Non-destructive Sensing Technologies and Applications

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- Applications
  - NIRS applications
  - Disease detection: citrus greening / citrus black spot
  - X-ray & MRI: fruit seed count

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NEAR-INFRARED SPECTROSCOPY (NIRS)

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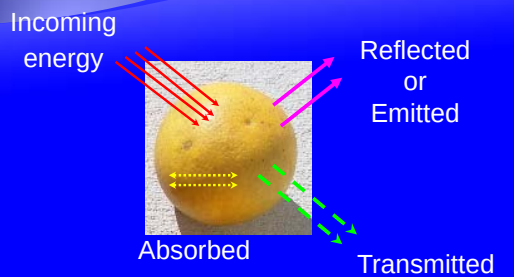
How objects interact with EM energy



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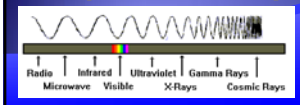
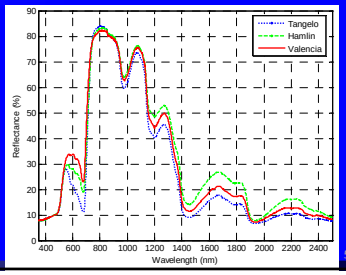
EM Spectrum & Spectral Signature



Spectrometry measures information related to the chemical composition of the materials with the wavelength

Average fruit spectral reflectance over a growing season from July to January (Kane & Lee, 2006)



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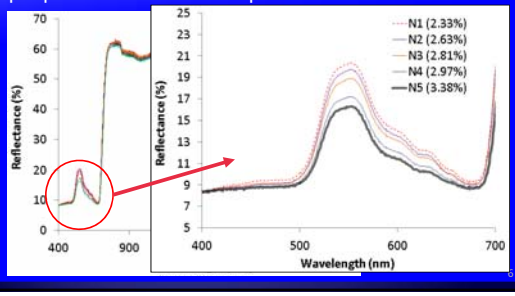
Beer-Lambert Law

- The concentration of an absorber is directly proportional to the sample absorbance



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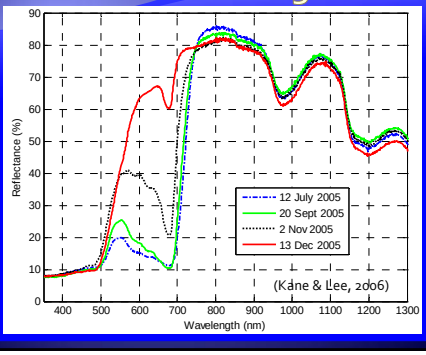
Fruit Reflectance Change: Hamlin



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Spectral Data Analysis

- Stepwise multiple linear regression
- Principal component regression (PCR)
- Partial least squares (PLS) regression
- Hierarchical dimension reduction
- Kullback-Leibler divergence (KLD)
- …

→ Develop prediction models (calibration)

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VIS/NIR Spectroscopy

- A widely used tool for detecting soil and crop properties utilizing spectral signatures
- Advantages: non-destructive measurement and easy sample preparation
- Applications:
  - ✓ Crop properties (nutrients, water, disease)
  - ✓ Soil properties (organic carbon, moisture, mineral nitrogen, phosphates, pH, particle size)
  - ✓ Weed detection

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NIRS APPLICATIONS

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NIR Brix Sensing (Miller & Zude, 2002)

- White & red grapefruits from Florida, 'Honey' tangerines

Table 1. Correct classification for grapefruit based on on-line NIR and laboratory Brix measurements

Test set	Breakpoint	% Correctly classified	% Accepted (true state = reject)	% Rejected (true state = acceptable)
#1 Interior white grapefruit, 5°C temp.	9 °Brix	62.1	17.2	20.7
#2 Interior white grapefruit, ambient temp.	9 °Brix	78.6	7.1	14.3
#3 Indian River grapefruit, size 40	10 °Brix	88.4	11.6	0.0
#4 Indian River grapefruit, size 32	10 °Brix	77.4	9.7	12.9
#3 & 4-NN	10 °Brix	88.5	6.9	4.8

Table 2. Correct classification for Honey tangerine based on hand-held NIR and laboratory Brix measurements. H-halogen light source, L-LED (4 white/2 red) LED light source.

		% Correctly classified		% Accepted (true state = reject)		% Rejected (true state = acceptable)	
Test set	Breakpoint	H	L	H	L	H	L
#1	14 °Brix	92	92	0	0	8	8
#2	14 °Brix	88	84	12	12	0	4
#1-NN	14 °Brix	100		0		0	
#2-NN	14 °Brix	92		8		0	

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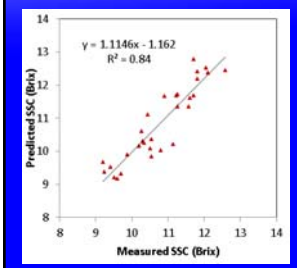
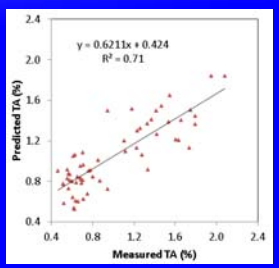
Soluble Solids & Titratable Acid (Ruslan et al., 2012)

- Valencia & Hamlin oranges, Thompson red grapefruits





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Preliminary Tests for CBS Detection

Healthy | Healthy | Symptomatic | Symptomatic

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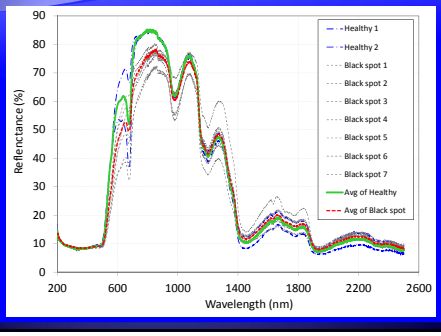
Spectral Signature of Healthy & CBS Symptomatic Fruit Samples



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NIR Summary

- Most commonly used method for quality evaluation
- Cost effective
- Mature technology
- Still needs more improvement for actual applications

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TIME-RESOLVED REFLECTANCE SPECTROSCOPY (TRS)

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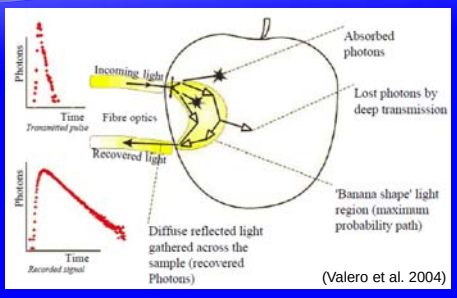
Time-resolved Reflectance Spectroscopy (TRS)



(Valero et al. 2004)

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Time-resolved Reflectance Spectroscopy (TRS)

- Using the light diffusion theory, light absorption and scattering coefficients are obtained.
- Simultaneous determination of chemical concentration & firmness
- More novel than standard spectroscopy
- Need a photon counting sensor (~$25,000)

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Apple Quality Attributes

Table 6
Summary of three classification models according to fruit quality attributes for apple

Fruit quality	Number of wavelengths in the model, and spectrum	Cluster description (average ± SD)				Performance, %	
		Cluster	Magness–Taylor force (F_M), N	SSC (S), °Brix	Total acidity (A), meq l^{-1}	Classification	Validation
Firmness	3 VIS					76	74
		1	17·5 ± 3·11				
		2	29·1 ± 3·65				
		3	41·2 ± 4·46				
Sugar	5 NIR					77	71
		1		11·5 ± 1·0			
		2		14·1 ± 0·9			
		3		17·5 ± 1·3			
Acidity	11 NIR					74	72
		1			41·3 ± 10·1		
		2			70·3 ± 10·2		
		3			114·3 ± 14·8		

Each model estimates one attribute (firmness, as Magness–Taylor force; sugars as °Brix; or acids as meq l^{-1}) independently, using absorption and scattering coefficients at several wavelengths; VIS, visible; NIR, near infrared; SSC, soluble sugar content; SD, standard deviation.

(Valero et al. 2004)

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MACHINE VISION

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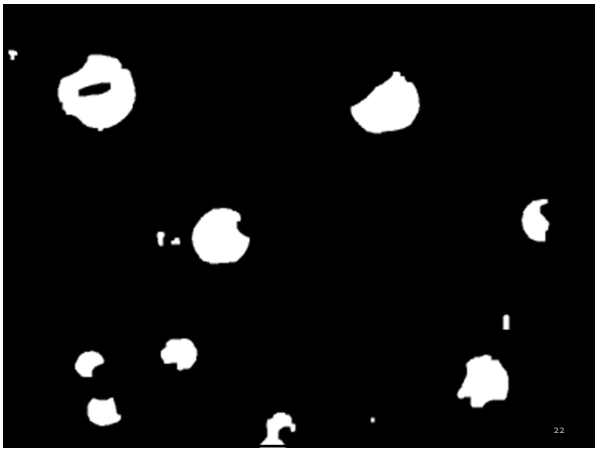

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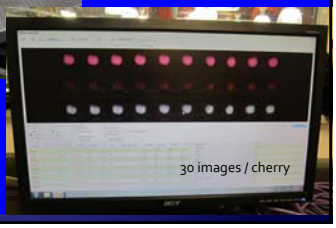
Cherry Grading



32 cherries / sec

http://www.gpgraders.com.au/products/cherry-grading/

30 images / cherry

Example of CBS Detection using Color Components

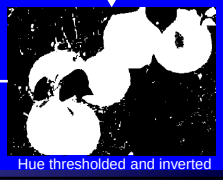
Identification of CBS Symptomatic Lesions using Outdoor Images

Original

(adapted from Dewdney, 2012)

Hue

Fruit only



Hue thresholded and inverted

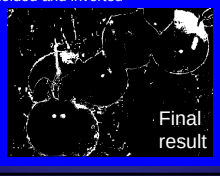
Identification of CBS Symptomatic Lesions using Outdoor Images

Hue thresholded and inverted

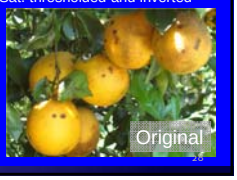
'AND'

Sat. thresholded and inverted

=



Final result

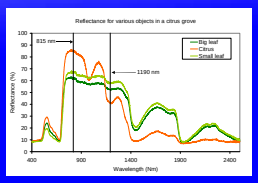


Original

MULTISPECTRAL / HYPERSPECTRAL IMAGING

So, if we combine …

+



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Hypercube

(Source: http://www.sciencedirect.com/science/article/pii/S003442570900073X)

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Applications

- Common applications – yield mapping, nutrient & disease detection, water stress, …
- Immature green citrus fruit detection
- Citrus greening disease (HLB) detection
- Blueberry fruit detection

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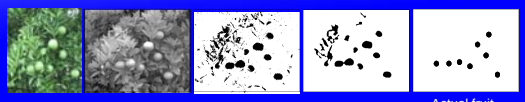
Immature green citrus detection



RGB image | Hyperspectral image | Pixel segmented image | Detected fruit | Actual fruit locations

Okamoto, H., and W. S. Lee. 2009. Green citrus detection using hyperspectral imaging. *Computers and Electronics in Agriculture* 66(2): 201-208.

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Multispectral Imaging

(Source: R. Ehsani)

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Summary for Multi- & hyper-spectral Imaging

- Hyperspectral imaging combines images with spectral information.
- Multispectral imaging is more suitable for practical applications due to cost and processing time.

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MAGNETIC RESONANCE IMAGING (MRI)

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Magnetic Resonance Imaging

- How MRI works? (2.5 min.)
  (http://www.youtube.com/watch?v=pGcZv5G805Y)

(Source: http://insideinsides.blogspot.com/2010/07/orange.html)

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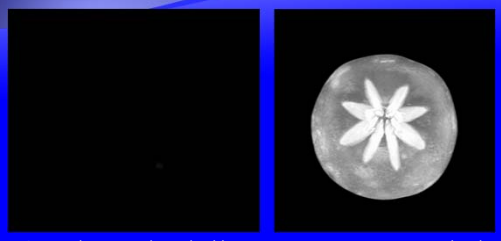
Persimmon



(Source: http://insideinsides.blogspot.com/2010/12/persimmon.html)

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More Facts on MRI

- Non-invasive & non-destructive method
- Not suitable for conveyor systems
- Takes long time for imaging
- Need much maintenance
- Safety
  - Strong magnetic field - avoid any metal objects!
  - Heating caused by radiowave absorption
- Cost
  - Conventional system: $1 – 3 million
  - Portable unit (Prepolarized MRI): $50,000 (http://www-mrsrl.stanford.edu/research.html#top)

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FLUOROSCOPY WITH X-RAY

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Fluoroscopy

- X-ray imaging technique for acquiring real-time moving images
- Low energy is sufficient for agricultural crops
- Instrument: less than $100,000

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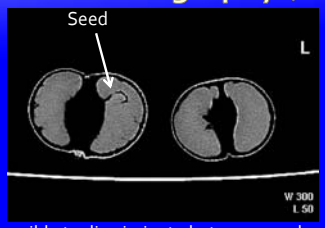
Mandarine Seed Detection using a Computed Tomography (CT) Image



(Source: http://spie.org/x84974.xml, 2012)

"Not possible to discriminate between seeds and pulp consistently using CT or x-ray images because of their similar densities…"

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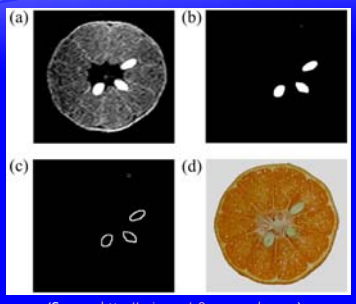
Mandarine Seed Detection using MRI

- 0.2 T used
- Took 7 sec



(Source: http://spie.org/x84974.xml, 2012)

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Overall Summary

- Many non-destructive sensing technologies are available
- Each has its own advantages and limitations
- NIRS, multispectral imaging, and X-ray have great potential and promising…

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THANK YOU!

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