Hyperspectral Images Applications

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- Bruise Detection of Apples
- Fish Freshness
- Citrus Fruit Inspection
- Sugar Distribution of Melons
- Sorting potatoes

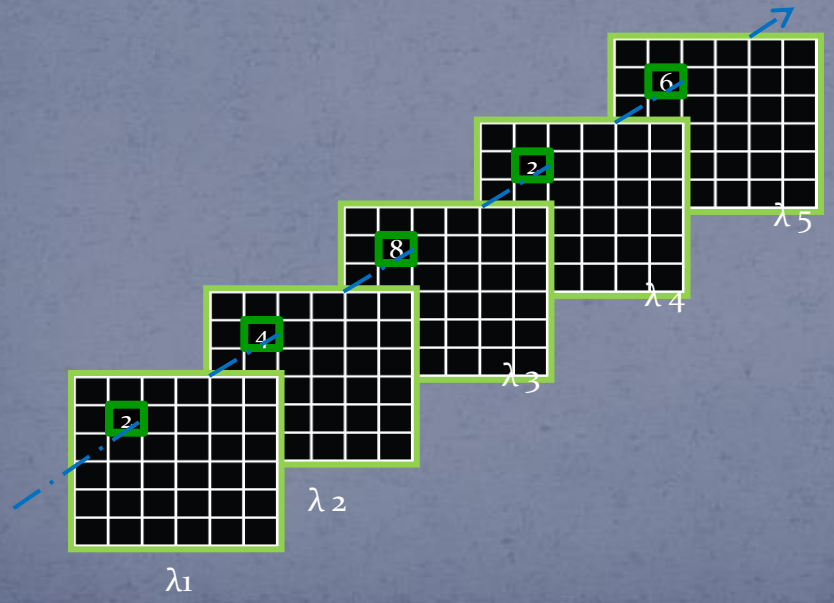
Forensic Science :
- Questioned Document Analysis
- Fire Investigation
- Bloodstain Visualization
- Fiber Comparison
- Gun Powder Residue Visualization
- Duct Tape Examination
- Fingerprint Enhancement

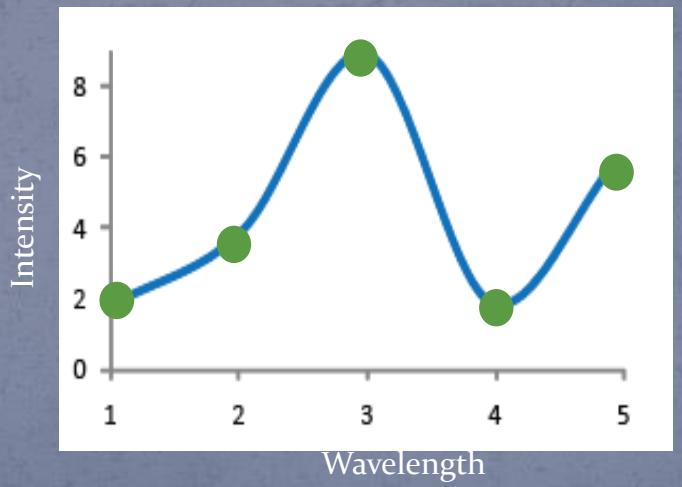
Medical :
- Diabetic Foot Ulcers
- Normal and Malignant Colon Tissue Citrus

What Is Hyperspectral Imaging?

Hyperspectral Imaging (HSI) is a spectroscopic method, combining digital imaging with conventional spectroscopy.

1. HSI collects images as a function of wavelength.
2. HSI provides an individualized reflectance or fluorescence spectrum for each pixel in an image.

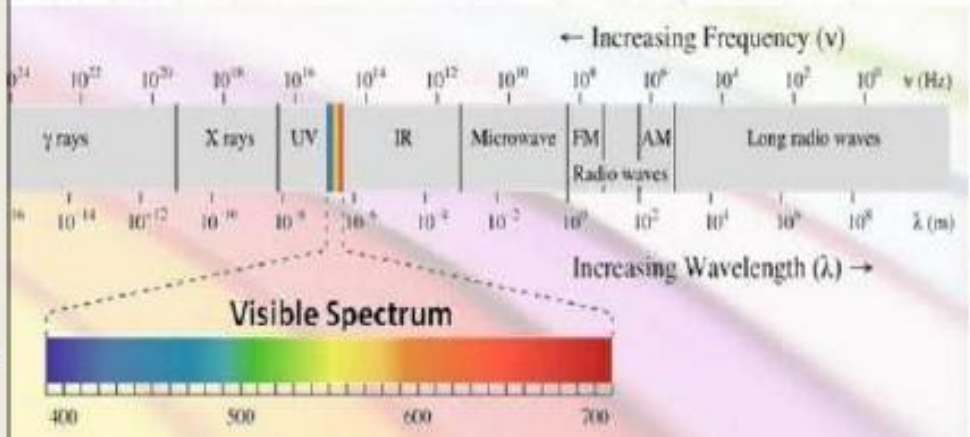




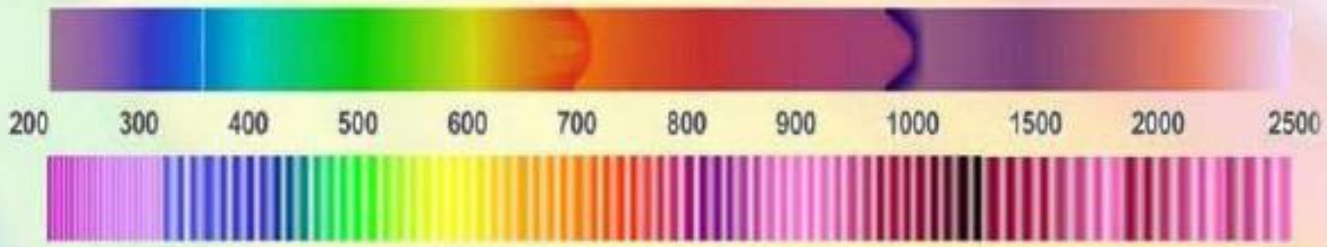
What Is Hyperspectral Imaging?

Humans can see visible light which has a spectral range between 400 to 700 nanometers. Themis Vision cameras can process and record information in the range of 200 to above 2500 nanometers.

Hyperspectral Imaging is the process of scanning, processing and displaying an image within this spectral range..



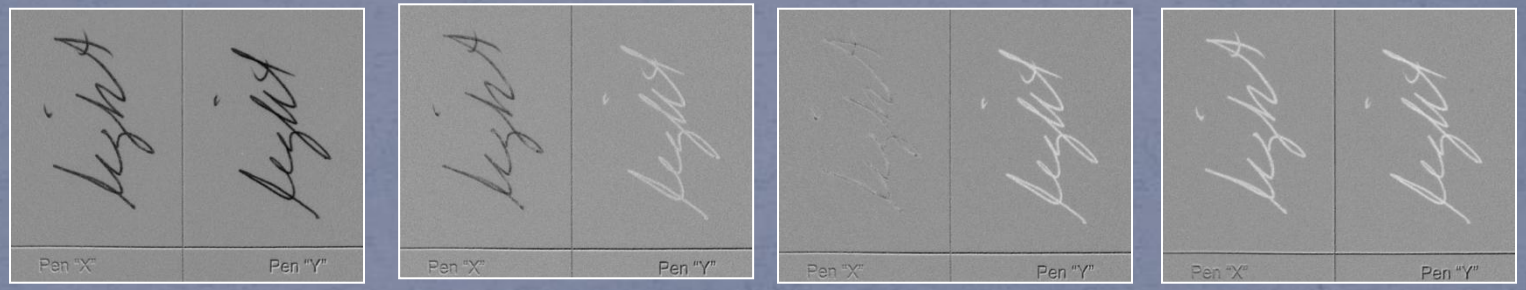
Spectroscopy can detect a much wider region of the EM spectrum than the visible range of 400 nm to 700 nm.



What Is Hyperspectral Imaging?

The images in a HSI dataset can be viewed to determine:

- At which wavelengths, if any, a difference in intensity is seen between two samples being compared
- At which wavelength differing contrast is displayed between an area of interest (i.e. a fingerprint or a stain) and the substrate



HSI images of two black ballpoint inks being compared at 620nm, 700nm, 720nm, 760nm (from left).

The HSI Instrument

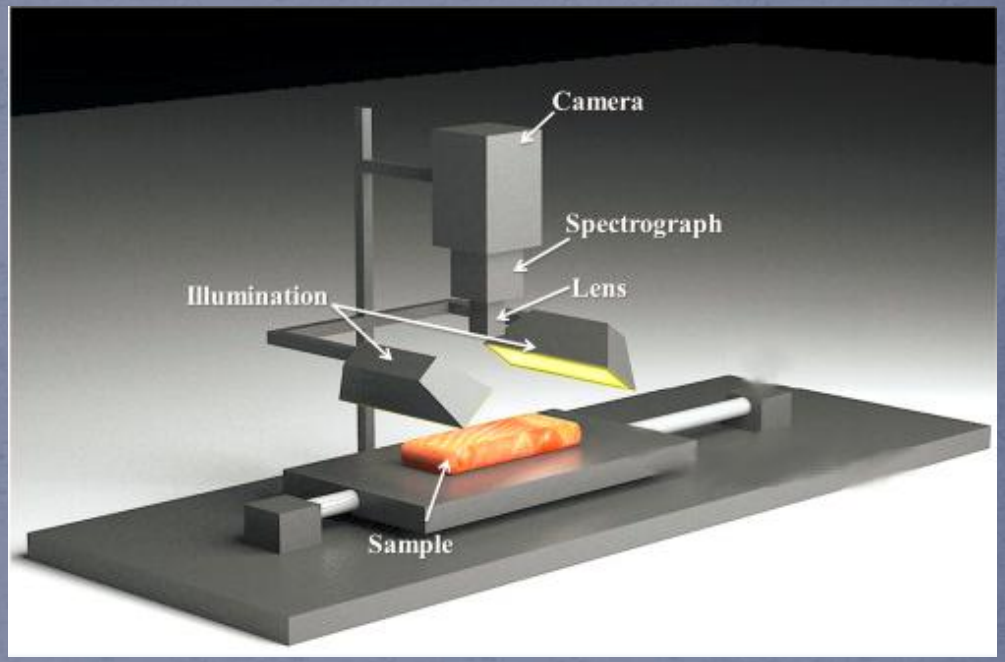
Instrument Components:

•**Light Source**: Illuminates the sample. White light can be used for visible and NIR data collection and specific wavelengths can be selected for fluorescence data collection.

•**Imaging Optics**: Collects sample reflectance or fluorescence wavelengths along with all illumination wavelengths.

•**Tunable Filter**: Allows only a specific wavelength corresponding to a particular image frame to be detected by the camera.

•**Imaging CCD**: Records intensities of individual pixels for each wavelength in the data collection range.



Introduction- Food Industry

- Hyperspectral imaging use in the food industry for quality and safety evaluation and inspection.
- Quality and safety is the key factor in modern food industry.
- Currently conventional food measurement methods are destructive and inefficient.
- Development of non-destructive and efficient measurement tool .
  - Optical sensing technologies.

Two Technologies

- A conventional imaging system or more specifically computer vision is a common technique for obtaining spatial information of the sample.
  - surface texture evaluation of food products and for surface defects detection in food inspection
- Conventional spectroscopy system is a technique for evaluating chemical properties or characteristics of food products.
  - cannot cover a large area or a small area with high spatial resolution

The Main Features Integration

- Hyperspectral imaging (or imaging spectroscopy) is based on two mature technologies of imaging and spectroscopy .
- It can simultaneously acquire spatial and spectral information.

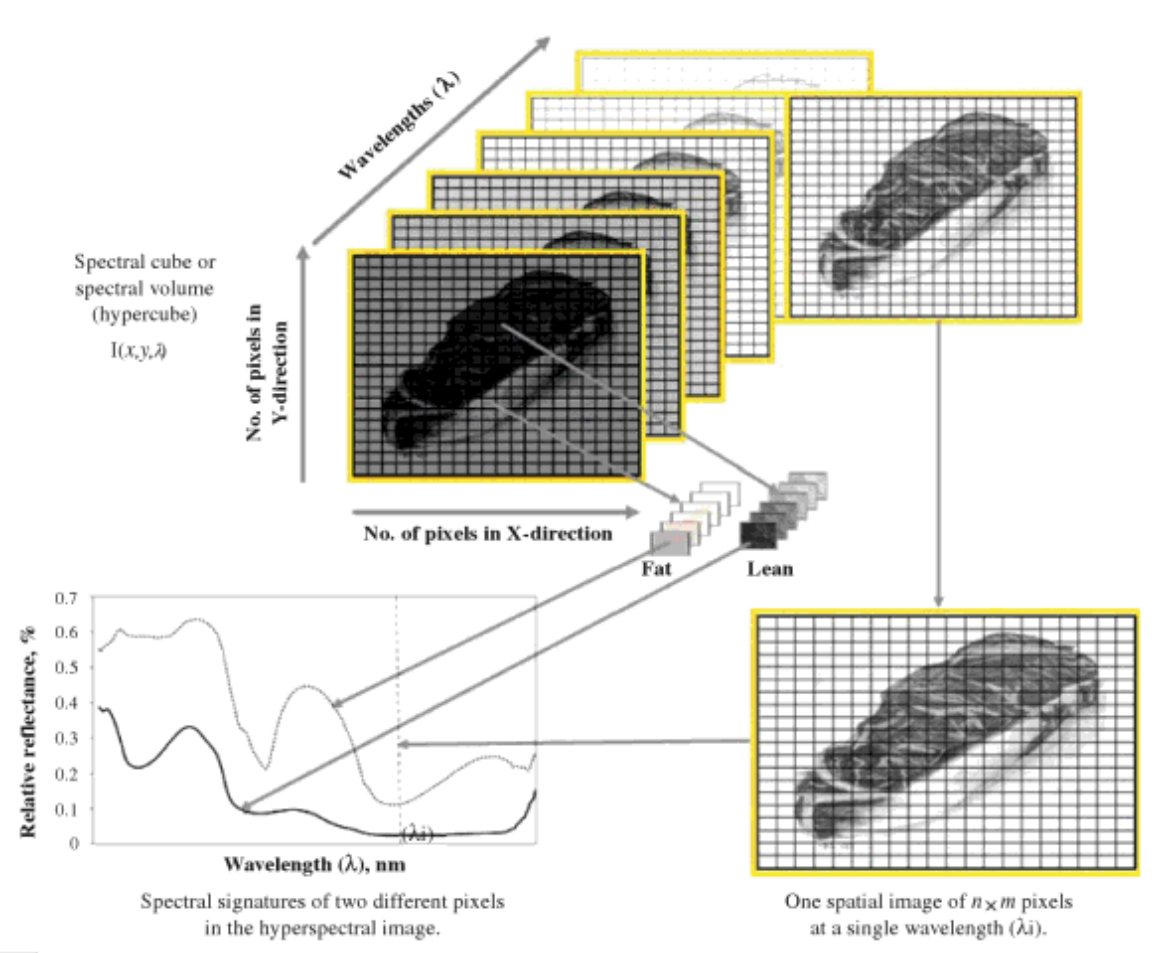
Main differences among imaging, spectroscopy, and hyperspectral imaging techniques

Features	Imaging	Spectroscopy	Hyperspectral imaging
Spatial information	√	×	√
Spectral information	×	√	√
Multi-constituent information	×	√	√
Building chemical images	×	×	√
Flexibility of spectral information extraction	×	×	√

Hyperspectral Imaging Technique

❖ Schematic diagram of hyperspectral image (hypercube) for a piece of meat.
Showing the relationship between spectral and spatial dimensions.

❖ Every pixel in the hyperspectral image is represented by an individual spectrum containing information about chemical composition at this pixel.



Hypercube

- In this hypercube, each spectral pixel corresponds to a spectral signature (or spectrum) of the corresponding spatial region.
- The measured spectrum indicates the ability of the sample in absorbing or scattering light, representing chemical properties of a sample.
- Hyperspectral imaging is a technique to provide the answer to the question of where is what.

Applications

Hyperspectral Imaging and Food Industry

- HSI can be applied to numerous areas of food industry:
  - Bruise Detection of Apples
  - Fish Freshness
  - Citrus Fruit Inspection
  - Sugar Distribution of Melons
  - Sorting potatoes

Bruise Detection of Apples

- Development of an automated bruise detection system will help the fruit industry to provide :
  - Better fruit for the consumer .
  - Reduce potential economic losses.

- Bruising normally happens to the tissue beneath the fruit skin.

http://www.youtube.com/watch?v=XY3vKATg8EY

Bruise Detection of Apples

- The bruise damages of apples are normally due to impact, compression, vibration, or abrasion during handling.
- The impact bruise may not be visible immediately when the impact applies.
  - The symptom appears after a certain period of time.

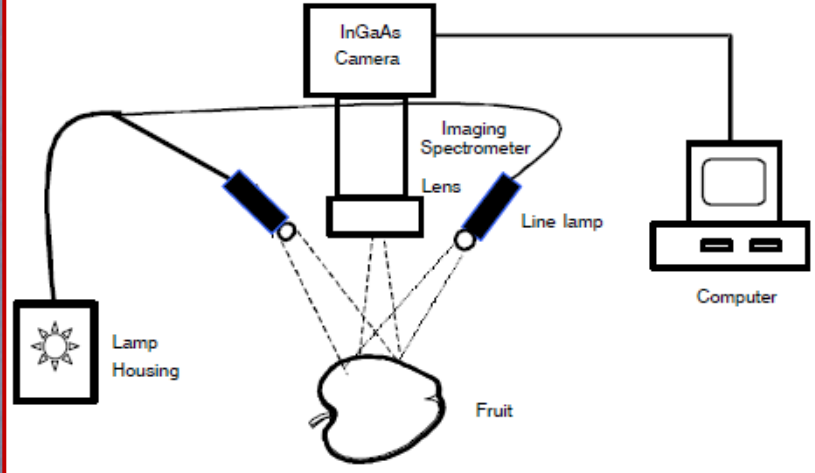
Therefore…

- Early detection of such impact bruise is needed in order to improve the product quality.

Bruise Detection of Apples – HIS System

A hyperspectral imaging system developed for the study.
The system mainly consisted of :

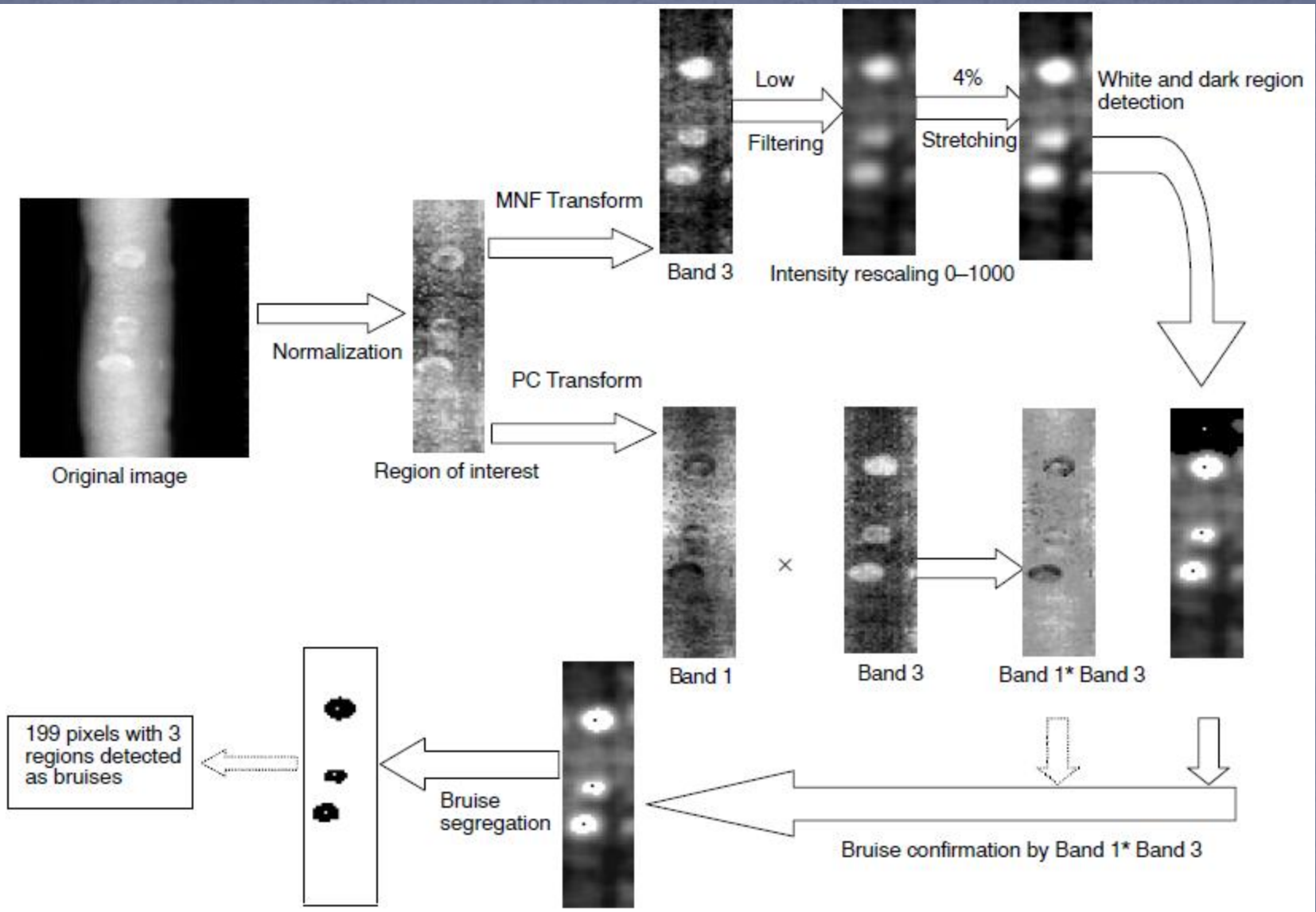
- An InGaAs area array camera (Sensors Unlimited,Princeton, N.J.) covering the spectral range between 900 nm and 1700 nm.
- An imaging spectrograph attached to the camera.
- A 25 mm focal length TV Lens
- Computer.



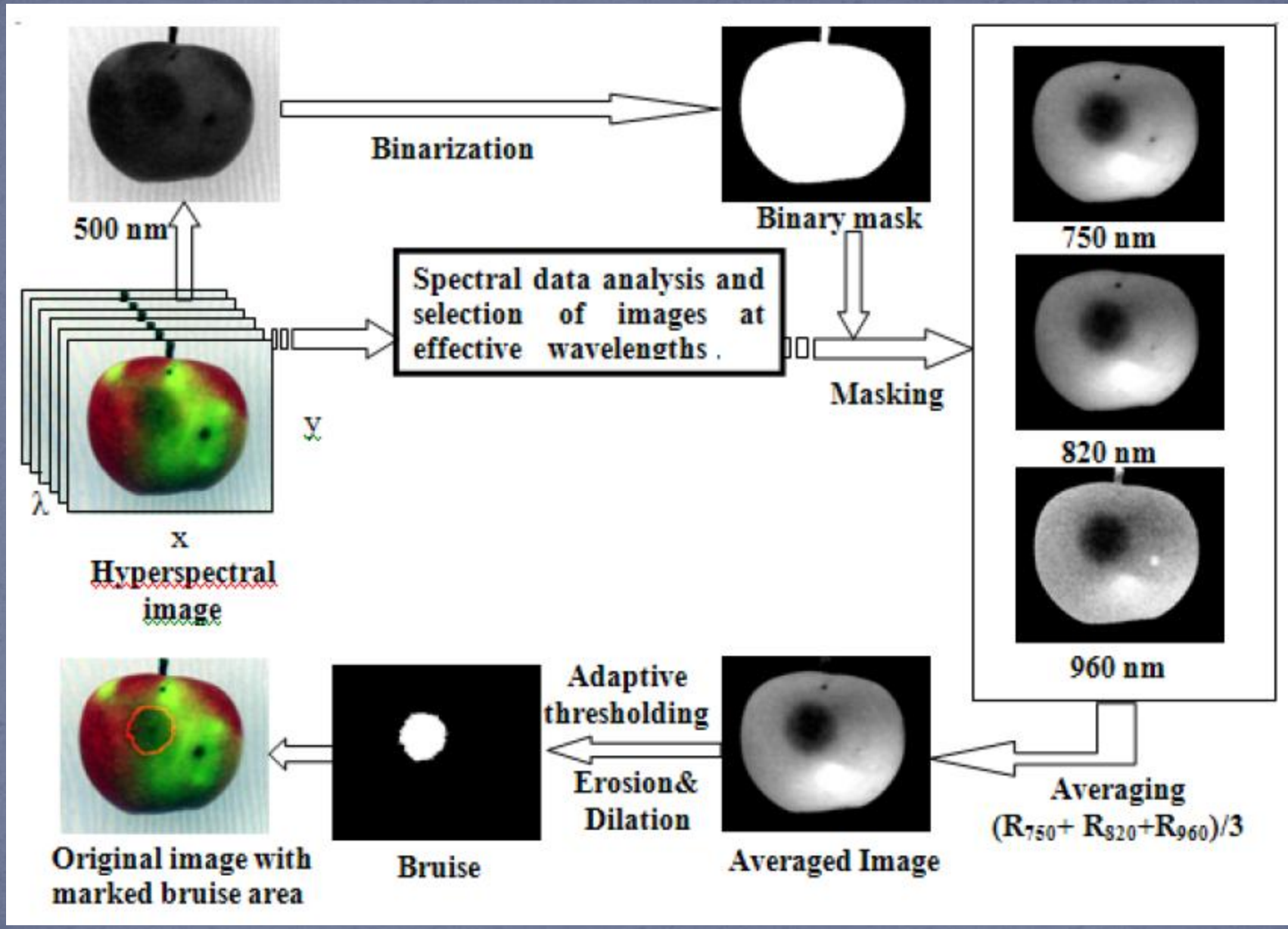
Schematic of the near–infrared hyperspectral imaging system for detecting bruises on apples.

Course Of Events …

- The light beam entered the spectrograph
  - It was dispersed into different directions according to wavelength.
- The dispersed light was then mapped onto the InGaAs detector .
  - resulting in a two–dimensional image, one dimension representing the spectral axis and the other the spatial information for the scanning line.
- By scanning the entire surface of the fruit.
  - three–dimensional hyperspectral image cube was created, where two dimensions represented the spatial information and the third represented the spectral information.

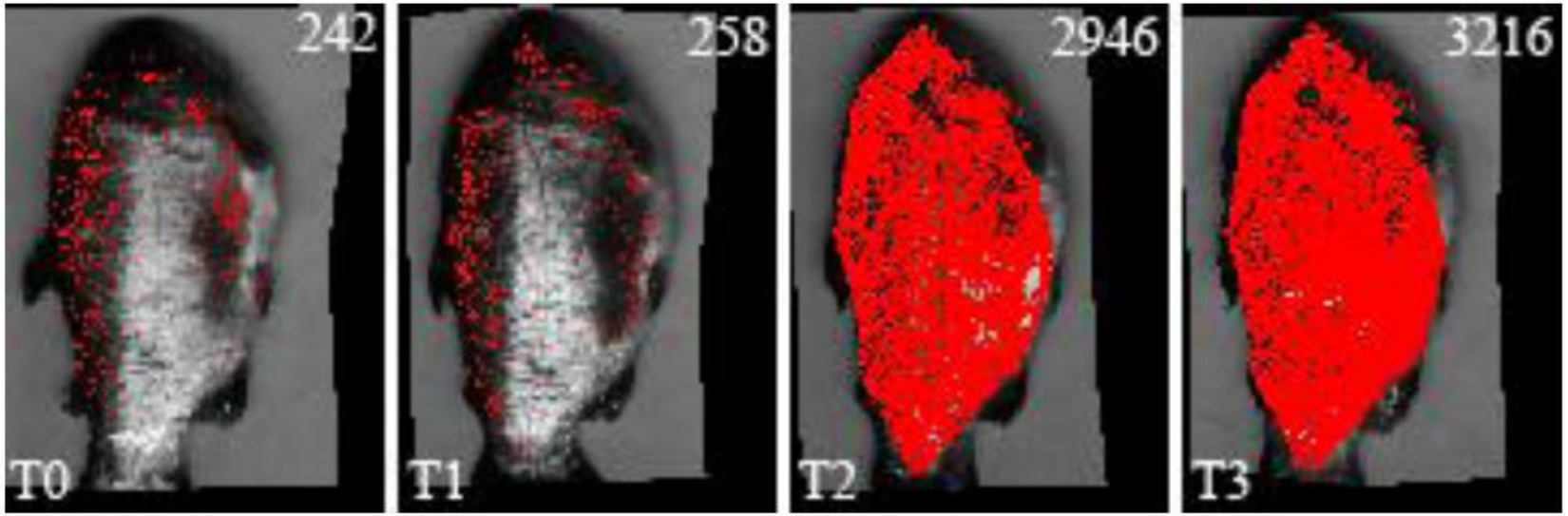


Flowchart showing the procedures used to detect bruises on apples.


Binarization
500 nm
Binary mask
Spectral data analysis and selection of images at effective wavelengths .
Masking
750 nm
820 nm
960 nm
y
λ
x
Hyperspectral image
Adaptive thresholding
Erosion& Dilation
Averaging
$(R_{750}+ R_{820}+R_{960})/3$
Original image with marked bruise area
Bruise
Averaged Image

Fish Freshness

- Using hyperspectral imaging as a method to provide an objective and qualitative evaluation of the state of the fish freshness.



Example of fish freshness classification (pixels in red are those classified as 'non-fresh').

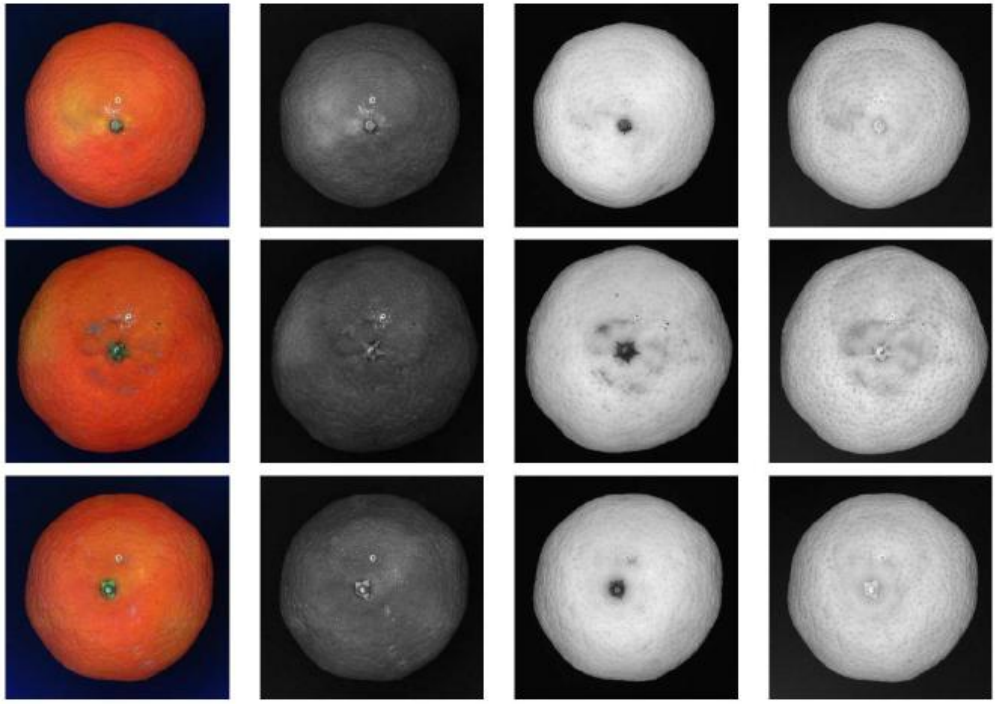
Fish Freshness

- The study focused on establishing a correlation between the spectral reflectance of selected areas of the epidermis and the time of storage in standard refrigeration.
- Hyperspectral imaging provide a valid contribution in relation to the monitoring of the organoleptic properties of fish production during all steps along the production chain.

Citrus Fruit Inspection

- Citrus fruit is another type of fruits that require early detection.
- A small number of fruit that infected by fungi can spread the infection to a whole consignment of citrus fruit.
- HIS technique allows studying the reflectance of defects and other regions of interest in particular wavelengths.
  - Important for early rot detection.

Citrus Fruit Inspection

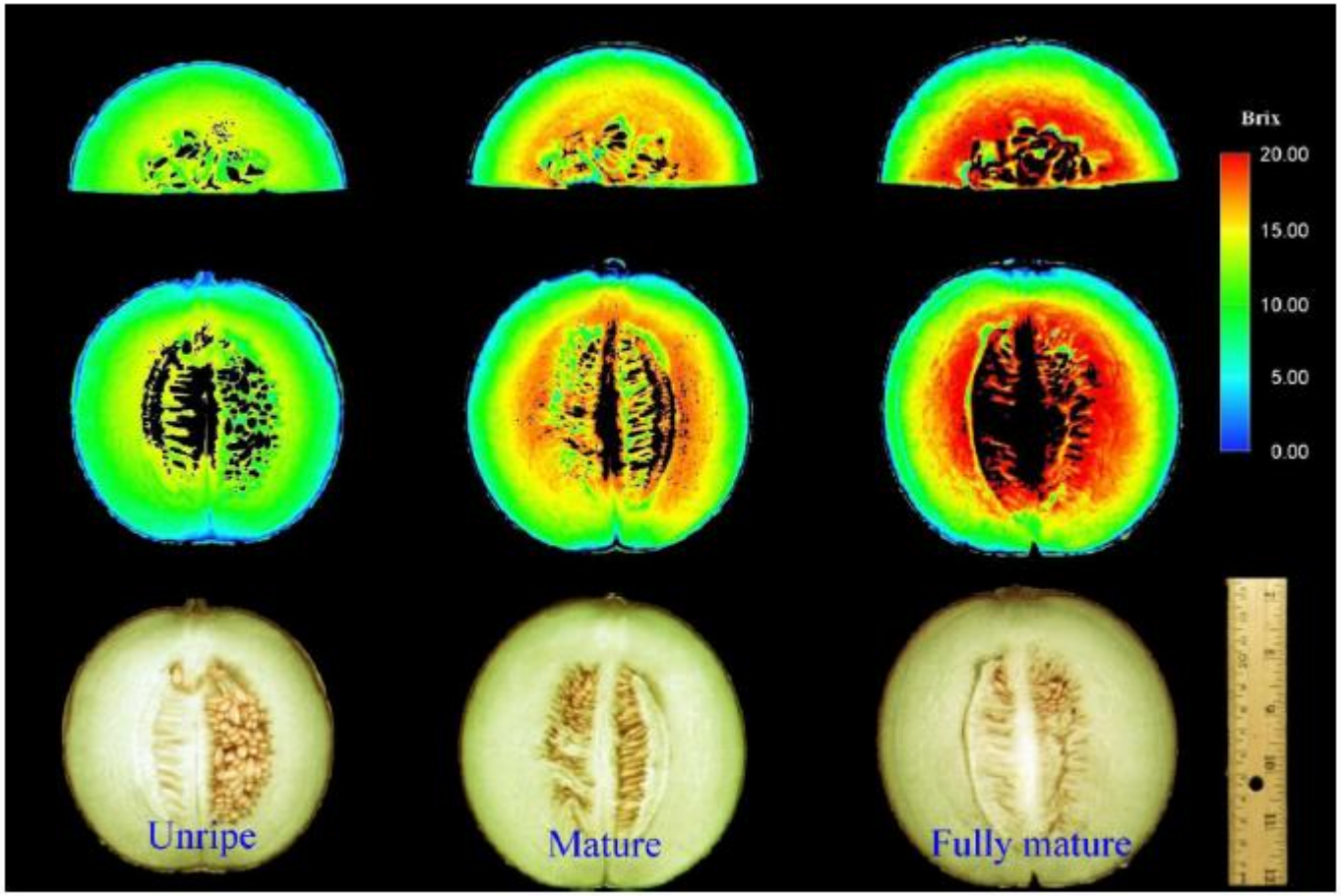


RGB and monochromatic images (550 nm, 660 nm and 950 nm) of various mandarins

Sugar Distribution of Melons

- Using HSI to predict the sugar content distribution in melons.
- It was found that the absorbance at 676 nm was close to the absorption band of chlorophyll and exhibited a strong inverse correlation with the sugar content.
- Each pixel of the absorption image was converted, a color distribution map of the sugar content.

Sugar Distribution of Melons



Sugar distribution map for unripe, mature and fully mature melons .

Sorting potatoes – HELIOS EC3 system

- The new technology, EC3, is meant as a bridging of spectroscopy and industrial image processing.
- EC3 systems were specially designed for system integrators.
- Can be easily configured for various materials (e.g. different plastics, minerals, food, ...) and the information of that materials are provided color coded.
- Following these "chemical color information" can be easily processed by standard image processing methods.

Sorting potatoes

http://www.youtube.com/watch?v=GzK-CcqryR8

- Detection sugar potatoes with chemical imaging.
- During the scan detects molecules in the potatoes that responding differently.
  - Meaning percentage of sugar and liquids different than normal.
- The chemical information transformed into the color space ,so EC3 could be integrated it to hypercube.
- By the hypercube it will be possible to detect defect potatoes.

Benefits of HSI in food Industry

- The application of an HSI system will, perhaps, be accelerated in the field of food safety.
- Public health officials realized benefits of spectral imaging in the food industry, including:
  - Shorter detection times.
  - Acquisition of a unique spectra for bacteria, permitting for more accurate results .
  - Monitoring the production of a large quantity of foods.
- Bottom Line non-destructive, quality and safety evaluation , inspection and economic.

Introduction- Forensic Science

- Infrared chemical imaging and Raman chemical imaging have enormous potential in forensic science.
  - because of their greater chemical specificity (compared with UV-visible chemical imaging techniques).

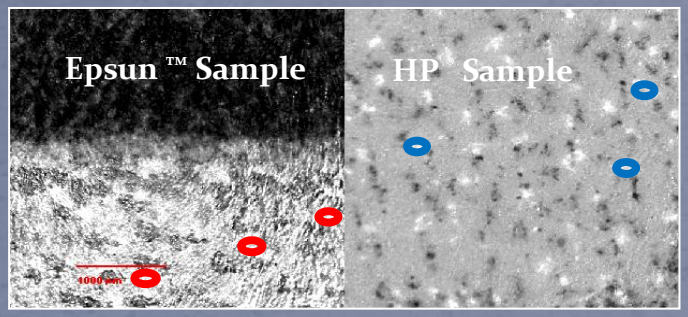
- Infrared (or Raman) spectra can be used to precisely identify materials in a heterogeneous sample.

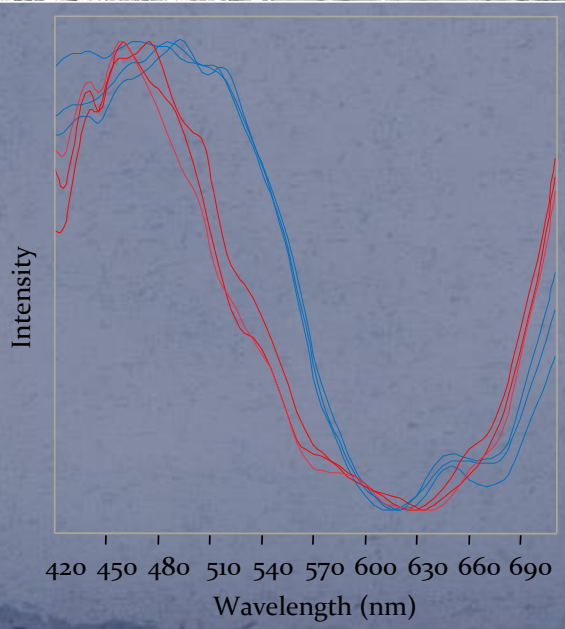
Hyperspectral Imaging and Forensic Science

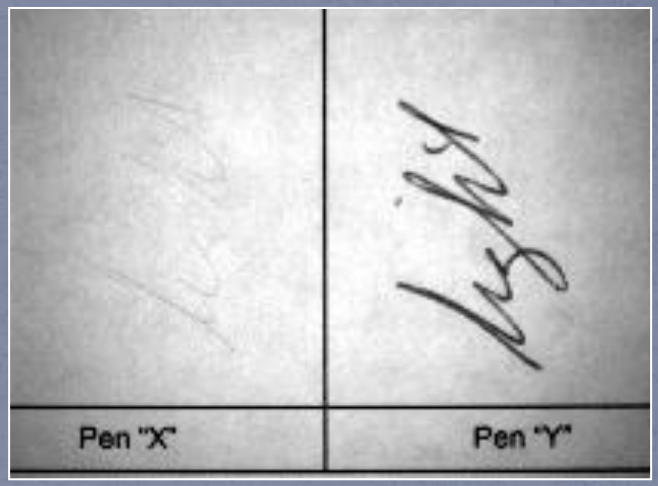
- HSI can be applied to numerous areas of forensic investigation:
  - Questioned Document Analysis
  - Arson Investigation
  - Bloodstain Visualization
  - Fiber Comparison
  - Gun Powder Residue Visualization
  - Duct Tape Examination
  - Fingerprint Enhancement
  - TLC Plate Visualization

Questioned Document Analysis

HSI can be applied to comparisons of traditional handwritten documents as well as computer printed or copied documents to reveal dissimilarities between samples.



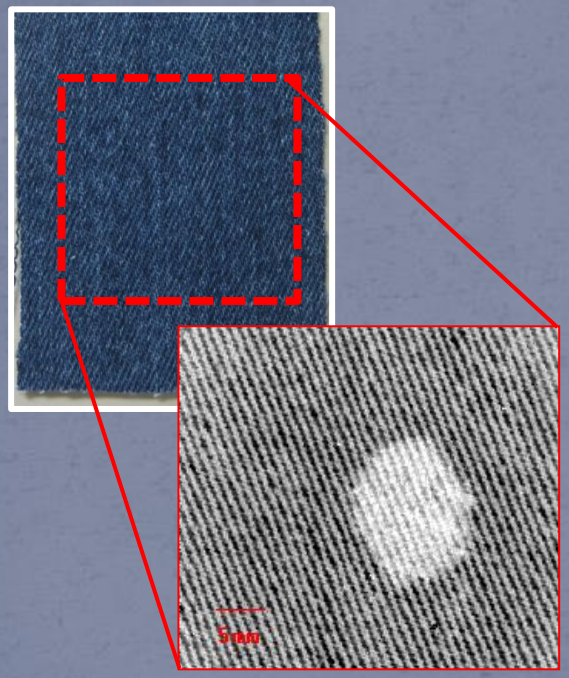


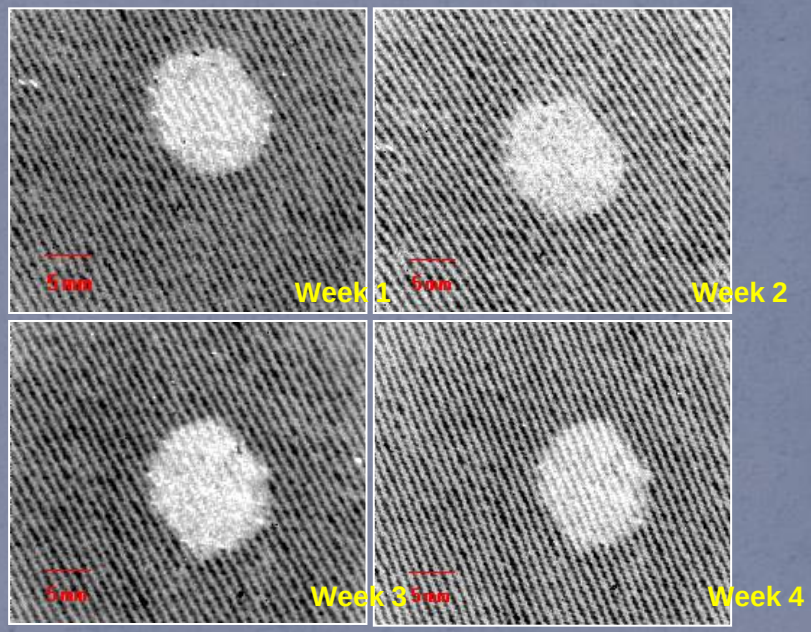


Top left: Hyperspectral image of two inkjet printer samples.
Bottom left: Spectral comparison of cyan ink droplets from the two inkjet samples.
Right: Hyperspectral image of two black ballpoint ink samples.

Fire Investigation

HSI can detect µL size quantities of ignitable liquid residues on substrates, even weeks after their deposition. HSI visualizes the fluorescence of the dyes and additives in the residues that persist after the hydrocarbon components evaporate.

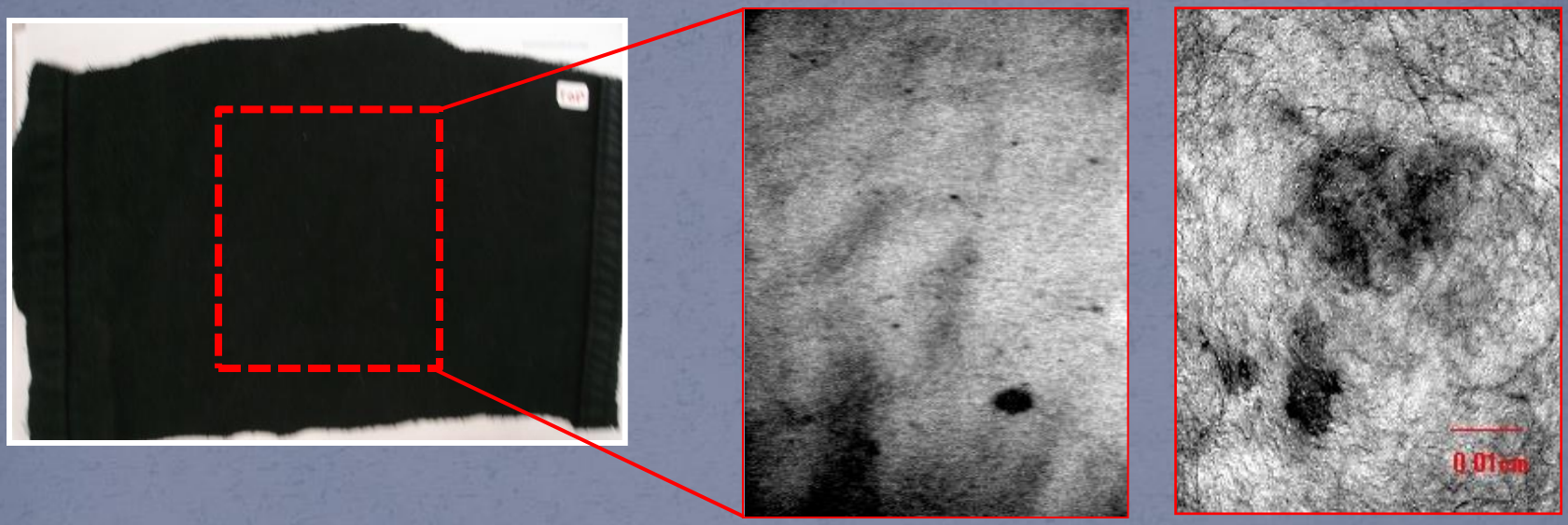




Left: Digital and fluorescence hyperspectral image of 20µL gasoline on denim fabric.
Right: Hyperspectral images of gasoline (20 µL) on denim 1-4 weeks after deposition.

Bloodstain Visualization

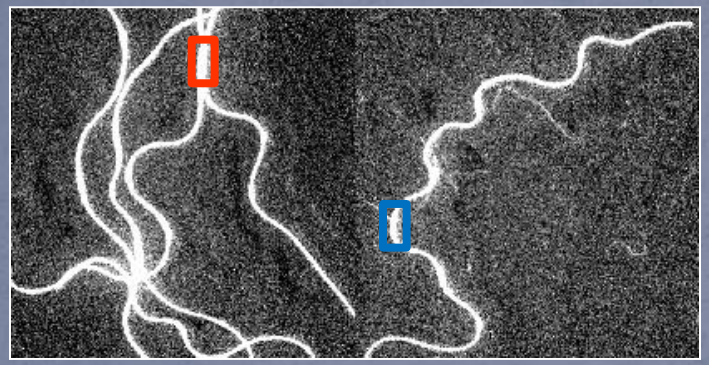
HSI can visualize contrast between bloodstains and dark substrates. Individual droplets can also be imaged in a magnified view to determine the shape of the droplet.

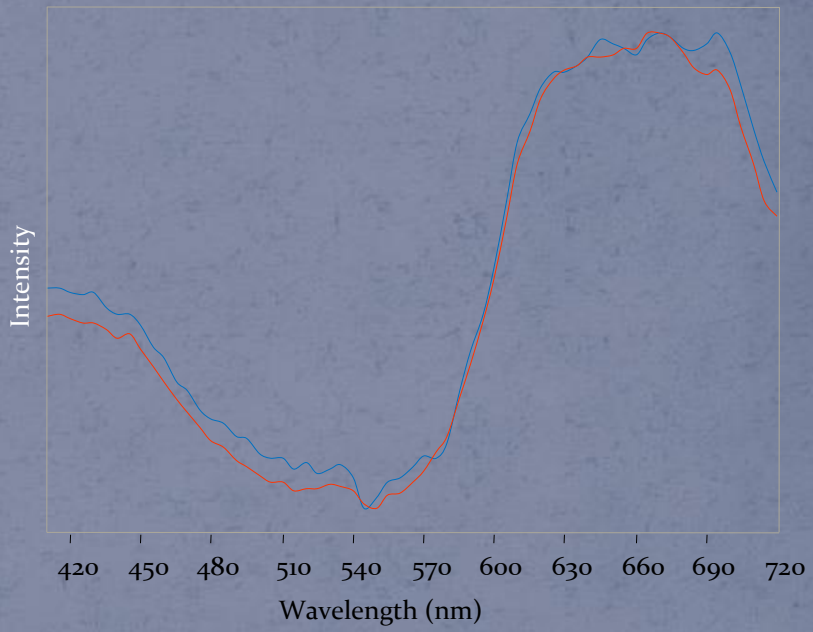


Left: Digital image of a piece of black fabric containing bloodstains which cannot be seen with the unaided eye.
Middle: Hyperspectral image of blood droplets on the black fabric.
Right: Magnified view of blood droplets on black fabric.

Fiber Comparison

HSI can collect both reflectance and fluorescence data of fibers being compared to determine if there are any differences in intensity between dye components.

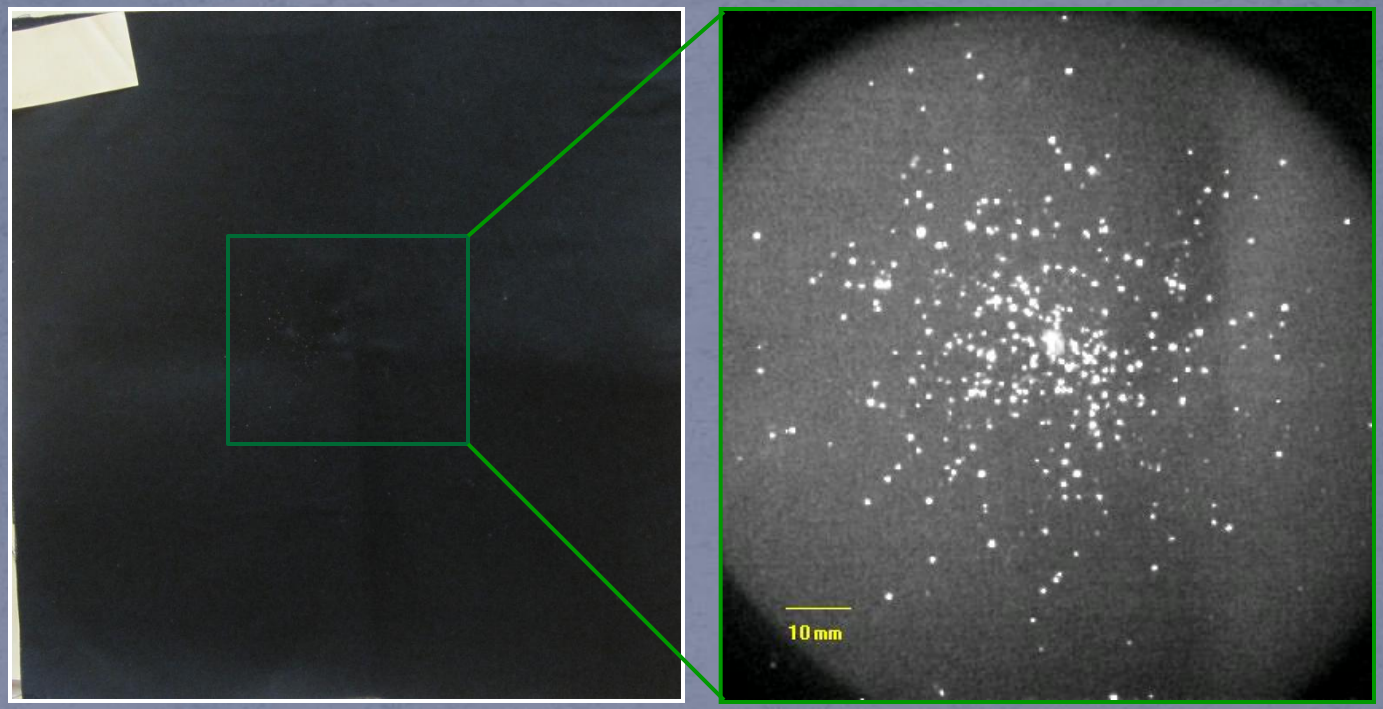




Left: Comparison of fluorescence hyperspectral images of similar fibers.
Right: Fluorescence spectra of the two fibers.

Gun Powder Residue Visualization

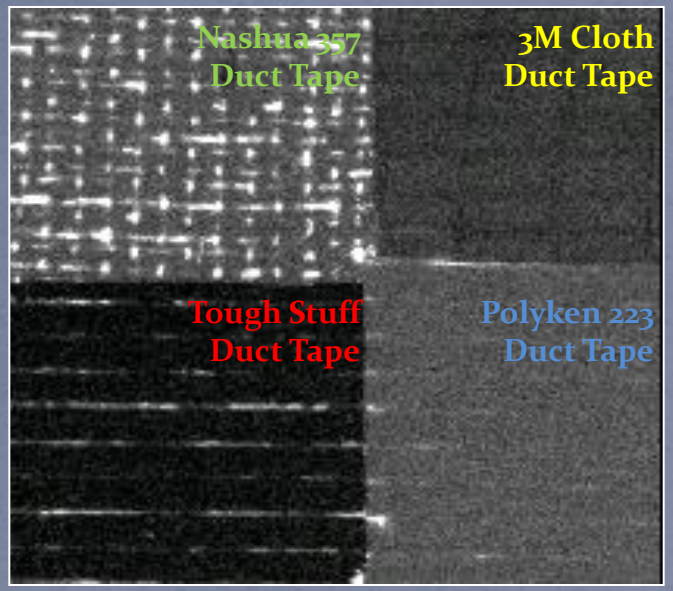
HSI can visualize the fluorescence of gun powder residue directly on a dark or patterned substrate.

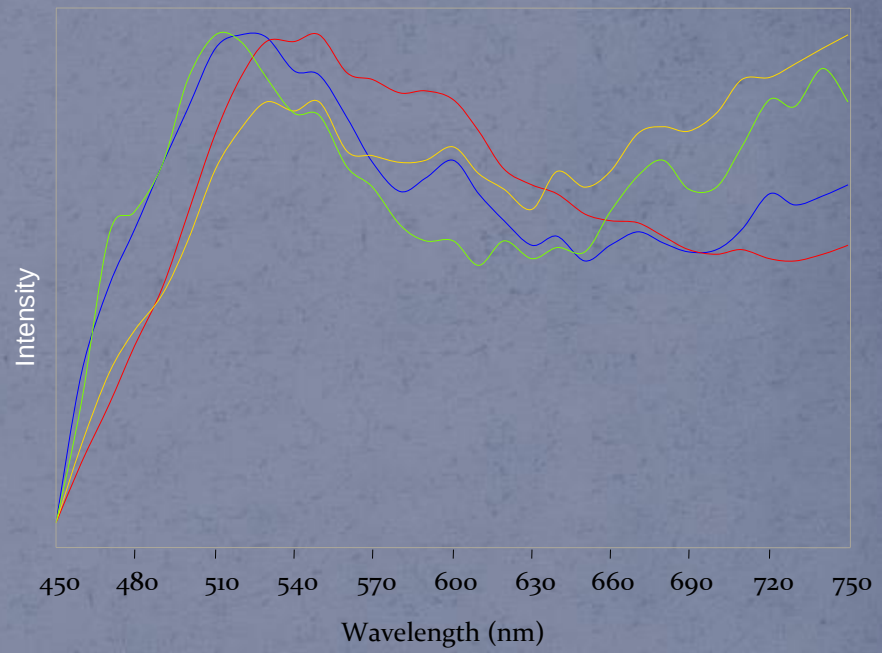


Left: Digital image of a piece of black fabric containing gun powder residue on its surface.
Right: Fluorescence hyperspectral image of gun powder residue on the black fabric.

Duct Tape Examination

HSI can aid in the examination of intact duct tape by providing fluorescence data for the adhesive, backing, and scrim of the tapes.





Left: Fluorescence hyperspectral image of four different duct tapes, adhesive side.
Right: Spectra of the four duct tapes being compared: Tough Stuff (red), Polyken (blue), Nashua 357 (green), and 3M Cloth (yellow).

Fingerprint Enhancement

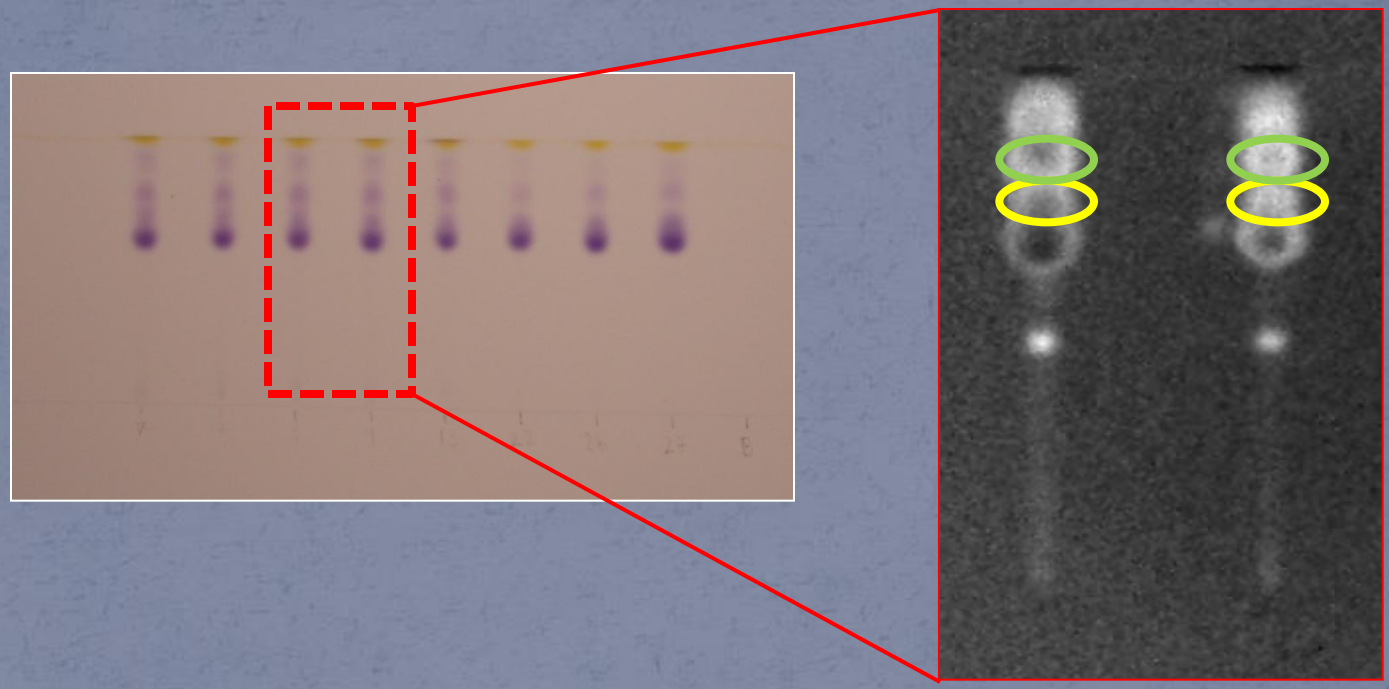
HSI can produce images with increased contrast between both treated and untreated fingerprints and the substrate on which they are placed, revealing ridge detail that was not previously discernible.

Left: Digital and hyperspectral image of an untreated latent fingerprint on white paper substrate.
Right: Digital and hyperspectral image of a ninhydrin-developed fingerprint on newspaper.

http://www.youtube.com/watch?v=8xiwllidjtE

TLC Plate Visualization

HSI, using both fluorescence and white light reflectance, can reveal additional features on TLC plates.



Top: Digital image of a TLC plate containing extracts of black ballpoint inks.
Bottom: Fluorescence hyperspectral comparison of two black ballpoint inks. HSI is capable of visualizing additional discriminating features.

Benefits of HSI in Forensics

- HSI provides both digital and spectral data
- HSI a versatile technology and can be applied to numerous forensic analyses
- HSI can be used in conjunction with traditional examination methods
- HSI results are intuitive to interpret for both the scientist and the jury
- HSI is nondestructive and requires little to no sample preparation
- Additional multivariate processing steps can be applied to HSI data without re-examining the evidence itself

Introduction - Medical Diagnoses

- Disease prevention and early disease detection are both paramount to maintaining good health.
- Early detection lead to effective therapy.
  - can applied to avoid permanent damage.
- An application of hyperspectral analysis could provide early detection of various types of cancer or retinal disease.
- In addition, hyperspectral imaging system could be used to test for infection or abnormalities in bodily fluids (blood, urine, semen) and to determine blood and oxygen levels in tissue, especially during surgery.

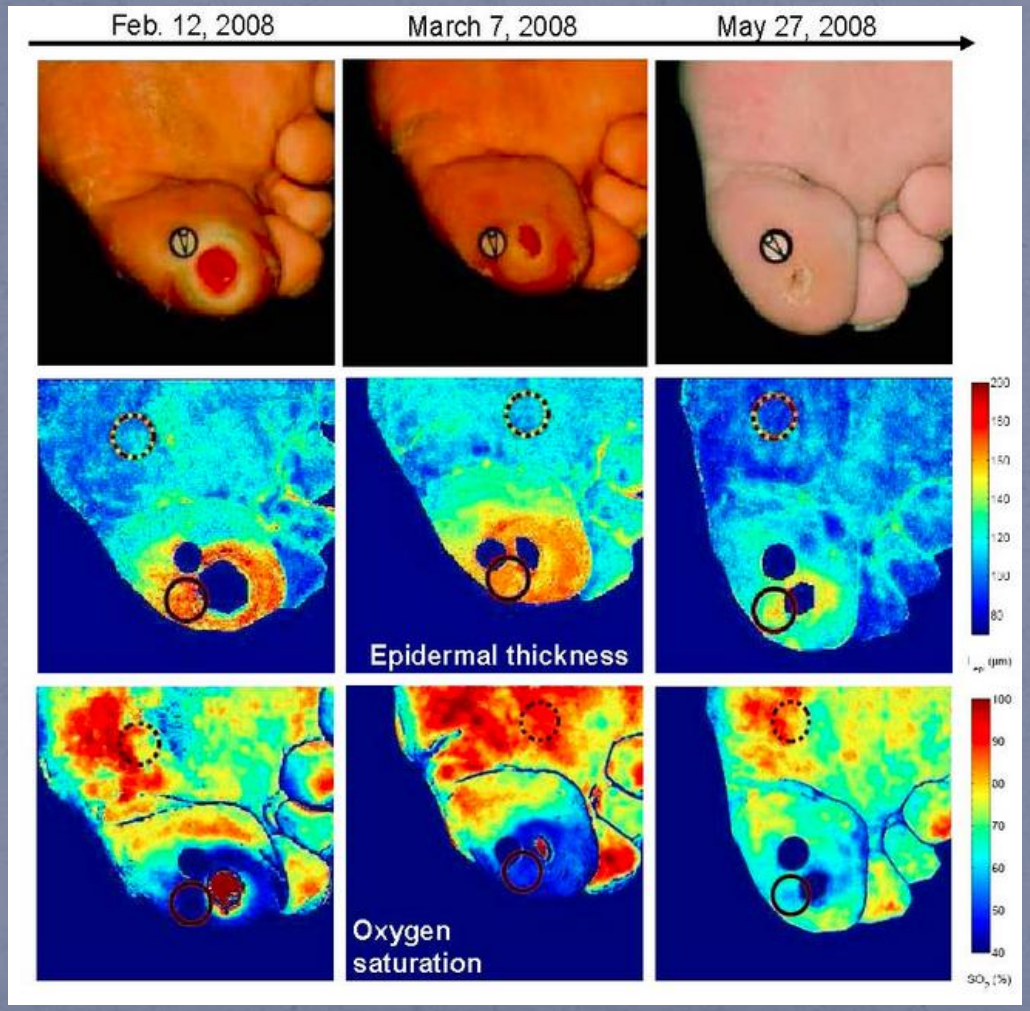
Hyperspectral Imaging and Medical Diagnoses

- HSI can be applied to numerous areas of medical diagnoses:
  - Diabetic Foot Ulcers
  - Normal and Malignant Colon Tissue

Healing of Diabetic Foot Ulcers

- Hyperspectral imaging of the feet of two diabetic patients was performed before, during, and after they developed foot ulcer.
- The present study examined the temporal changes observed before the ulcer became apparent to the naked eye until it healed and closed.
- Variables of interest were local epidermal thickness, dehoxyhemoglobin, oxyhemoglobin, as well as oxygen saturation.

Healing of Diabetic Foot Ulcers



Healing of Diabetic Foot Ulcers -Conclusion

- This study showed that epidermal thickening and decrease in oxyhemoglobin concentration can be detected non-invasively prior to ulceration at pre-ulcerative sites.
- The algorithm was also able to observe reduction in the epidermal thickness combined with an increase in oxyhemoglobin concentration around the ulcer as it healed and closed.
- This methodology can be used for early prediction of diabetic foot ulceration in a clinical setting.

Hyperspectral Analysis of Normal and Malignant Colon Tissue

- Evaluate the diagnostic efficiency of hyperspectral microscopic analysis of normal and neoplastic colon biopsies prepared as microarray tissue.

- Analytic algorithm.

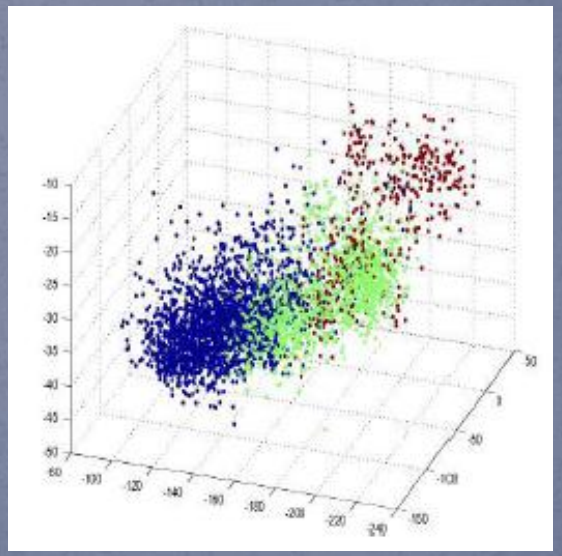
Mathematical Algorithms

- **Data Preprocessing and Normalization**
  - De-noise the original 128 spectra.
  - Normalize the pixel spectra.
- **Tissue Type Classification**
  - The first step is to differentiate among tissue types: gland nuclei &

    cytoplasm, and lamina propria.

Algo 1 :

- **Local Discriminant Bases**
  - This algorithm identifies spectral features that discriminate between the tissue types and projects the spectra onto these features.

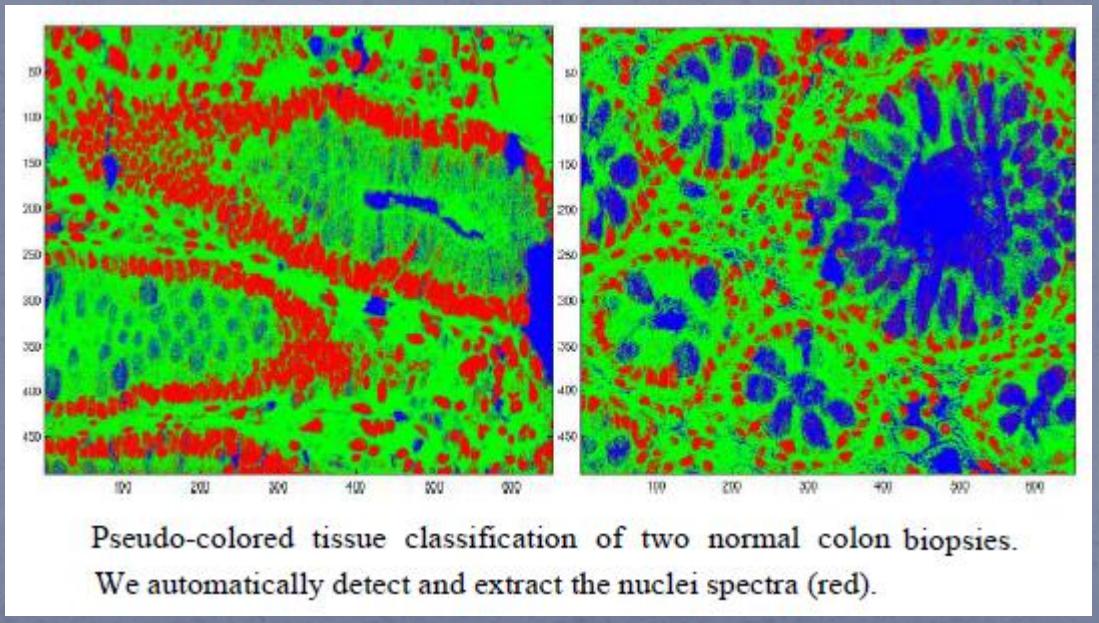


Projection of the normal training set onto these tissue features: nuclei (red), cytoplasm (green) lumens/lamina propria (blue).

Mathematical Algorithms

Algo 2 :

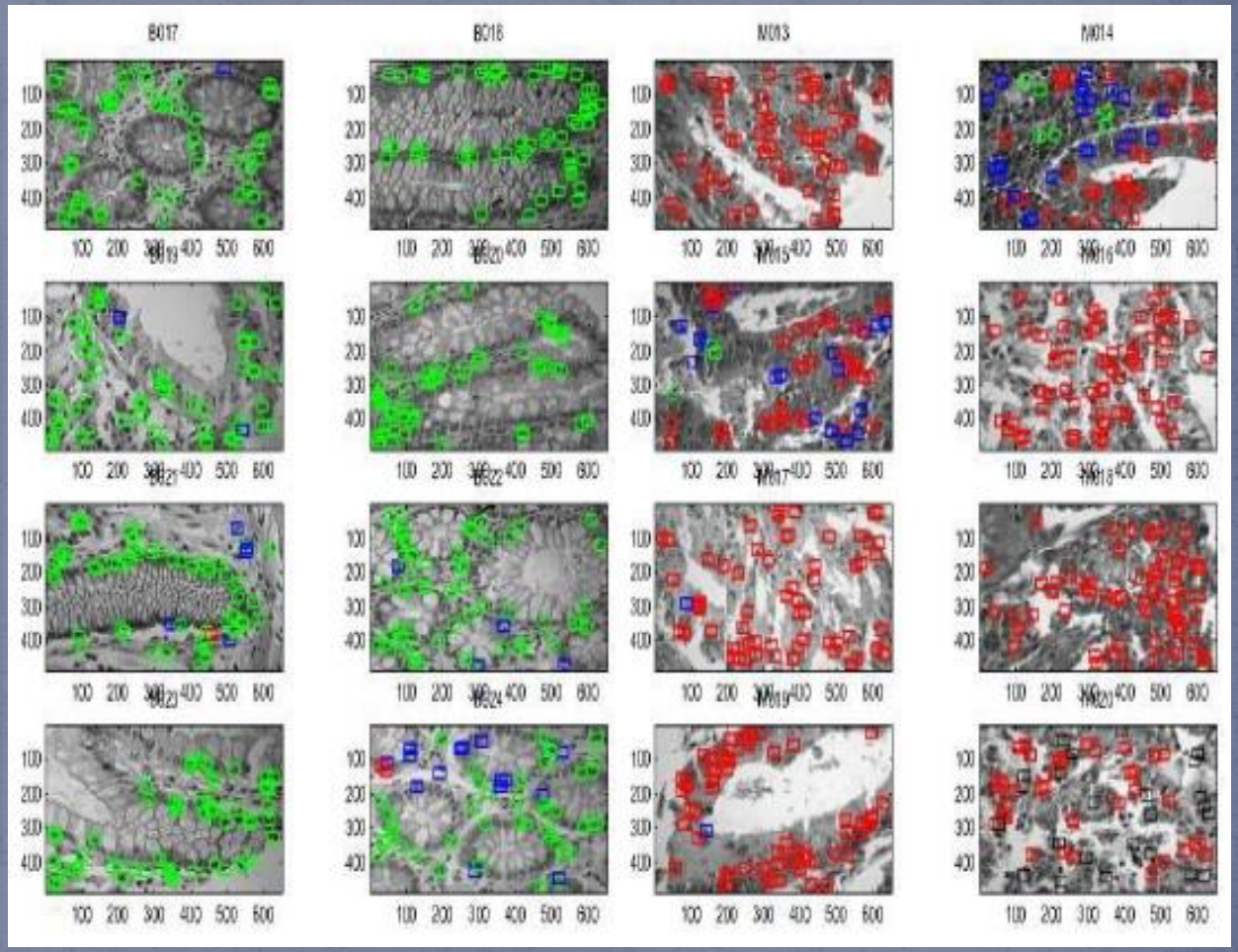
- **Nearest-Neighbor classification**
  - This algorithm acts on that projection and classifies each spectrum as one of the tissue types



Pseudo-colored tissue classification of two normal colon biopsies. We automatically detect and extract the nuclei spectra (red).

Normal and Malignant Colon Tissue

- **Spectral classifier on nuclei.**
- **Normal** (left 2 cols) :
  - GREEN – true negative (normal classified as normal);
  - BLUE – indeterminate
  - RED – false positive (normal classified as abnormal)
- **Abnormal** (right 2 cols):
  - GREEN – false negative (abnormal classified as normal)
  - BLUE – indeterminate
  - RED – true positive (abnormal classified as abnormal).



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