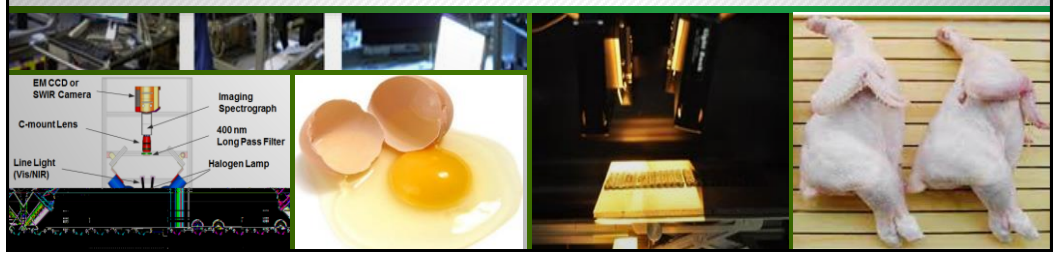
Spectral imaging application for quality and safety measurement for agricultural materials

Byoung-Kwan Cho

Chungnam National University, South Korea



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2 Recent Applications on Spectral Imaging

3 Closing Remark

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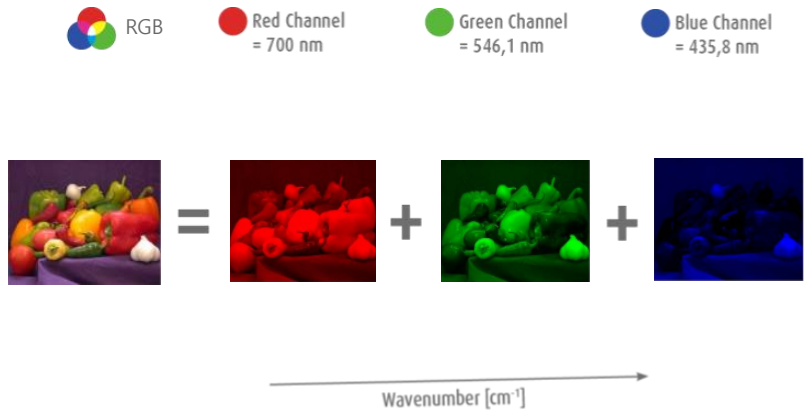
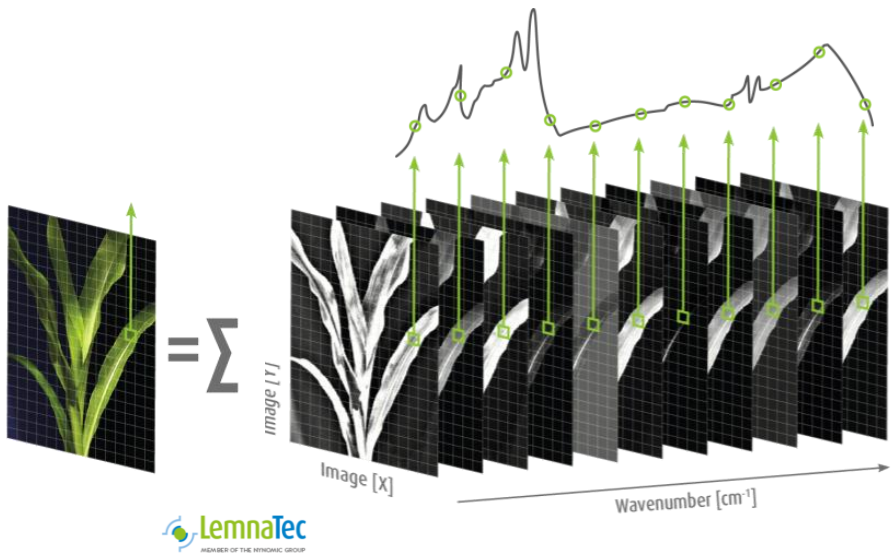
Spectral Imaging

- RGB – Color Image



Spectral Imaging

- RGB vs. Hyperspectral image

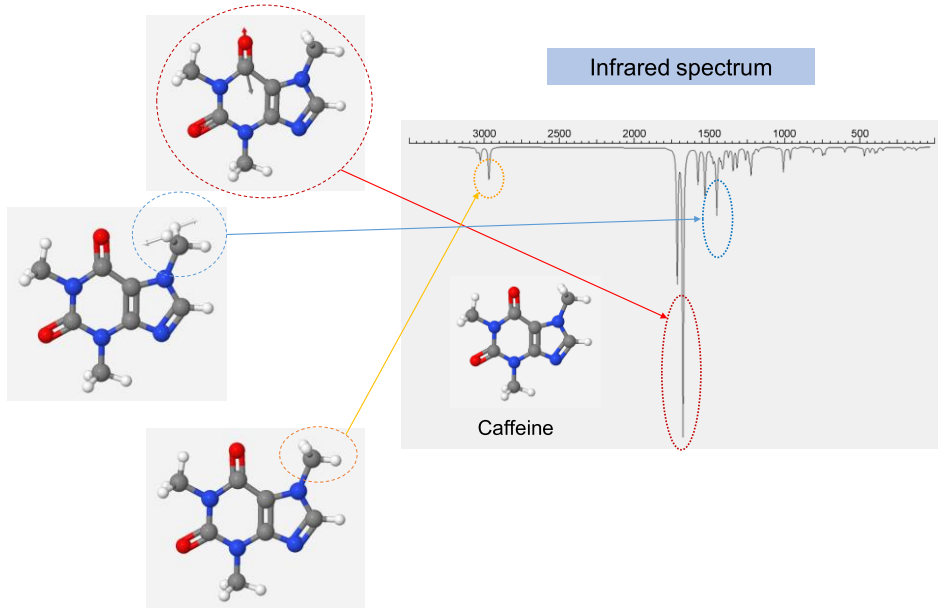


Spectral Imaging

- Hyperspectral image
  - Each pixel contains a continuous spectrum that is used to identify the condition of the materials.

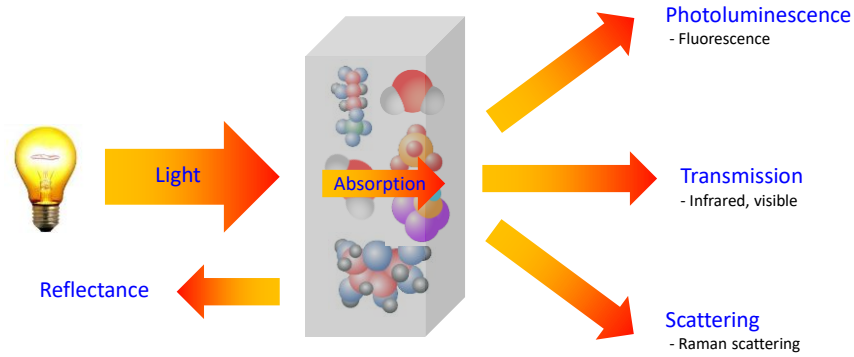
LemnaTec

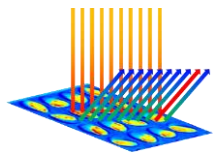
Spectral Imaging – Vibrational Spectroscopy

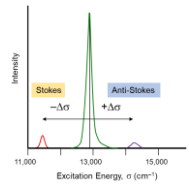


Spectral Imaging

- Interaction of Radiation and Matter

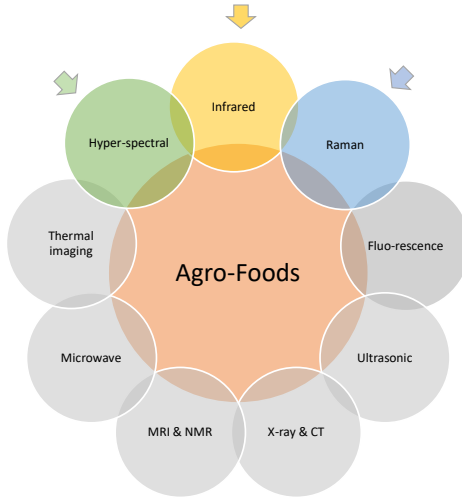




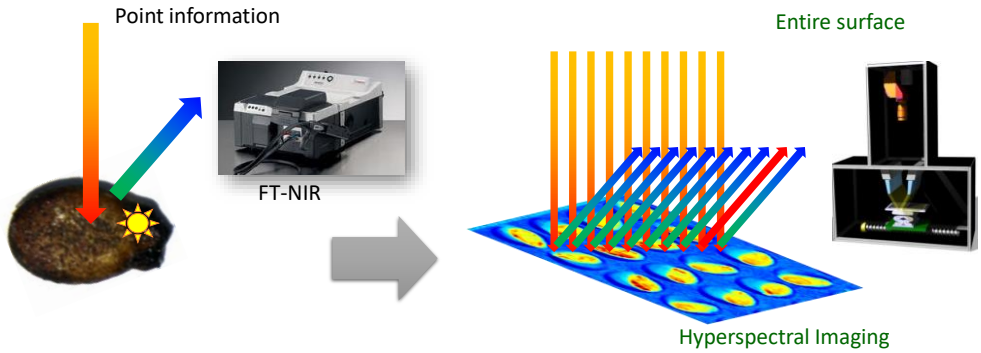


Spectral Imaging

- Sensing Technology



Why Spectral Imaging?

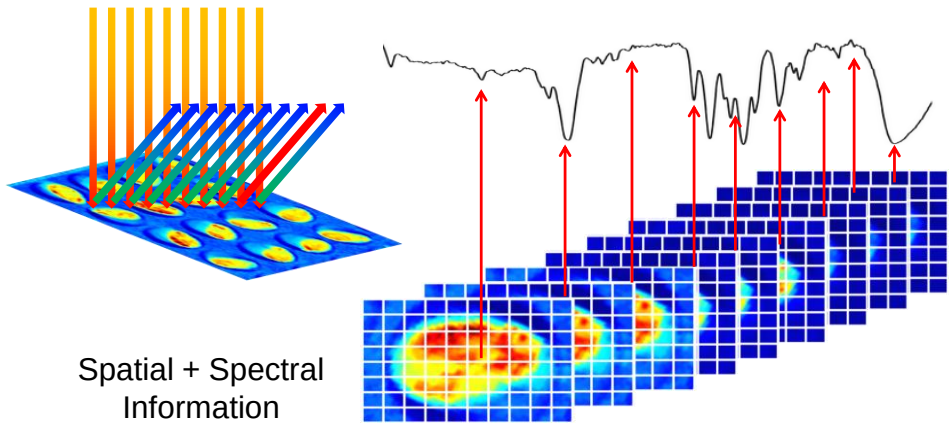


- Sensitive to Chemicals
- Rapid & Nondestructive Measurement
- Point Measurement & Not for Massive Samples

- Massive Sample Inspection
- Spectral + Spatial Information
- Rapid Chemical Imaging

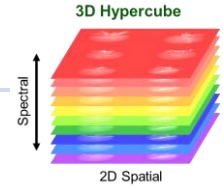
Hyperspectral Image?

- Spatial + Spectral Information Simultaneously

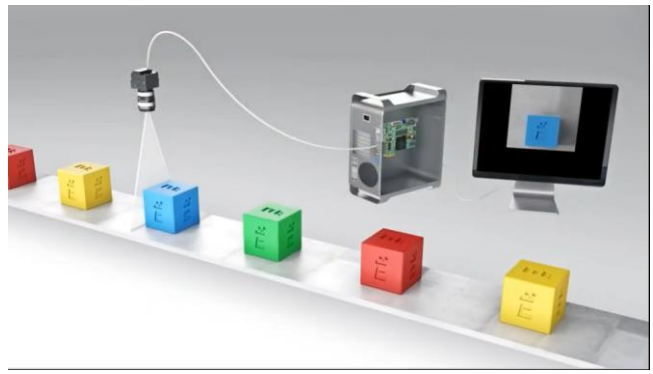


Spatial + Spectral Information

How to measure Hyperspectral Image?



- Line Scanning Method (preferred)

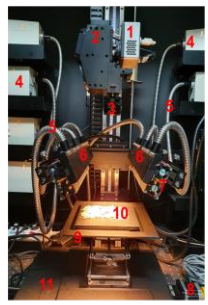


  - Easy to be implemented for Online Application
  - Real-Time Inspection and Sorting

Hyperspectral Reflectance Imaging

Hyperspectral Line-Scan Imaging Systems

① Vis/NIR

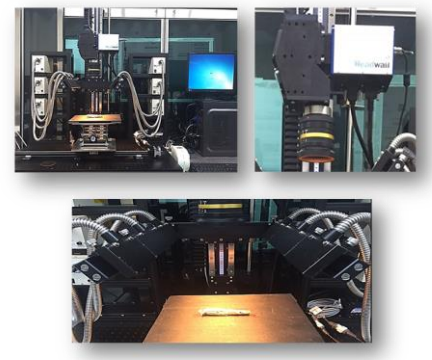


Vis-NIR HSI components

1. Detector cooler
2. EMCCD camera and Spectrograph
3. Object lens
4. Light source (Halogen)
5. Optic fiber
6. Light
7. Cooling fan
8. DC motor
9. Adjustable table
10. Sample
11. Sliding table

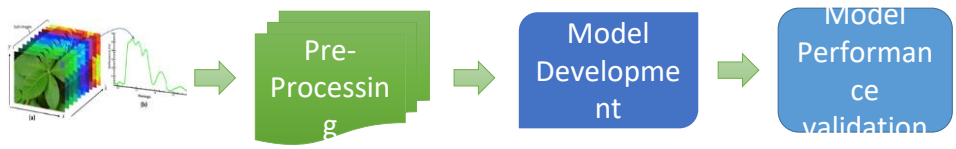
- Resolution : 1004 × 1002
- Wavelength : 400–1,000 nm

② Short Wave Near Infrared



- Resolution : 320 × 200
- Wavelength : 1,000–2,500 nm

Analysis of Hyperspectral Image



Preprocessing:

- Background removal
- Spectral data extraction → ROI
- Spectral pre-processing: Normalization, Derivative, etc

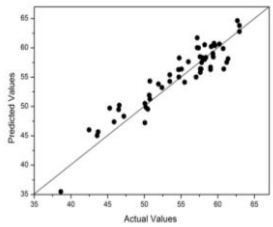
Model development:

- Regression: PCR, PLSR, SVM, ANN
- Classification: PCA, PLS-DA, ANN, CNN

Hyperspectral Reflectance Imaging

- Chemical Imaging for Food Ingredients

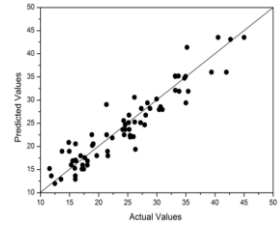
Moisture content



R^2 : 0.939, SEP : 1.28%

Moisture content (AOAC 950.46)

Fat content



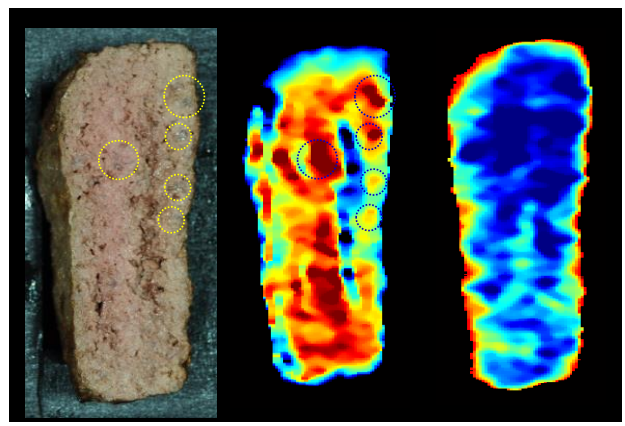
R^2 : 0.876, SEP : 3.03%

Fat content (AOAC 996.06)

Hyperspectral Reflectance Imaging

- Hyperspectral image + Spectral Analysis Model → Chemical imaging

Color image Fat Water



Hyperspectral Reflectance Imaging

- Foreign Object Detection


Cabbage


Carrot


Green Onion


Onion


Potato


Radish


Zucchini

Photographs of representative Foreign Materials

Hyperspectral Reflectance Imaging

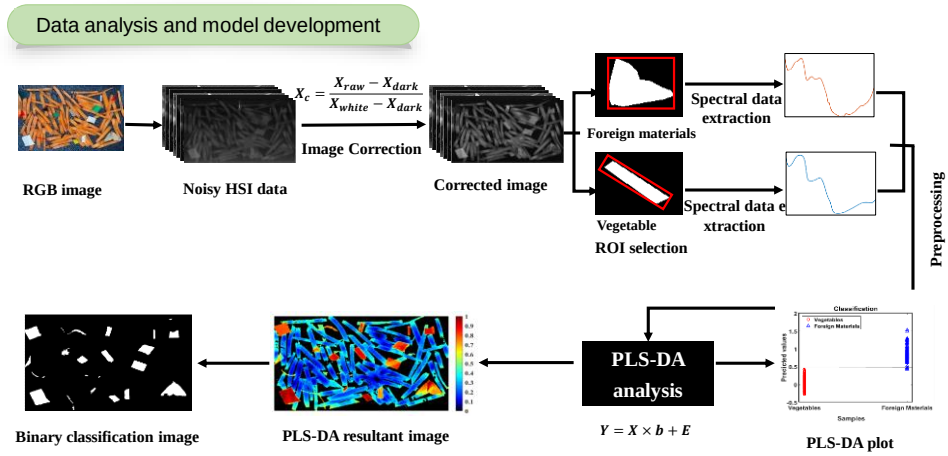
- Foreign Object Detection


Cabbage Carrot Green Onion Onion Potato Radish Zucchini

- ❖ X-ray : feasible for high density materials, but difficult for soft materials
- ❖ MRI : expensive and not feasible for high-throughput screening
- ❖ Ultrasound : sensitive to the air medium, not feasible for uneven surface
- ❖ Terahertz : highly attenuated in the water medium, limited spatial resolution, low S/N

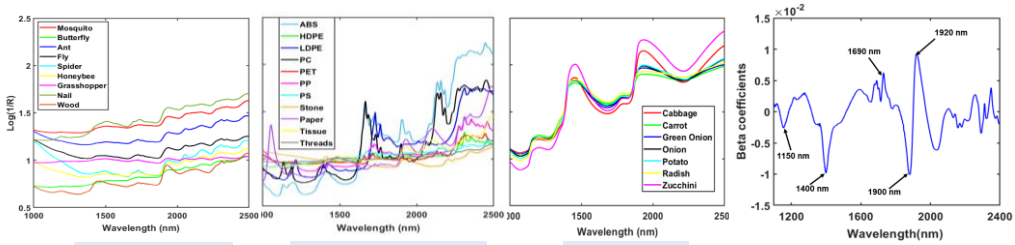
Hyperspectral Reflectance Imaging

- Foreign Object Detection



Hyperspectral Reflectance Imaging

- Foreign Object Detection

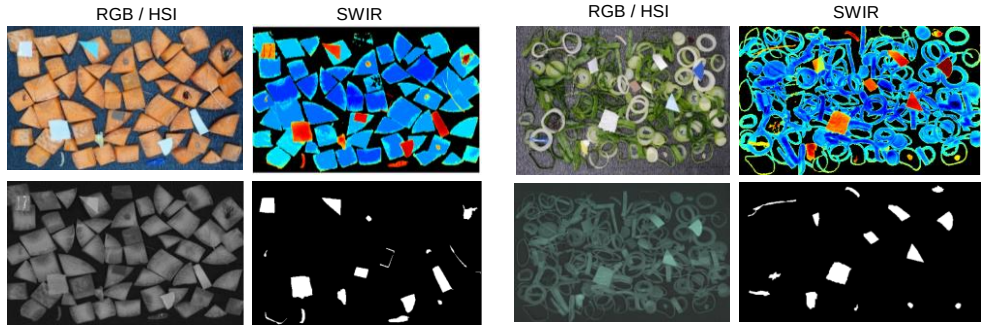


Biological FMs | Non-biological FMs | Vegetables

Sample Name	Selected wavelength (nm)	Group in NIR
Plastics	1150	-CH_3 first overtone of asymmetrical stretching
Vegetables	1400	O—H stretch first overtone of moisture content
Bugs	1690, 2062	C—H overtone of chitin and lipid
Vegetables/paper/wood	1900	C—H stretch first overtone and O—H stretch of Starch
Vegetables	1920	combination of O—H stretch and O—H deformation of water

Hyperspectral Reflectance Imaging

- Foreign Object Detection



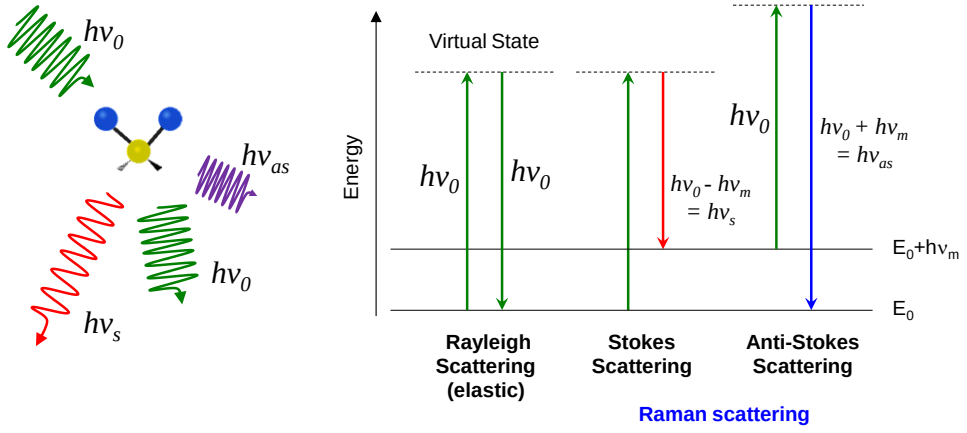
Minimum size of detected FMs using SWIR HSI technique are Mosquitoes (0.61 mm) and stone (2.44 mm)

Very thin FMs like stapler pin (0.4 mm thickness) and thread (0.5 mm thickness)

Hyperspectral Raman Imaging

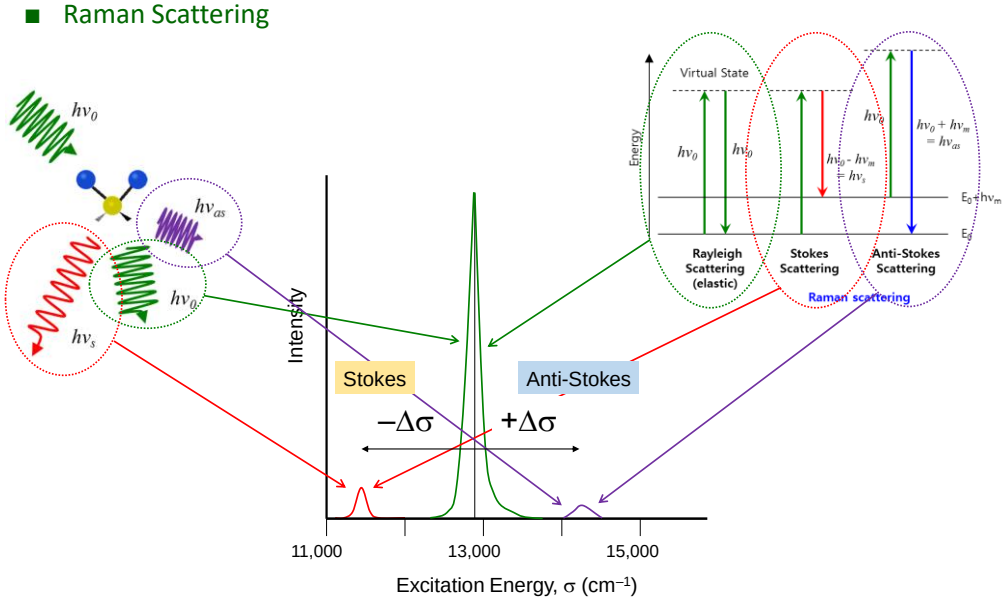
Hyperspectral Raman Imaging

- Raman Scattering



Hyperspectral Raman Imaging

- Raman Scattering



Hyperspectral Raman Imaging

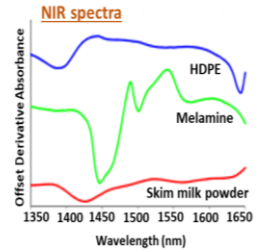
- Advantage of Raman

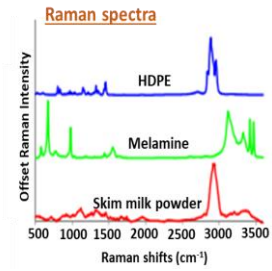
Limitations of NIR, IR spectroscopy

- Water (moisture) interference
- Less sensitivity to inorganic matters
- Week signals and broad peaks
- Require complicated data analysis

Advantages of Raman

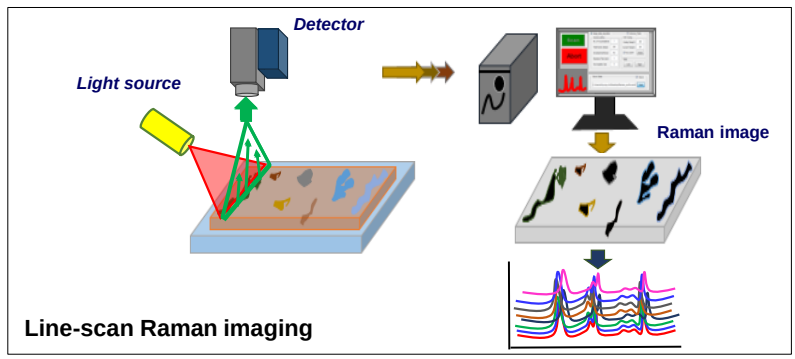
- **Not interfered by water**
- **Well resolved Raman peaks**
- Highly sensitive to chemicals
- Seeing through glasses and polymers
- **Ease of data analysis**





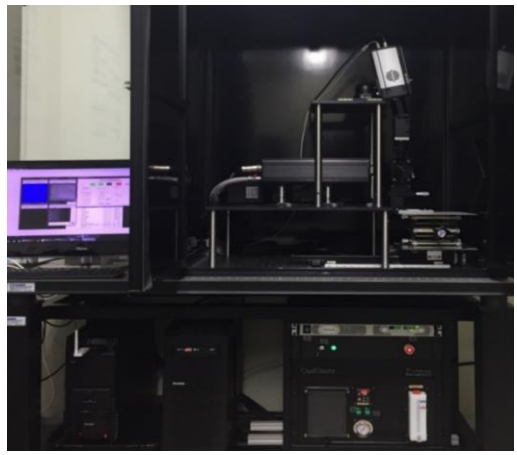
Hyperspectral Raman Imaging

- Line-scan Raman imaging
  - Use a wider laser line and relatively larger size of detector
  - Line-scan Raman imaging: one dimension of the sample can be scanned at a time

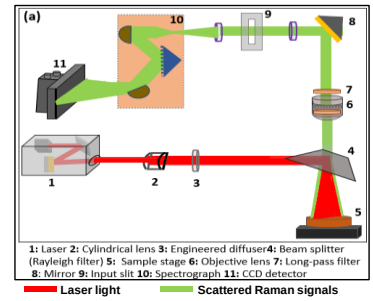


Hyperspectral Raman Imaging

- Line-scan Raman imaging system



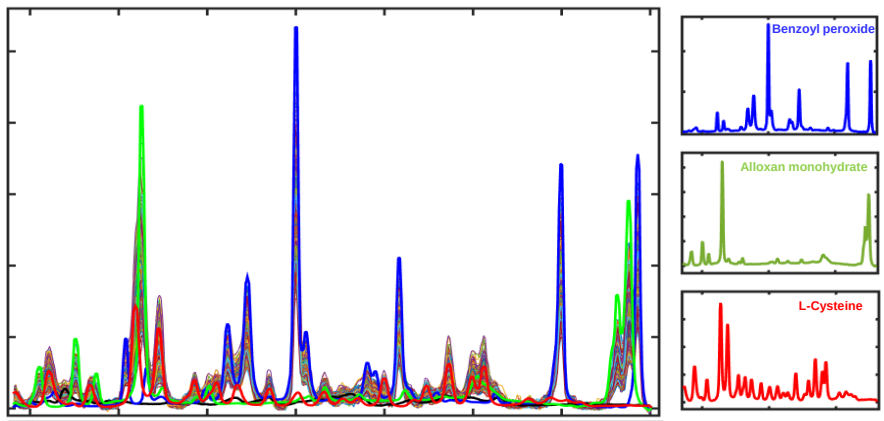
- **Optical design**



- **Specifications**
  - Excitation laser : 785 nm, ~450 mW
  - Spectrometer : -763 to 2837 cm^{-1}
  - Spectral Resolution: 3.5 cm^{-1}
  - Spectroscopic camera : 16 bit
  - Detector size : 1024 × 1024 pixels

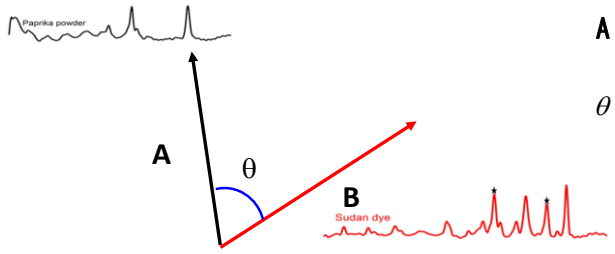
Hyperspectral Raman Imaging

- Chemical Adulterants in Wheat flour



Hyperspectral Raman Imaging

- Spectral Angle Mapper (SAM)
  - SAM measure the angle between two spectral signature
  - Effective and fast, particularly when the pure spectra of reference material (adulterant) is available



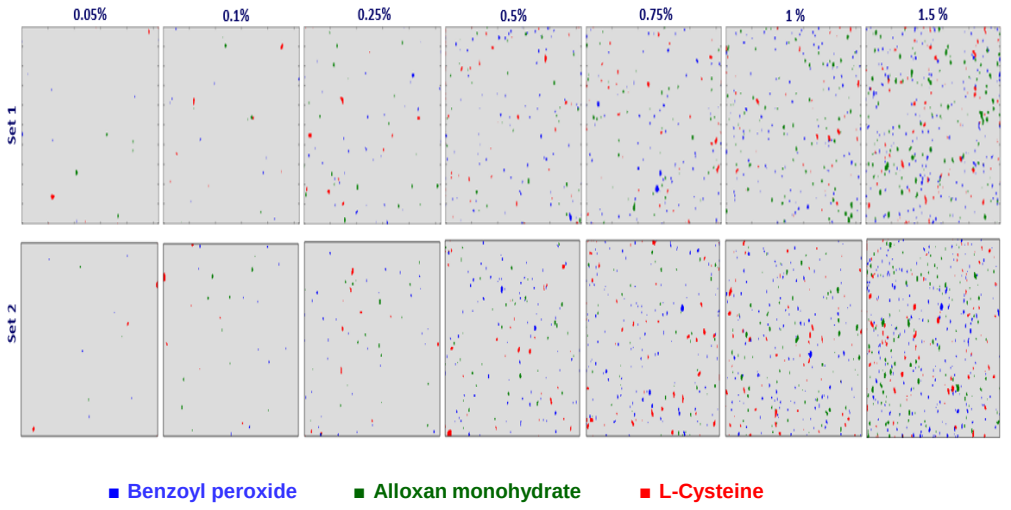
$$\mathbf{A} \cdot \mathbf{B} = |\mathbf{A}||\mathbf{B}| \cos\theta$$

$$\theta = \cos^{-1}\left(\frac{\mathbf{A} \cdot \mathbf{B}}{|\mathbf{A}||\mathbf{B}|}\right)$$

$$SAM\ (a,b) = cos^{-1}\left(\frac{A\ .\ B}{|A||B|}\right) = cos^{-1}\left(\frac{\sum_1^n ab}{\left[\sum_1^n a^2\right]^{1/2}\left[\sum_1^n b^2\right]^{1/2}}\right)$$

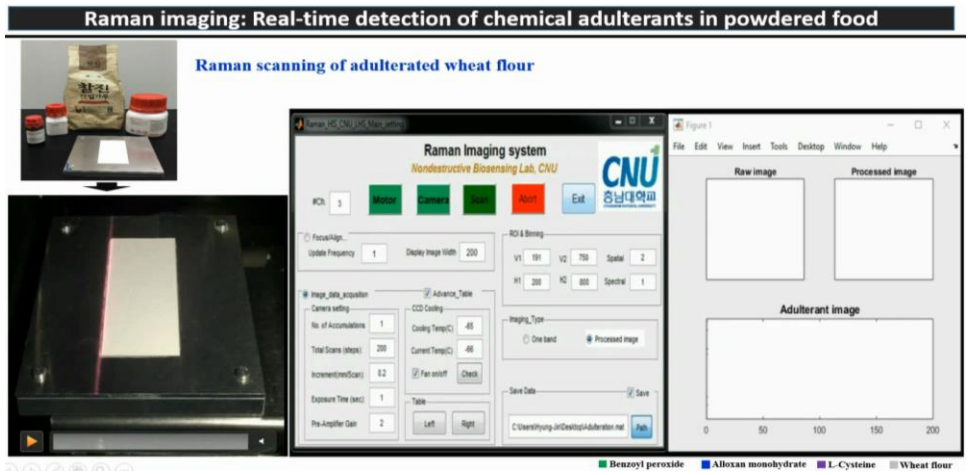
Hyperspectral Raman Imaging

- Color coded chemical images of 3 adulterants in wheat flour



Hyperspectral Raman Imaging

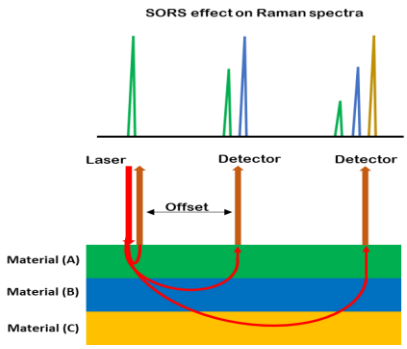
- Real-time Analysis & Visualization

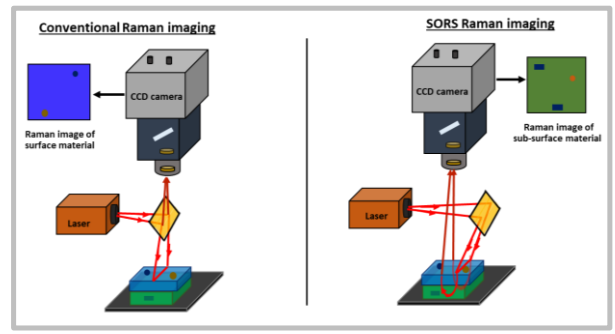


Macro-scale Spatially Offset Raman Imaging

Line-scan Spatially Offset Raman Imaging

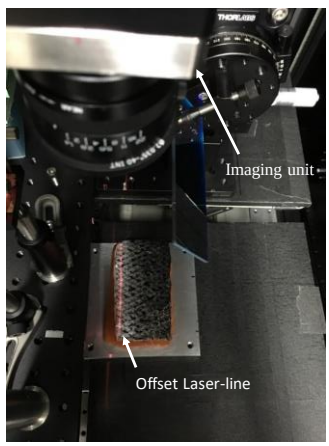
- Spatially offset Raman (SOR) Imaging
  - Considerably higher penetration depth than conventional Raman spectroscopy
  - Determine the chemical composition of sublayer





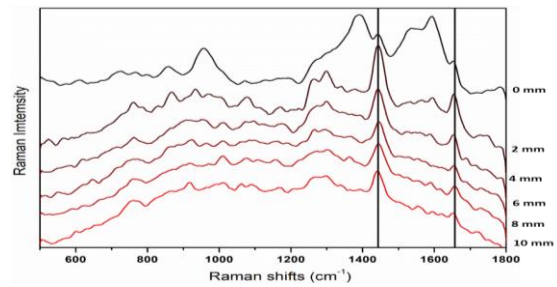
Line-scan Spatially Offset Raman Imaging

- Sublayer information of Salmon



SORS system

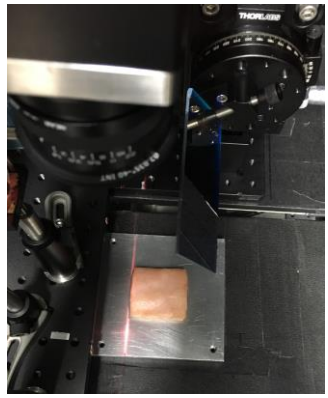
Spectroscopic techniques are limited to dark (black) color



Subsurface signals cannot be collected with no-offset

Line-scan Spatially Offset Raman Imaging

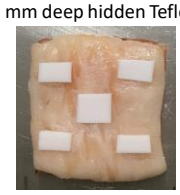
- Sublayer information of Pork

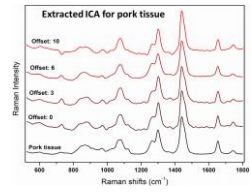


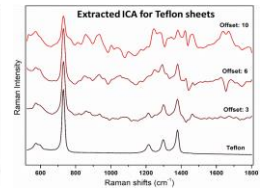
SORS system

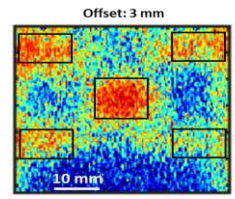
Pork tissue (front)

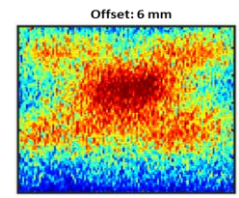
6 mm deep hidden Teflon





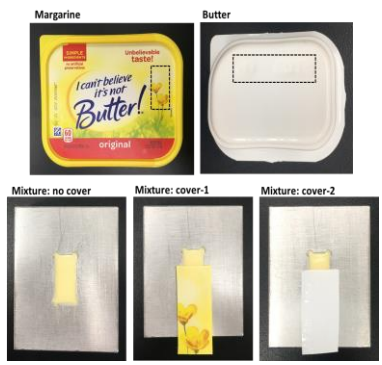


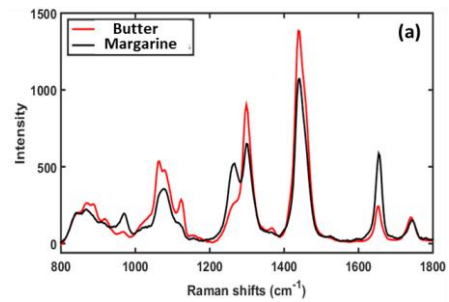




Line-scan Spatially Offset Raman Imaging

- Detecting Packaged Foods

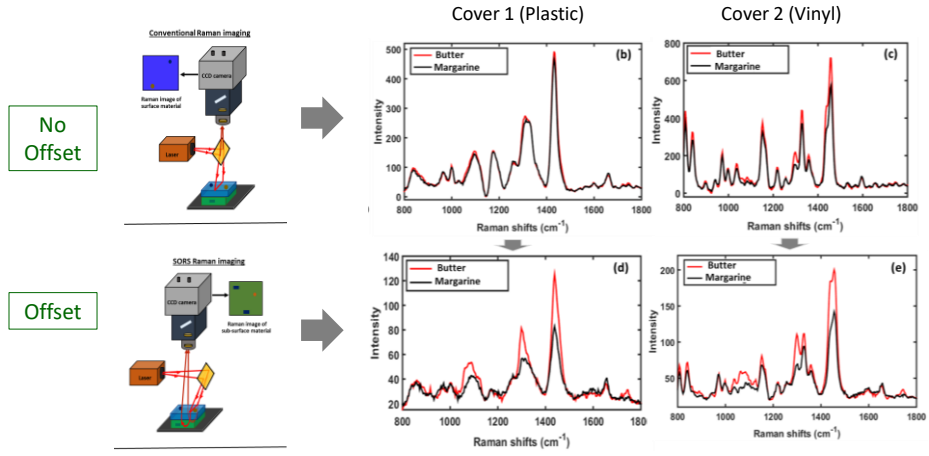




- Significant different between Raman spectra of butter and margarine

Line-scan Spatially Offset Raman Imaging

- Detecting Packaged Foods



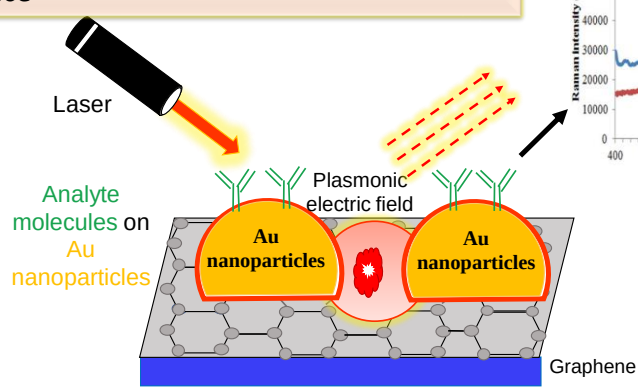
- A significant difference in Raman spectra when SORS geometry used for covered sample
- Qualitative (classification) & quantitative (concentration) measurements are possible.

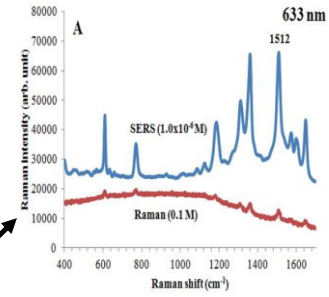
Surface Enhanced Raman Spectroscopy

What is SERS

❖ Surface-Enhanced Raman Scattering

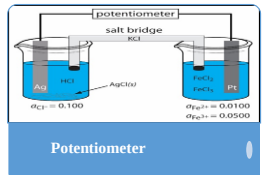
- ❑ The first time discovered in 1974.
- ❑ Pyridine molecules were adsorbed
- ❑ On the Electrochemically roughened silver surface





Comparison

Conventional methods

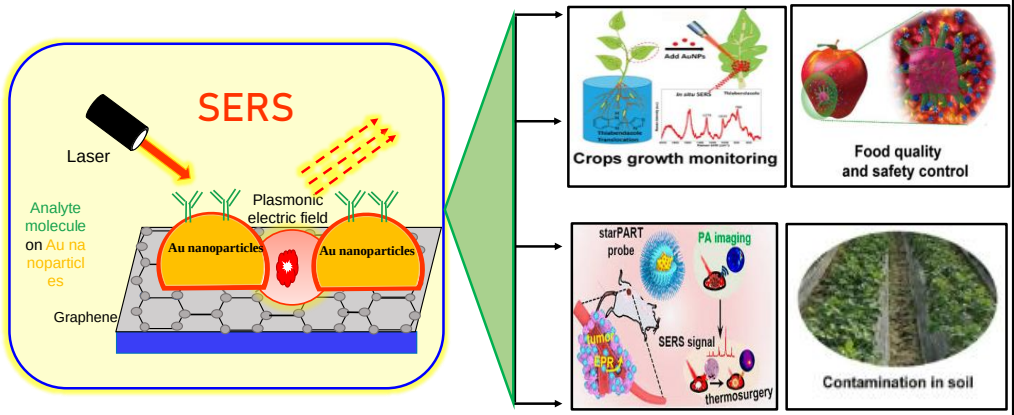


Destructive
Time consuming
Less sensitivity
Low LOD

Advantages of SERS

- ➢ Raman technique typically suffers from low sensitivity due to the limited number of scattered photon
- ➢ SERS offers greatly amplified signals by several orders of magnitude
- ➢ Surface-enhanced Raman scattering (SERS) is an emerging and powerful optical technology that can provide a nondestructive and ultrasensitive detection even down to a single molecular level.
- ➢ Continuous development of nanotechnology, has significantly broadened the scope of SERS and made it a hot research field in chemistry, physics, materials, biomedicine etc.

Application of SERS



Trends in research on SERS based plasmonic

- **Figure 1**a,b illustrate the statistics of SERS publications in different areas
- The data presented in the figure indicate that there is a growing interest in the usage of SERS

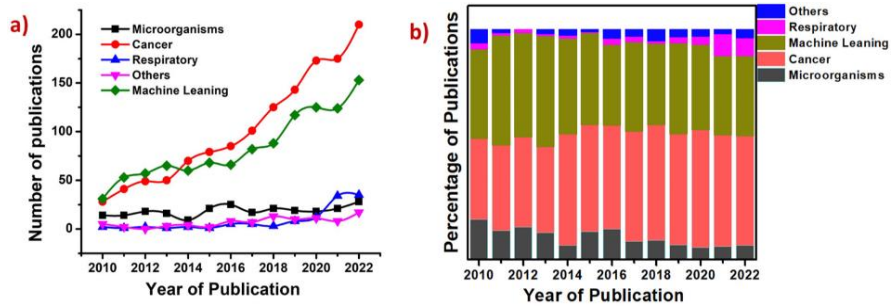
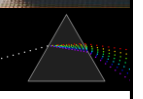


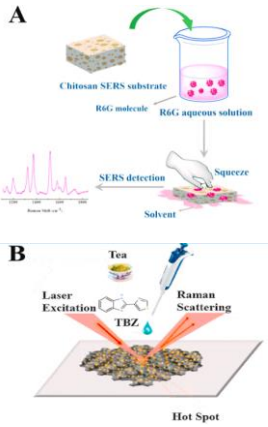
Figure 1. (**a**) Trends in research on SERS based plasmonic applications in the detection of microorganisms, cancers, respiratory diseases, other diseases such as heart ailments and diabetes and the use of different machine learning techniques for SERS based biosensing. (**b**) Bar chart with percentage contribution from each area shown on the label for the past 12 years.

Application of SERS in food safety

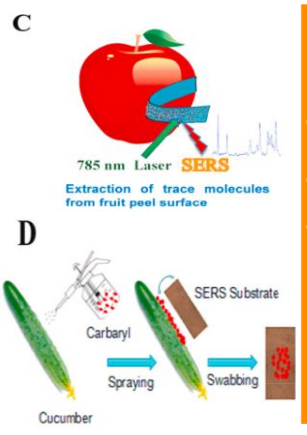


❖ SERS technology is undoubtedly a powerful detection method and serve several applications in the food industries.

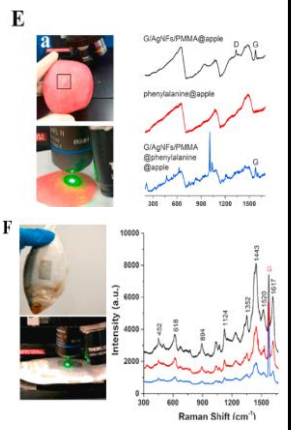
Infiltration



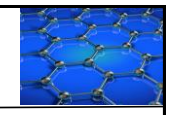
Swab–sampling



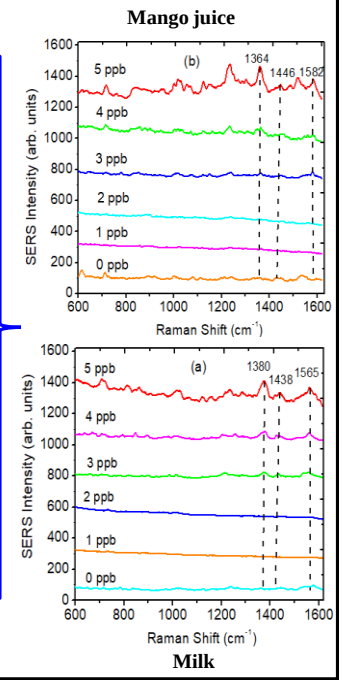
In situ–detection



Recent works:



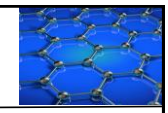
Pesticides detection in milk and juice

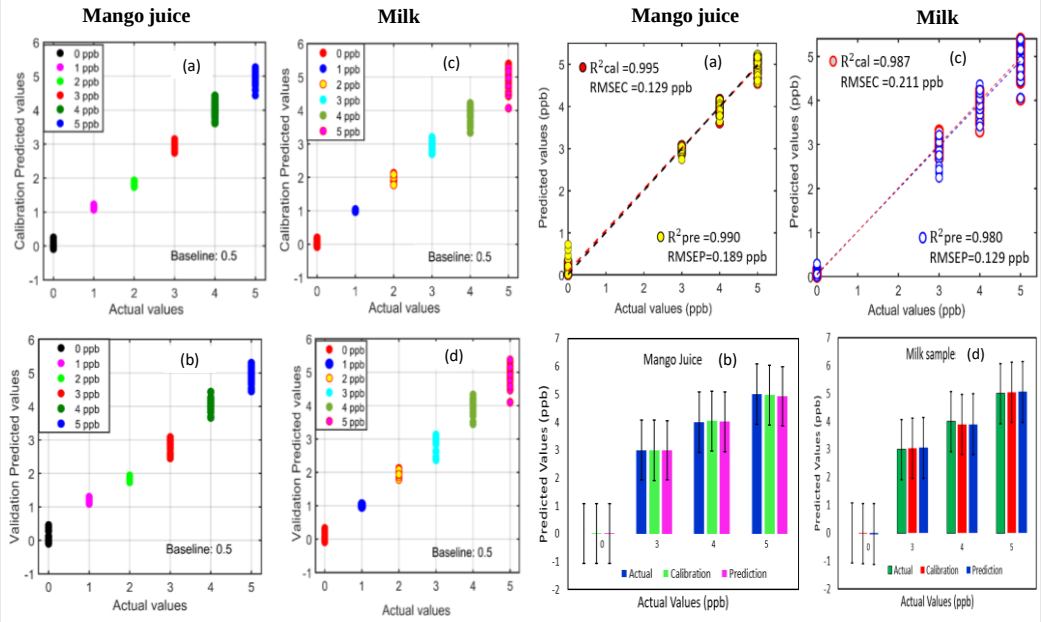


LOD values for juice and milk: 0.57 ppb, and 0.15 ppb

Non-destructive Biosensing laboratory

Recent works: PLS–DA, and PLSR results



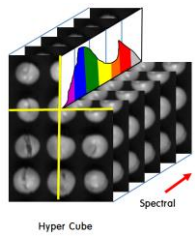


Non-destructive Biosensing laboratory

Detection limit: 3

Closing Remark

- Demands for high quality & safety food materials increases
  → High Demand for Accurate, Rapid, Nondestructive measurement techniques



- Spectral information
  → Efficient and robust analysis techniques
- Spatial information
  → Advanced image analysis & AI technique

- Spectral imaging would be much more popular in the future
  → Price & Performance is improving continuously.
- The development of portable and field-deployable SERS instruments is important for real-time, on-site applications.
- The key goals for upcoming work will be to increase stability, decrease development costs, and shorten acquisition times for data collection.

Thanks!

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