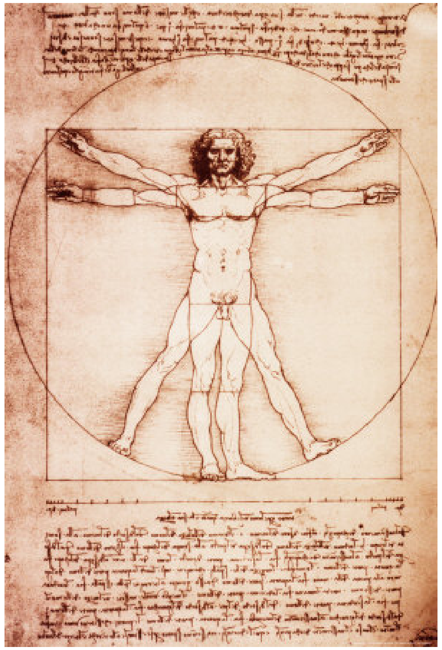
The NIST Hyperspectral Image Projector for Digital Tissue Phantoms

While Earth remote sensing is now capable of monitoring the health of the planet, Optical Medical Imaging is still in the Dark Ages

David W Allen

CEOS WGCV March 2, 2010



Overview

- Earth Remote sensing 40 years
- Medical Imaging 100 years
- Optical medical imaging just beginning
- Many of the same optical technologies used for Earth remote sensing have not been applied to human health
- There is a strong need for cal/val in Optical Medical Imaging

Primary Goals of Optical Medical Imaging

- **Safer**

  -Reduce preventable errors

  -Non-ionizing radiation
- **Faster**

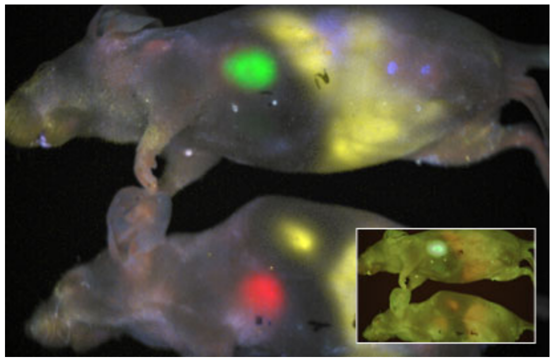
  -Provide the physician timely information
- **Cheaper**

  -Cost should not be part of the decision process in evaluation (i.e. MRI)
- **More Accurate**

Non-Optical vs. Optical

- X-ray imaging
- X-ray tomography (CT)
- Mammography
- Ultrasound
- Magnetic resonance imaging (MRI)
- Positron emission tomography (PET)


- Hyperspectral imaging
- Fluorescence imaging
  Endogenous, Exogenous
- Thermal imaging
- Optical Coherence tomography
- Raman Spectroscopy
- OptoAcoustics
- In vivo Confocal microscopy
- Polarization imaging
- Elastic scattering
- Optical tomography

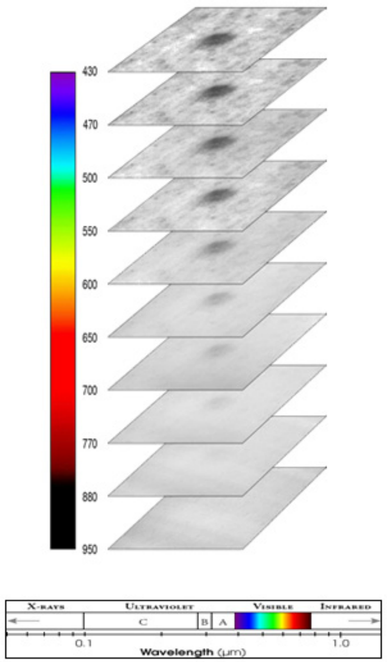


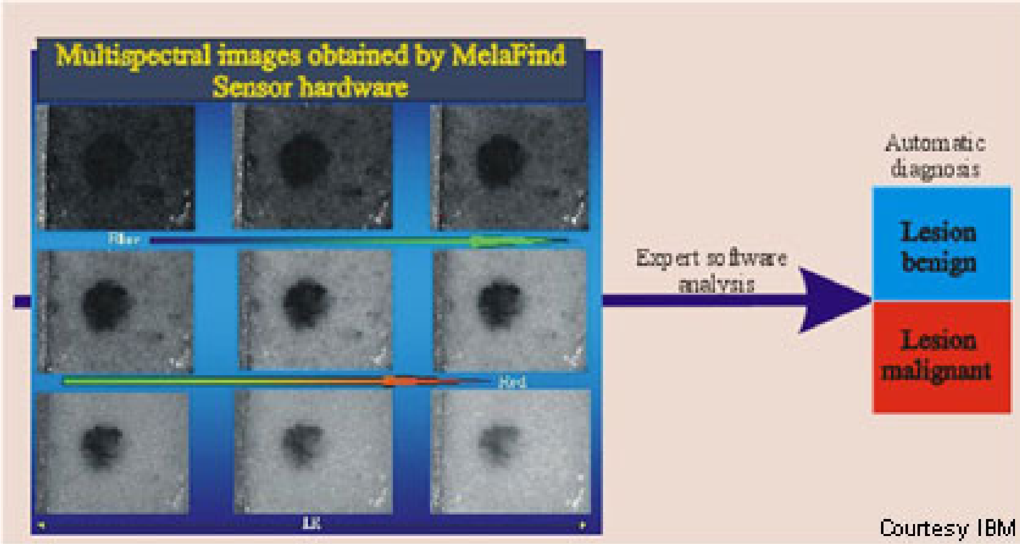
Shortcomings of current medical imaging

- Cost
- Specificity
- Time
- Sensitivity
- Spatial resolution
- Minimally invasive (ionizing radiation)
- Rapid results
- Soft tissue
- Qualitative

EOS Melafind

http://www.eosciences.com/

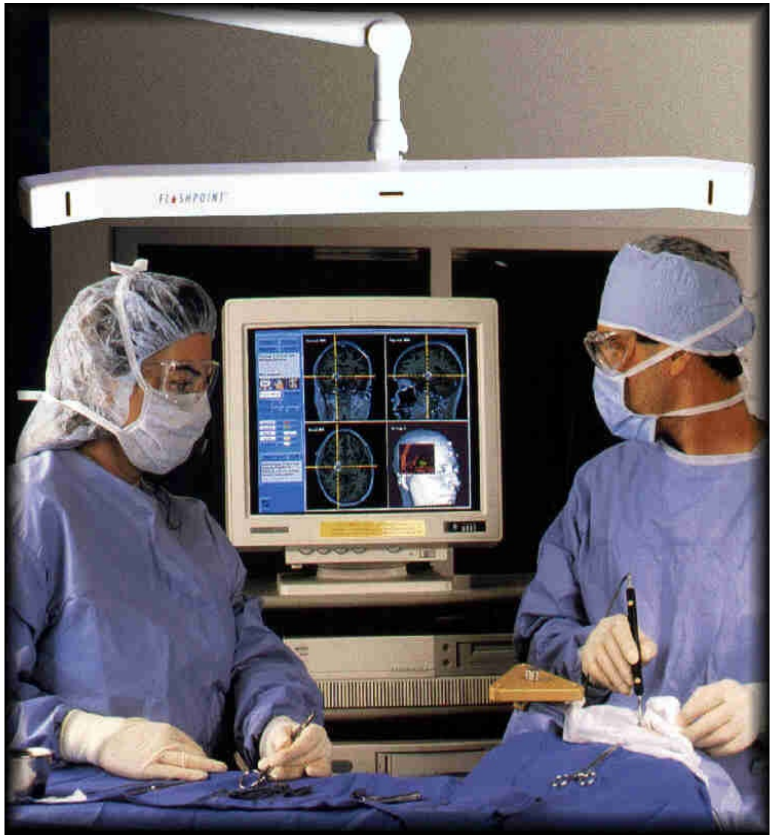




In a clinical trial at seven locations across the U.S. last February, researchers used MelaFind to study more than 1,800 skin lesions from 1,300 patients, finding that MelaFind's ability to accurately rule out skin cancer was 2.5 times greater than that of dermatologists.

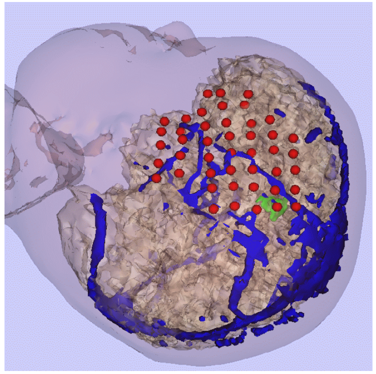
The new photo technology accurately **detected 98.3 percent of melanomas** and **reduced unnecessary biopsies by 90 percent**, says Dr. Darrell Rigel of the New York University School of Medicine and a consultant for Electro-Optical. –ABC News

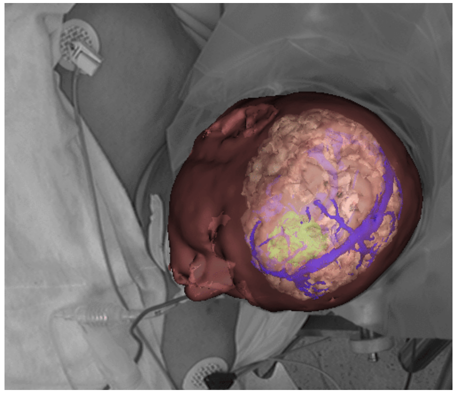
Augmented Reality



Now

http://groups.csail.mit.edu/vision/medical-vision/surgery/surgical_navigation.html

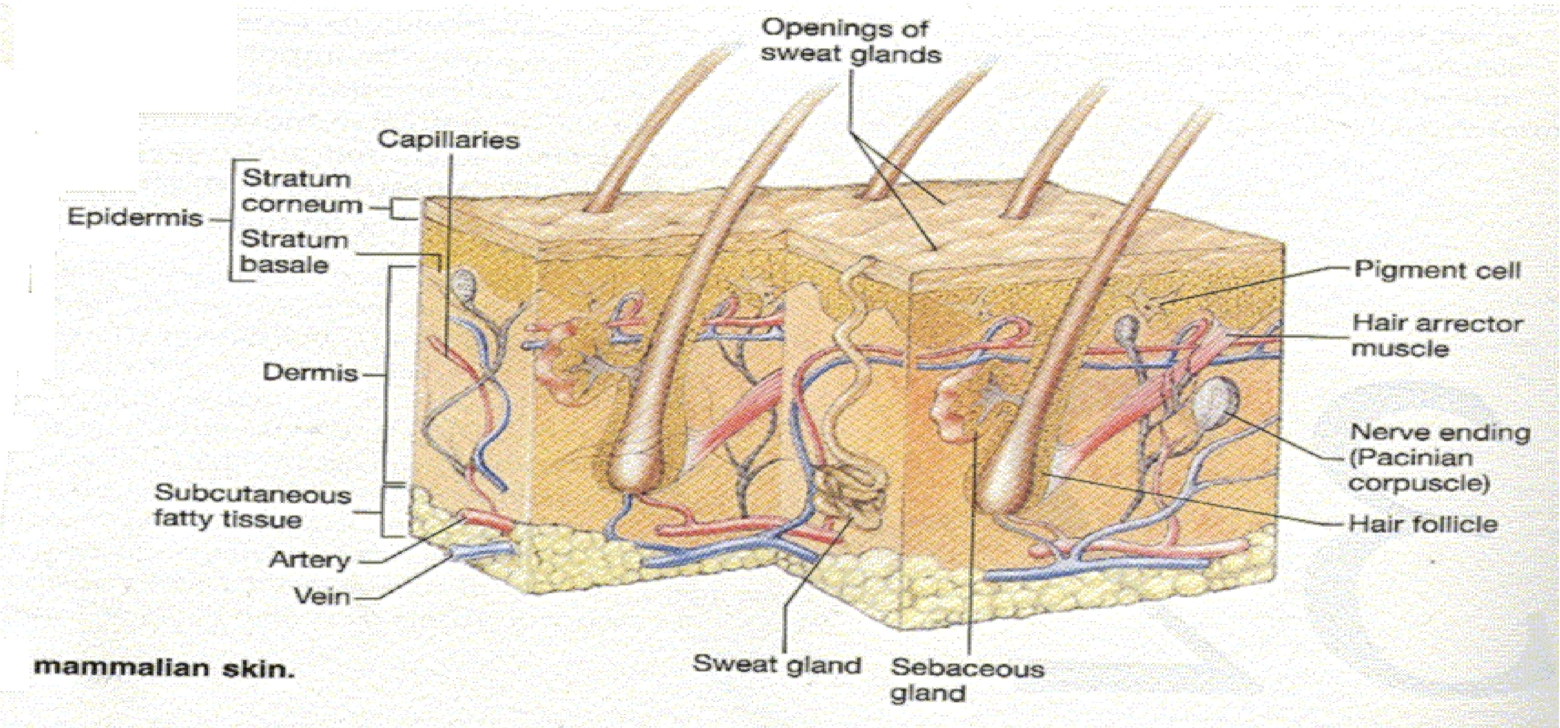




Near future

Tissue Optics

- Tissue is a very non-uniform medium. Therefore it absorbs and scatters light.



Tissue Phantoms

http://www.bme.ogi.edu/~prahl/projects/phantoms.html

Motivation: Laboratory sources do not simulate reality

We test and calibrate with uniform/simple laboratory sources…
Examples:

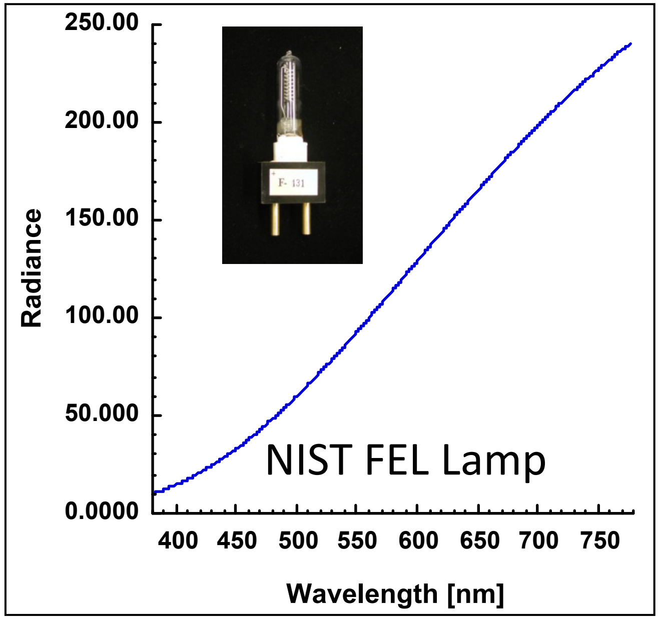
- Lamp-illuminated integrating sphere
- Blackbody
- Standard bar or resolution charts

But reality is spatially and radiometrically non-uniform and complex…

Example: AVIRIS image of North Island Naval Air Station, San Diego, CA

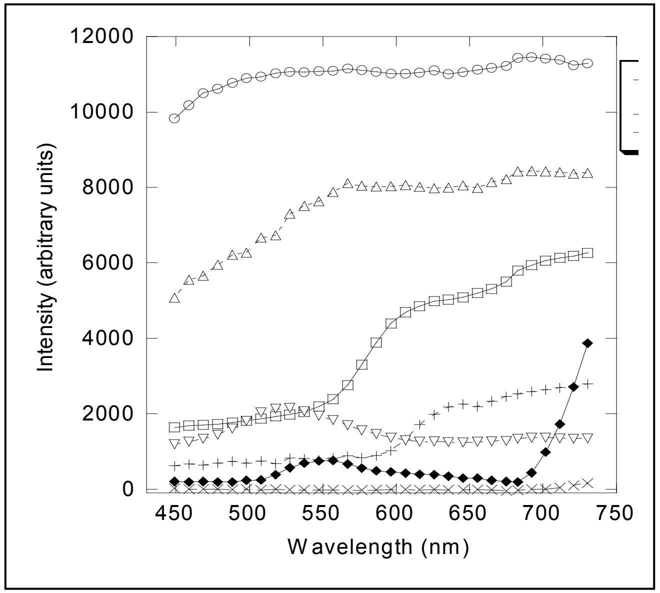
Motivation: The same situation applies spectrally

Lamp standards and blackbodies offer only a near-Planckian-shaped spectrum.



But reality has many different spectra…

Example: Software (ENVI/SMACC) was used to find these 7 eigenspectra from the San Diego Naval Air Station data cube.



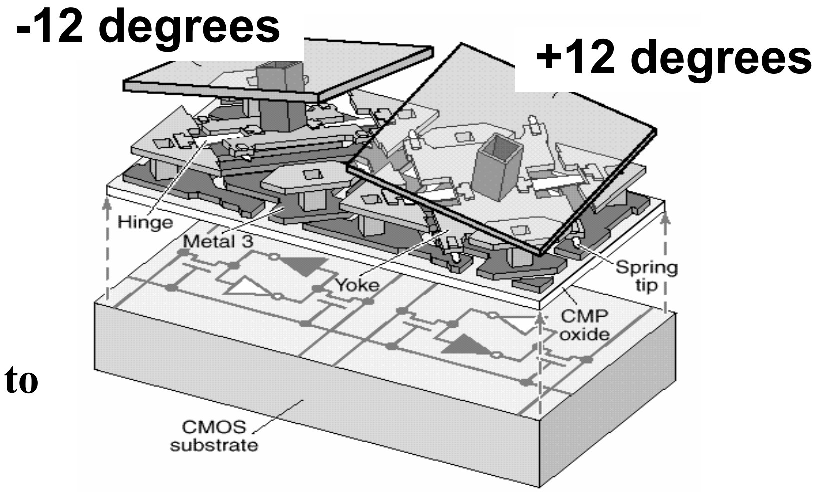
SMACC Reference: J. Gruninger, A. J. Ratkowski, and M. L. Hoke, "The sequential maximum angle convex cone (SMACC) endmember model," *Proc. SPIE* **5425**, 1-14 (2004).

The HIP uses Digital Micromirror Devices (DMD)

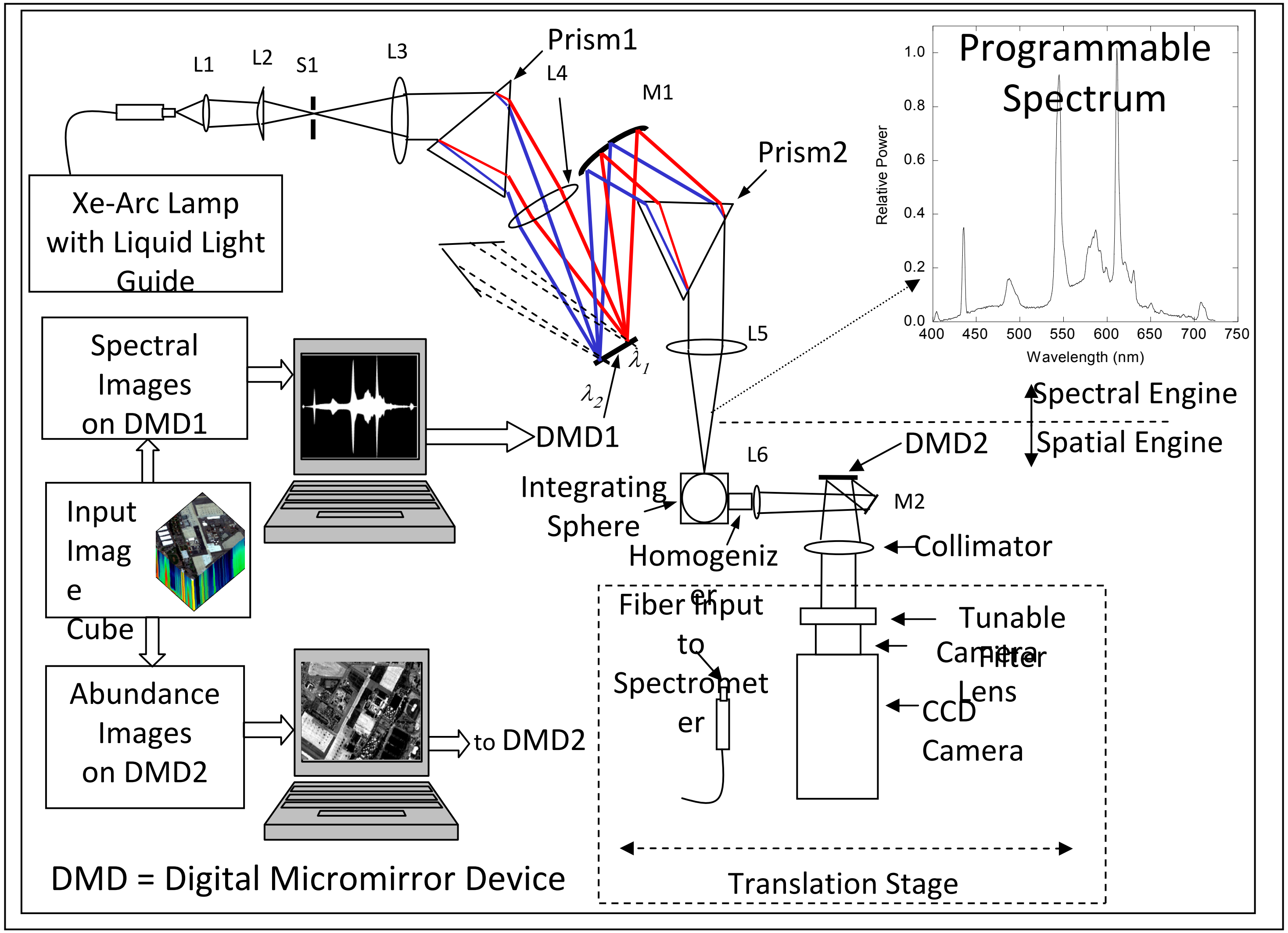
- **An array of MEMS micromirror elements**
- **Developed by Texas Instruments (TI)**
  - 1024 x 768 elements, +/- 12 degree tilt angle
  - Aluminum mirrors
  - 13.68 micron pitch
  - < 24 microseconds mechanical switching time
- **For the breadboard HIP DMDs, we have used the TI D1100 electronics board with an Accessory Light Processor (ALP) electronics board to enable high speed and gray scale**
- **For the prototype HIP DMDs, we are using the TI D3000 and ALP3: 13.3 kHz binary frame rate**
- **The standard glass windows are replaced by windows optimized for each spectral range**
- **Control algorithms are being written by NIST using LabVIEW with a USB interface to a standard PC**

MEMS = Micro-Electro-Mechanical System

Two Pixels from the DMD Mirror Array



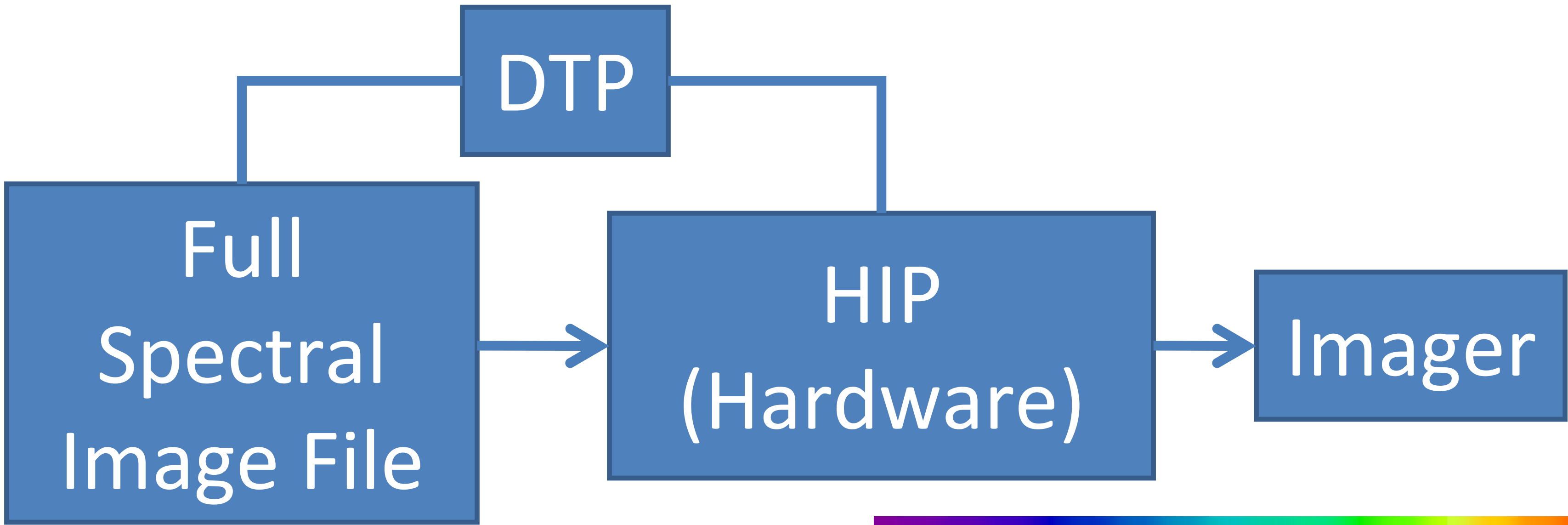
Hyperspectral Image Projector (HIP) Visible-band Breadboard



Digital Tissue Phantom

What is a Digital Tissue Phantom?

A projection system which can provide full spectral and spatial scenes of relevance to an optical medical imager (microscope, endoscope, or wide field imager)



Digital Tissue Phantom

Why a Digital Tissue Phantom?

- Indefinite shelf life
- Can disseminate exact copies
- Can simulate spatial, spectral, and temporally complex scenes
- Can provide scales of radiance, concentrations, etc. (SI traceability)

Digital Tissue Phantom

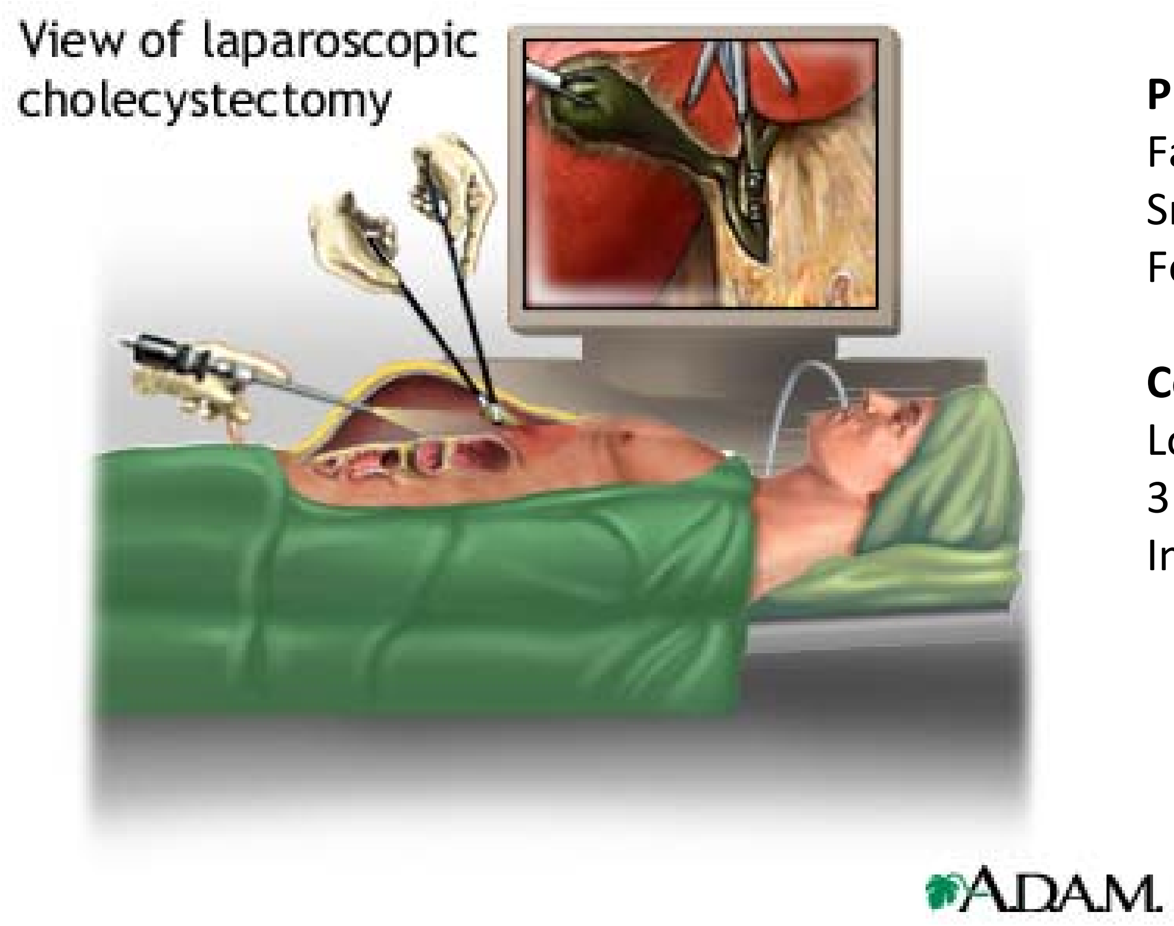
The DTP does not need to be an exact copy of the original, but instead it provides a scene of known radiance with an equivalent level of spectral, spatial, and even temporal complexity.

Digital Tissue Phantom

What type of Tissue/Conditions

- Burns
- Diabetes
- Cancer
- Kidney
- Gallbladder

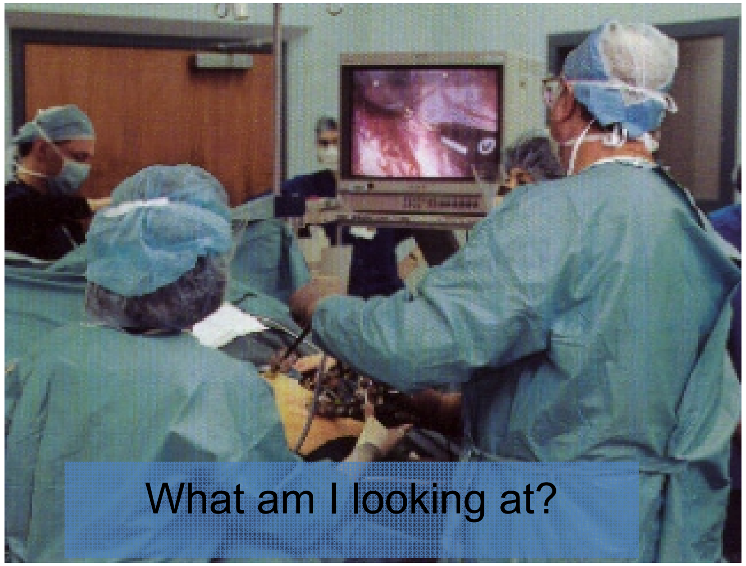
Less Invasive Surgery



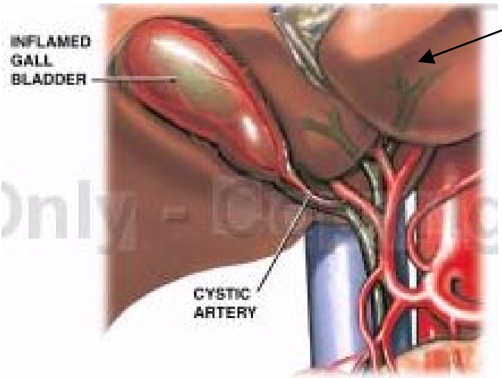
Pros:
Faster Recovery
Smaller Scars
Fewer Complications

Cons:
Loss of tactile senses
3D to 2D visualization
Injury

Visualization Tools for Surgery



Example: Cholecystectomy (gall bladder removal)



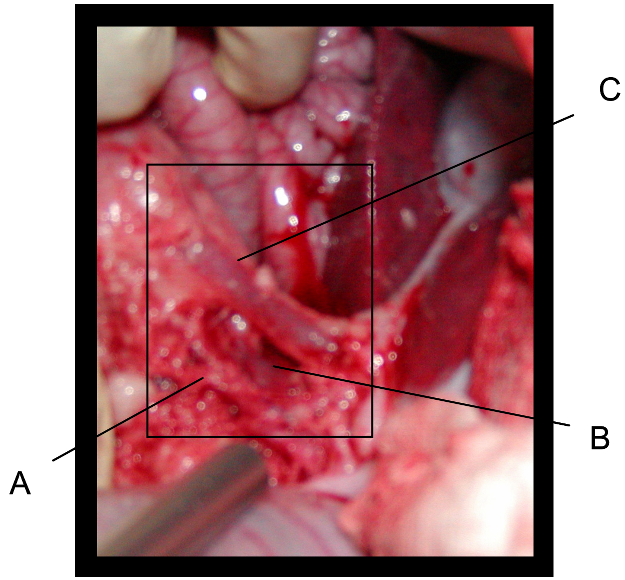
Typical anatomical placement; however, this is encased in a ligament
The surgeon would like to know where to cut exactly to avoid bile duct damage, which can be fatal, unrepairable, or expensive to fix

Technical Solution: near IR hyperspectral imagery for feature discrimination

400,000 per year 0.5% error rate

Full Content Scenes Example: Bile Duct

Hepatoduodenal ligament dissection of live anesthetized swine indicating anatomical structures identified and confirmed by the attending veterinarian picturing the (A) Artery, (B) Vein, and(C) Common Bile Duct.

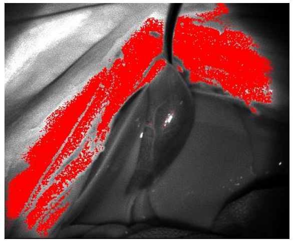


Source: Zuzak, et al

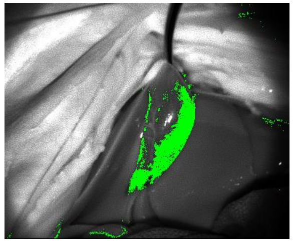
Image Decomposition - Near IR

Classification according to components spectra

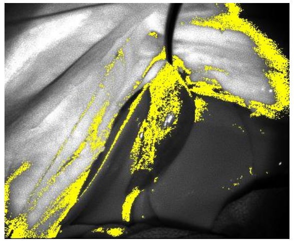
skin



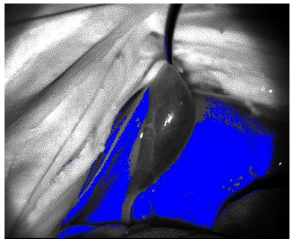
gall bladder

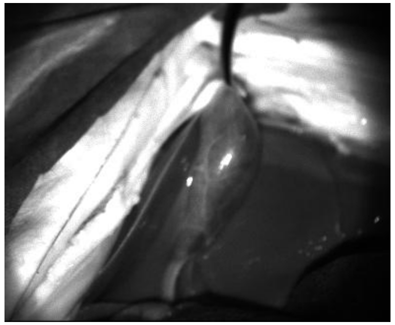


duct

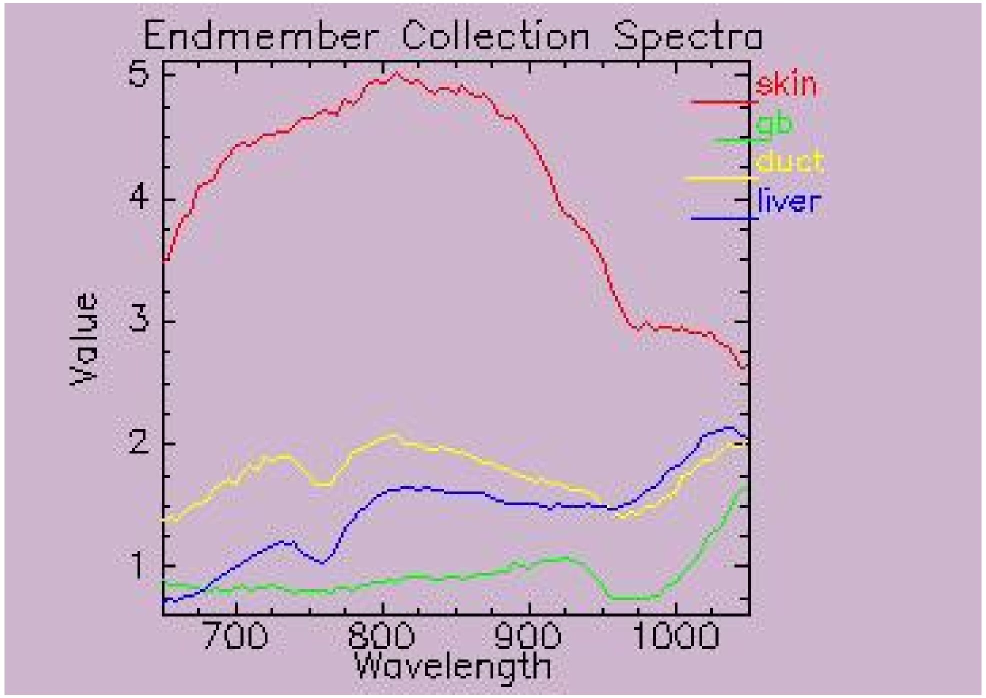


liver

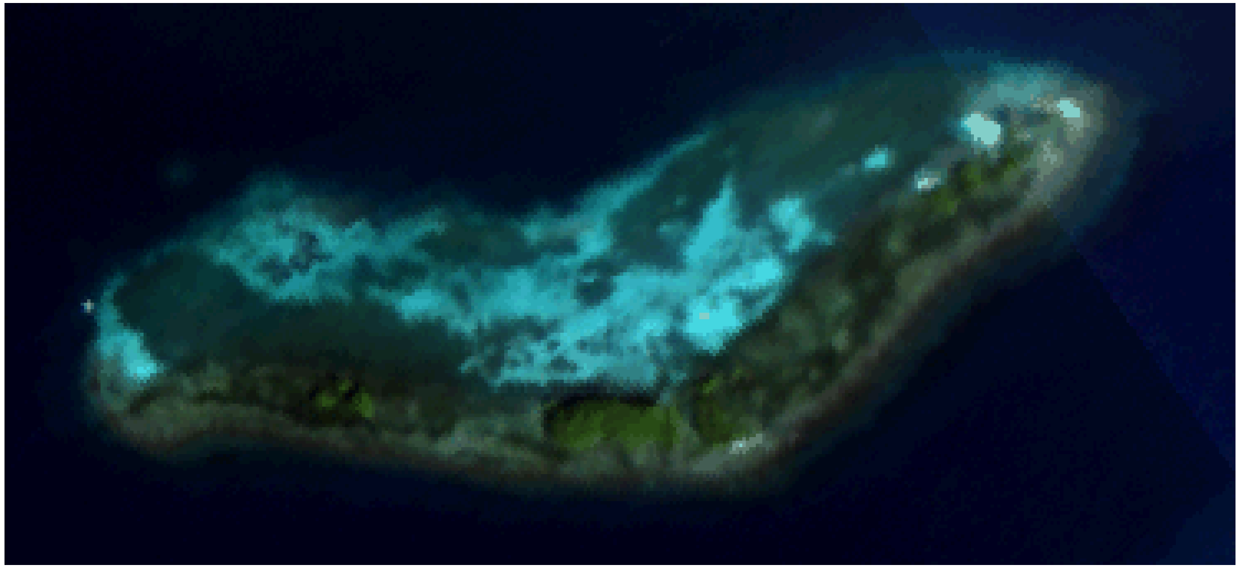




Original NIR image at 800 nm



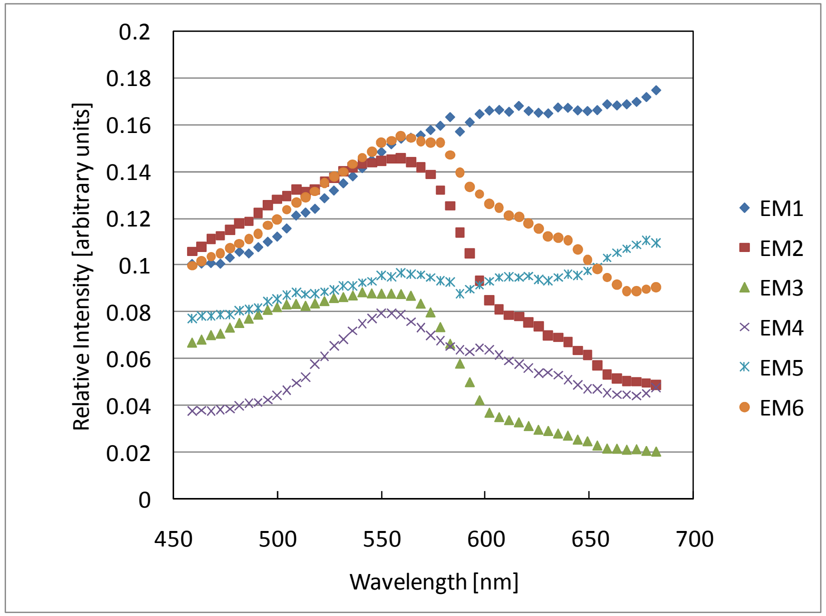
Enrique Reef Scene

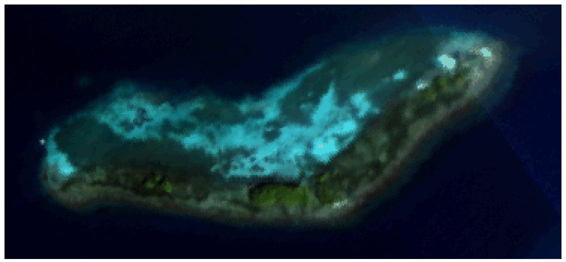


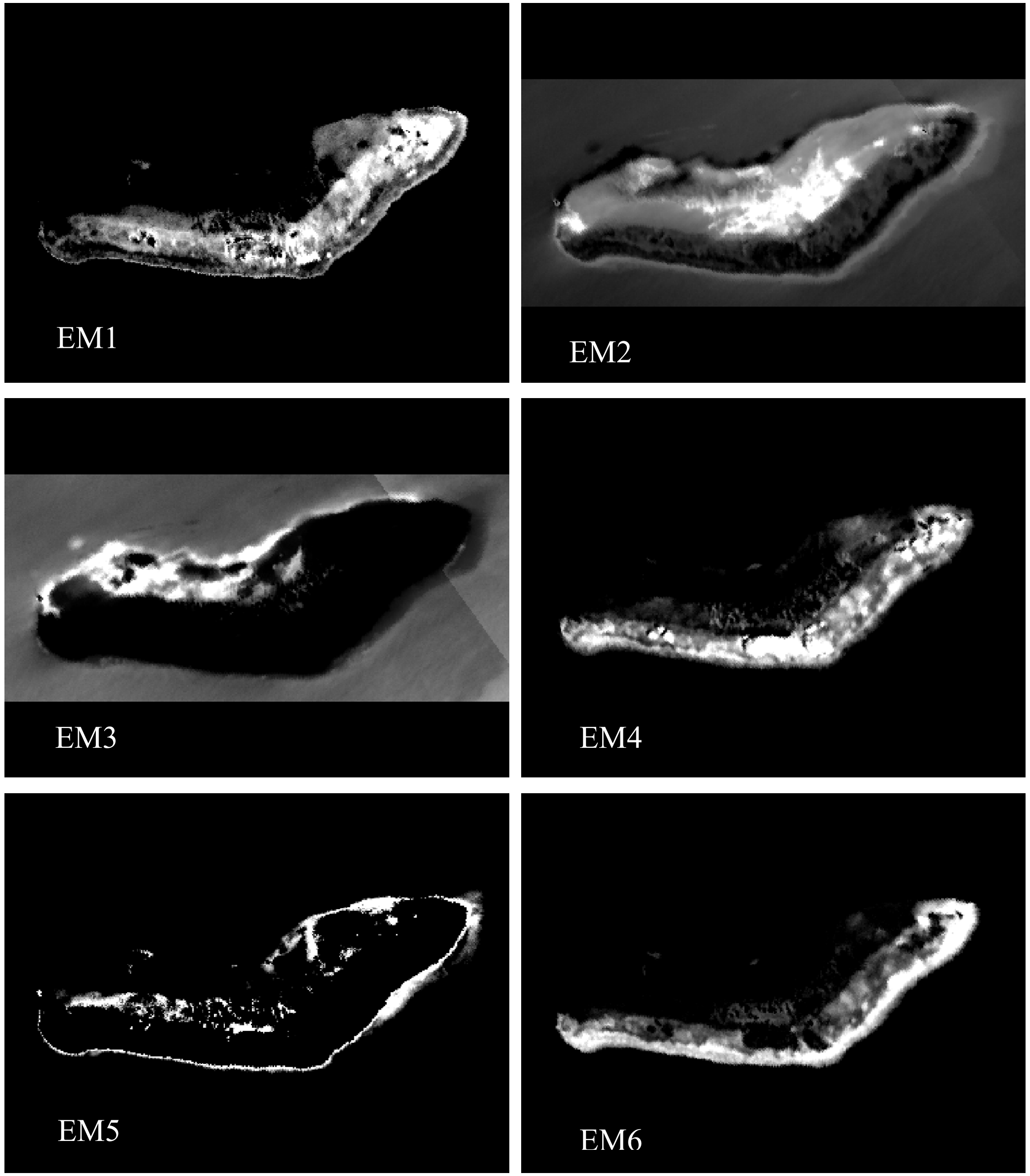
- 1.5 km by 0.5 km
- Approximately 3 m to 20 m depth
- 4 meter spatial resolution, 400 nm to 995 nm, 132 bands
- Image size 372 by 167 pixels
- Radiometric resolution 12 bit
- Original measured using AISA Eagle Imaging Spectrometer (pushbroom from aircraft platform)

http://www.autovision.net/docs/AISA%20Eagle%20_brochure_green.pdf

Endmember (EM) Extraction Results from SMACC

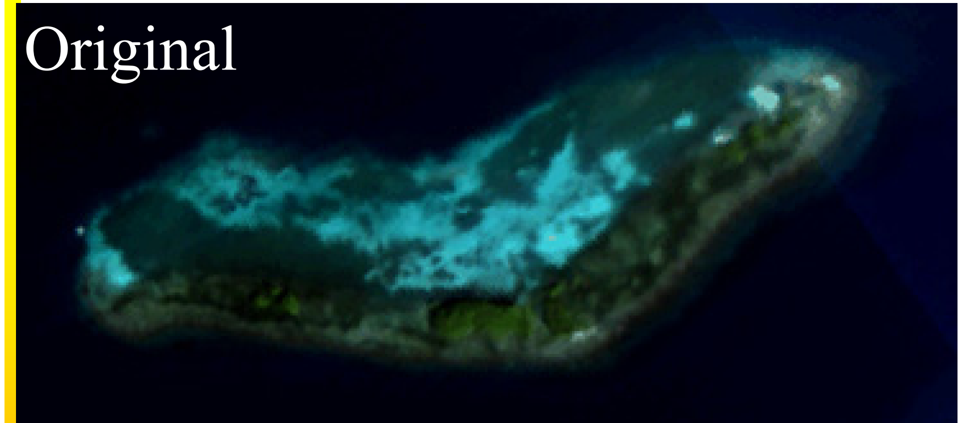


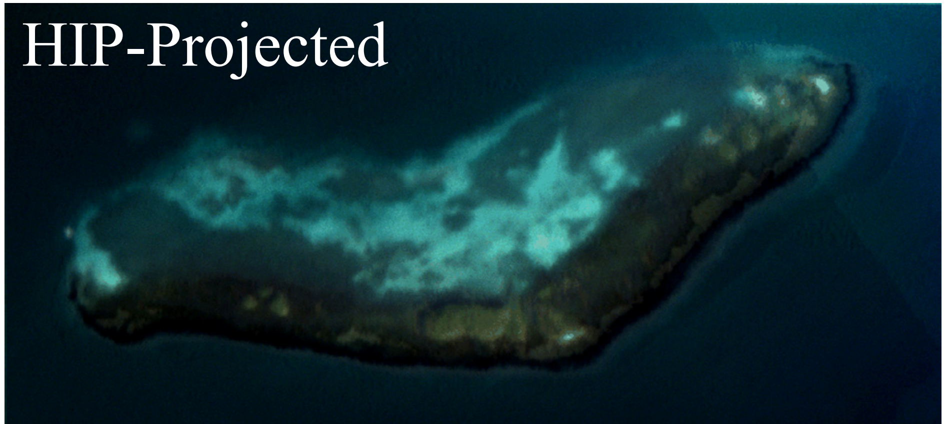




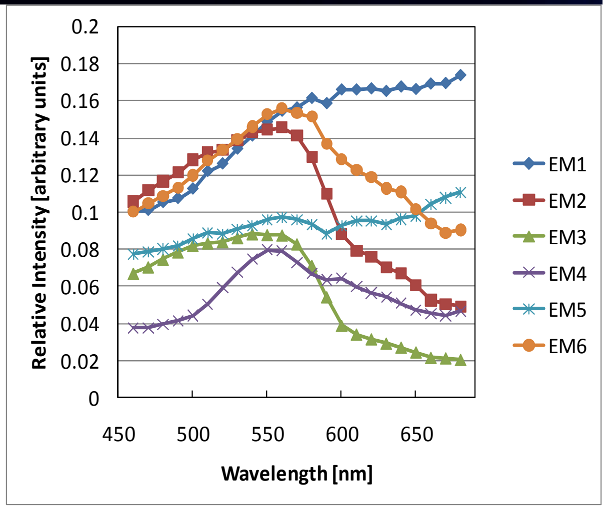
HIP Projection Software Status

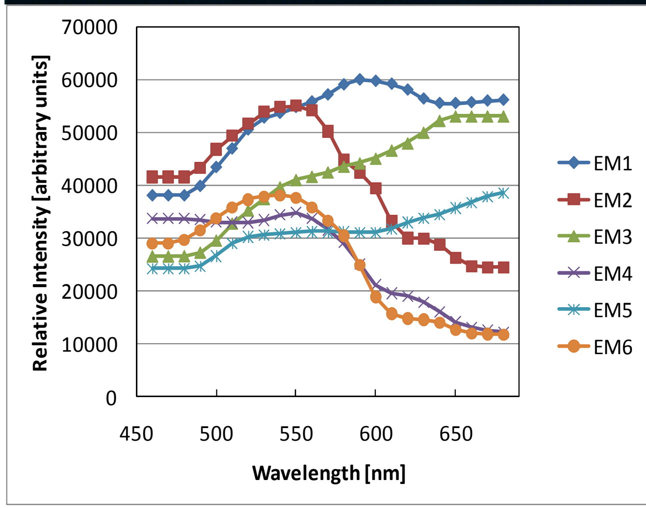
- “Original” is an actual hyperspectral image cube of a coral reef measured from an aircraft platform
- “HIP-Projected” is the original as projected by the HIP breadboard directly into a laboratory imaging spectrometer
- Images below are color composites from only three (460 nm, 550 nm, 650 nm) of the 23 bands measured
- Differences result from a combination of imperfect HIP breadboard and imperfect imaging spectrometer calibration





Eigenspectra of the original image cube

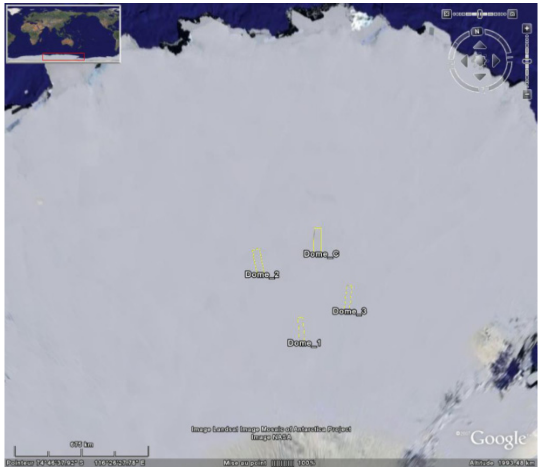




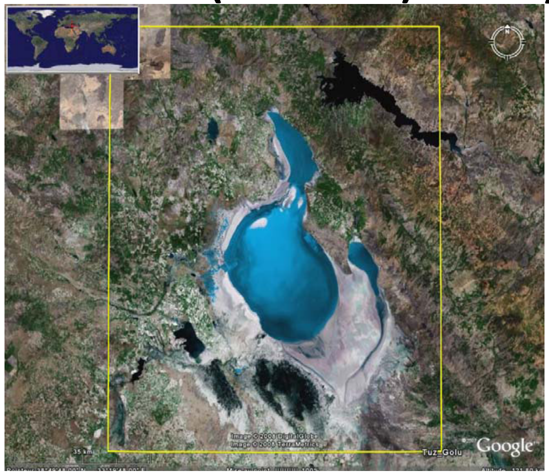
Eigenspectra of the HIP-projected image cube

Hyperspectral Image Projection for Remote Sensing Cal/Val

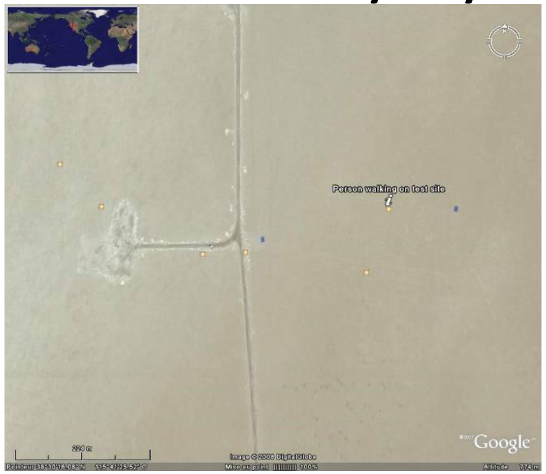
Dome C - Antarctica



Tuz Gölü (Salt Lake) Turkey



Railroad Valley Playa



Test Site → HIP (Hardware) → Satellite Sensor

Presenting the Test Site via the HIP to the sensor pre-launch for later on-orbit comparison

In Conclusion

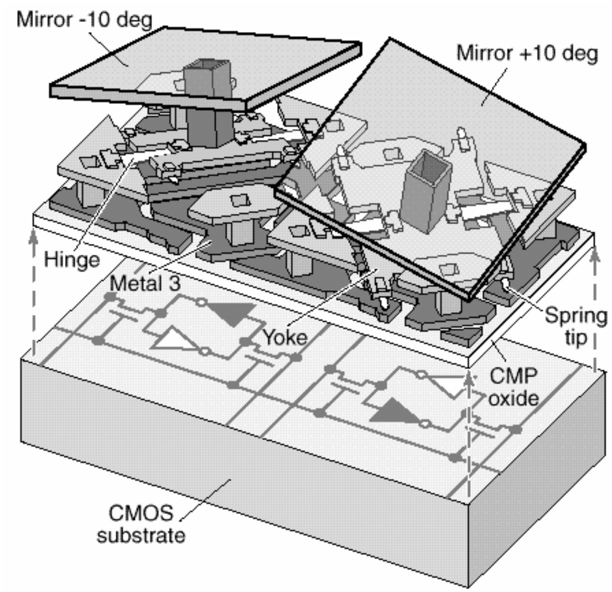
•Remote Sensing technology is migrating into Optical Medical Imaging

•The Optical Medical Imagers will need the same cal/val considerations

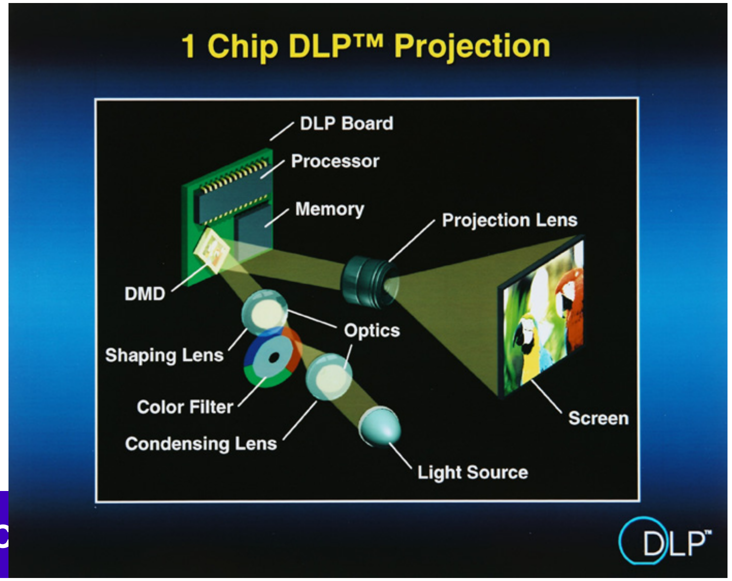
•The Hyperspectral Image Projector allows the observation of the same scene (by different sensors, different days, etc) with all of the spectral and spatial complexity as the real scene

Backup Slides

Digital Micromirror Device (DMD)



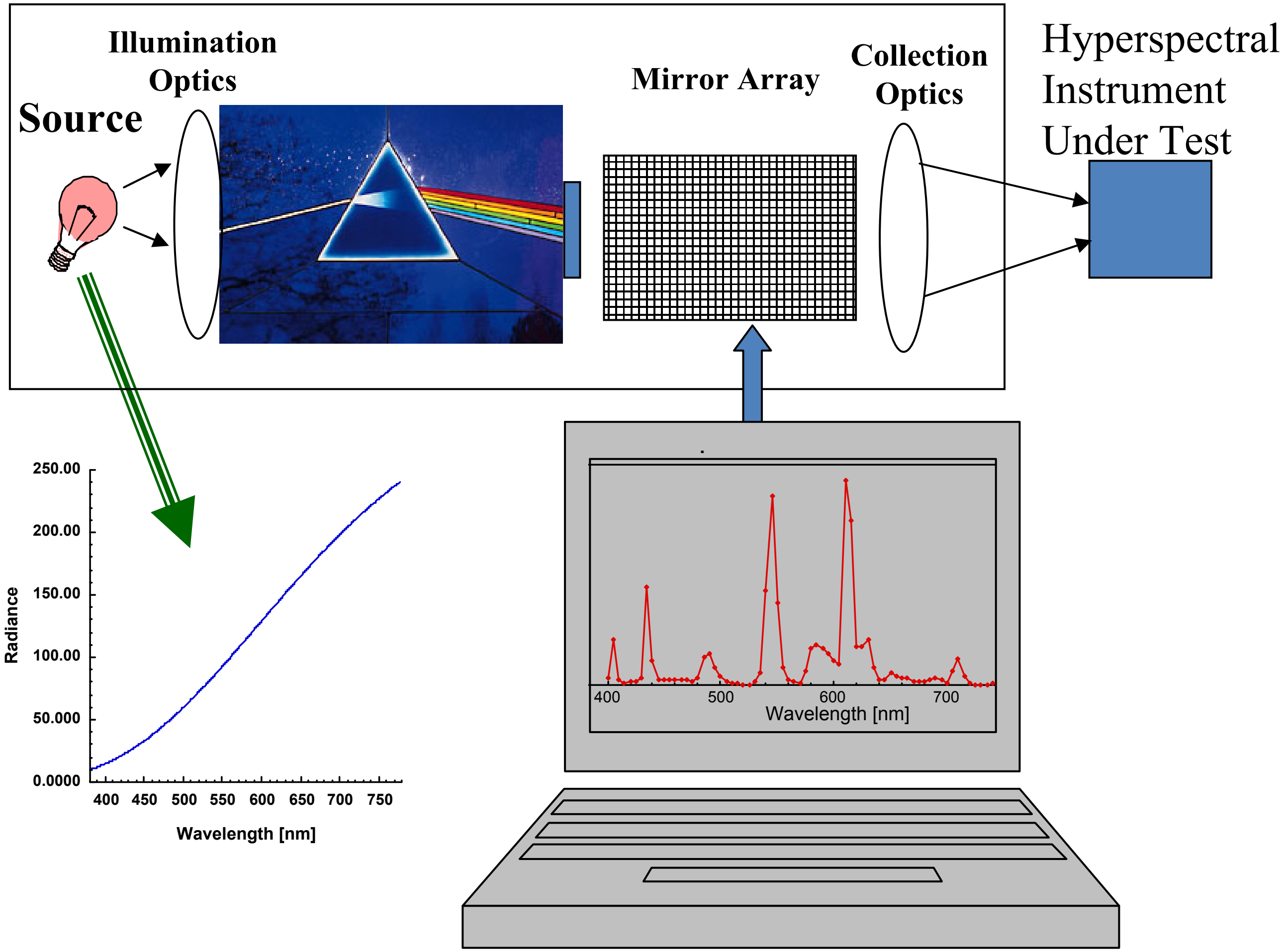
- An array of MEMS micromirror elements
- Can be purchased commercially from Texas Instruments (TI):
  - 1024 x 768 elements
  - Aluminum mirrors
  - 13.7 micron pitch
- For visible to 2500 nm applications



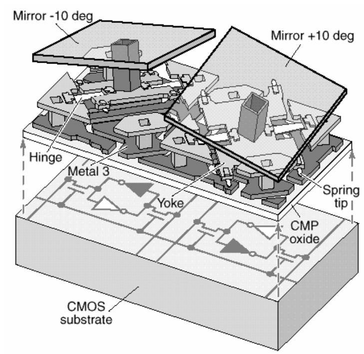
Hyperspectral Scene Generator

Spectral light engines

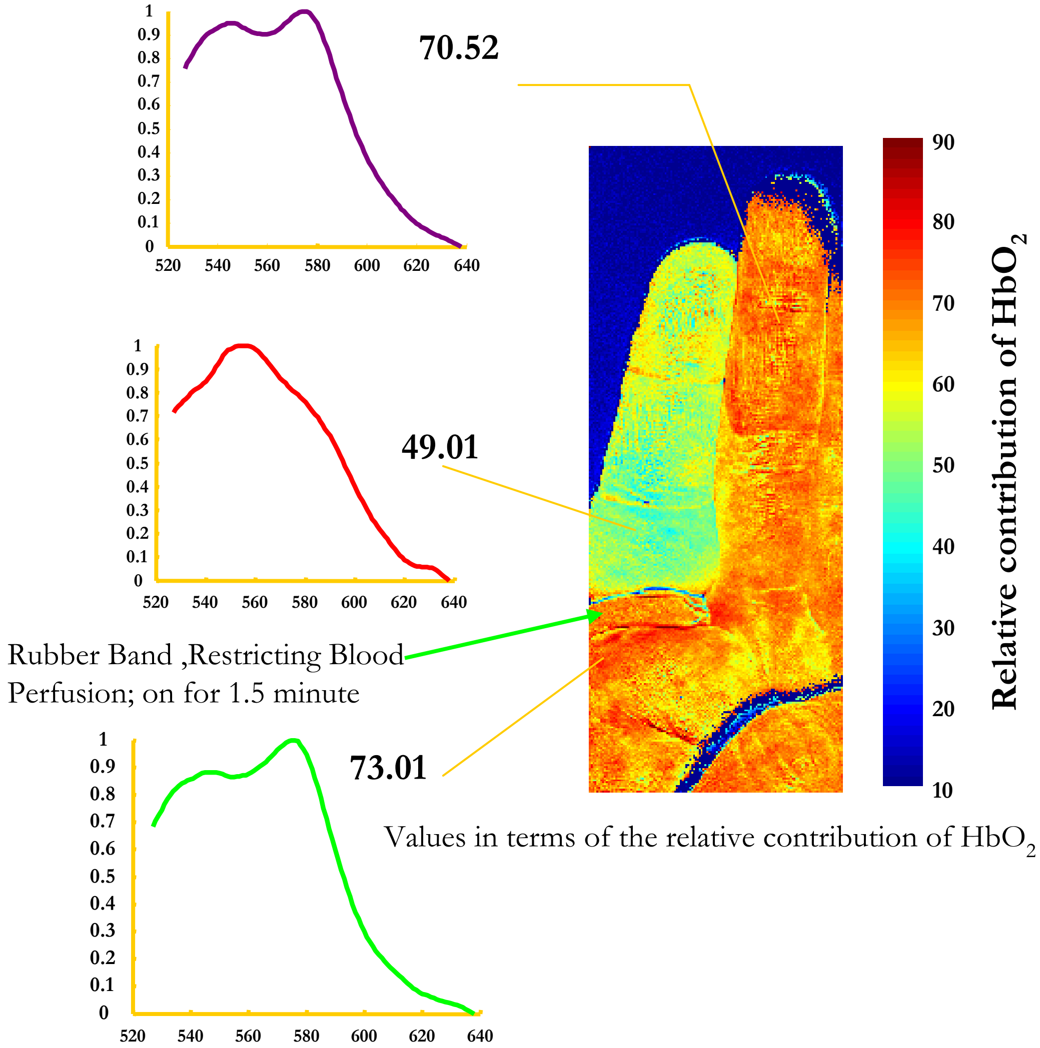
– to mimic complex source distributions (simulated or measured) with high resolution



Programmable Mirror Array
1024 x 768
Aluminum Mirrors
Each: 12 um x 12 um



Visible Reflectance Hyperspectral Imaging Contribution of HbO_2, During Occlusion



Values in terms of the relative contribution of HbO_2

Zuzak, et al UTA

Conclusion:

•Optical Medical Imaging had lagged due to the optical complexity, instrumentation, and measurement standards.

•Optical Medical Imaging can greatly benefit from technologies developed for remote sensing.

•Inherent advantages of OMI over EOS
  -variety of active illumination sources
  -can use contrast agents

•Its all about getting accurate information quickly.

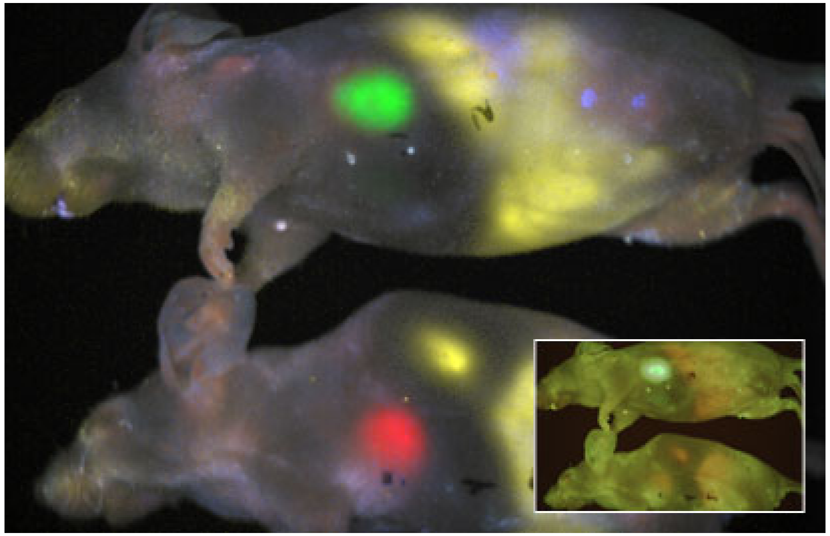
Shortcomings, More specific…

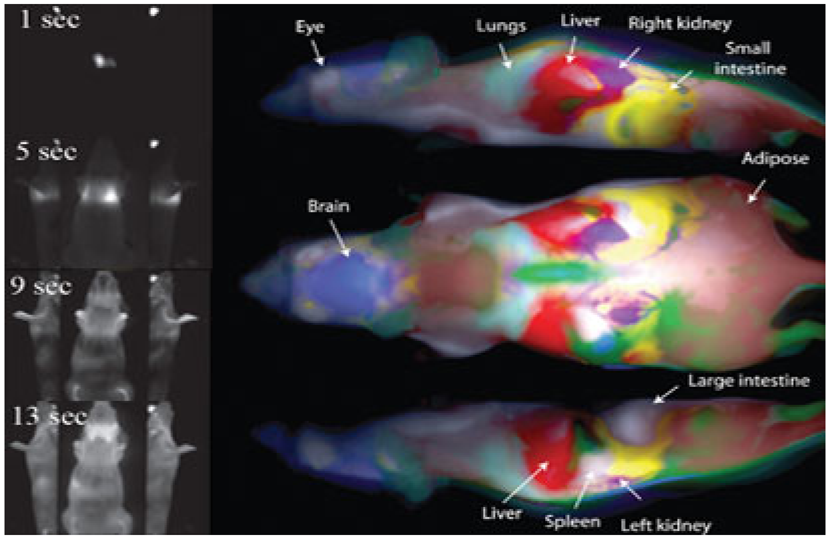
- After 10 mammograms 50% chance of false positive *Journal of the National Cancer Institute* (Vol. 92, Issue 20)
- Benefit-to-risk ratio of 48.5 lives saved for each life lost due to radiation exposure http://www.ahrq.gov/clinic/3rduspstf/breastcancer/brcanrr.htm
- Burns- severity based on visual observation
- Colonoscopies- up to 23 % missed cancerous polyps http://www.ahrq.gov/clinic/uspstf08/colocancer/coloartwhit2.htm
- Melanoma- Up to 33 % missed cancerous moles http://www.eosciences.com/
- Drug response- Did it grow or shrink?

Jaffe, C. C. Oncologist 2008;13(Supplement 2):14-18

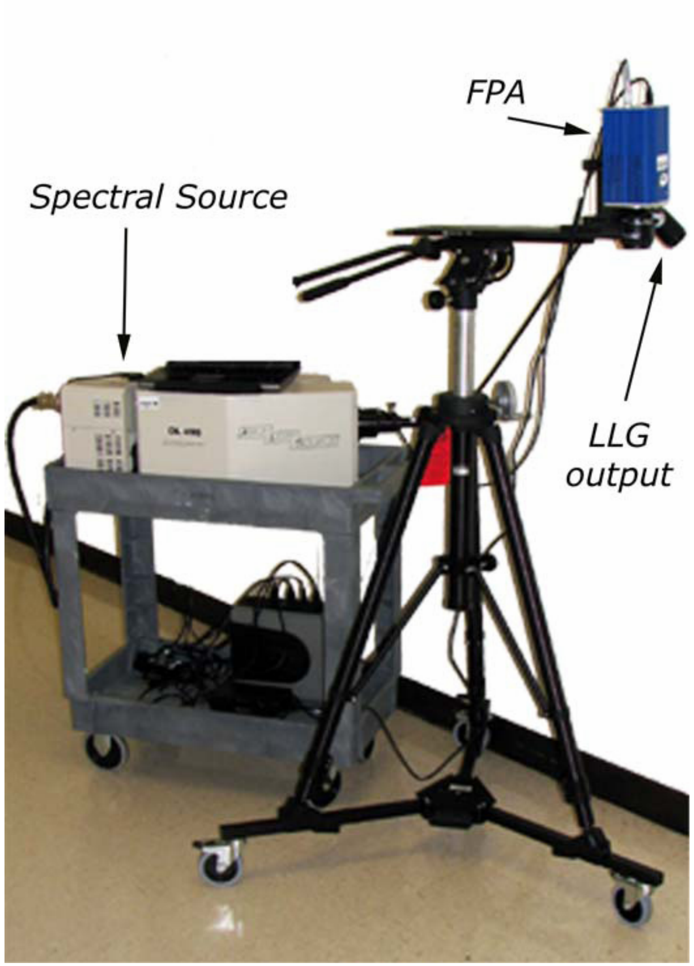
Fluorescence Imaging

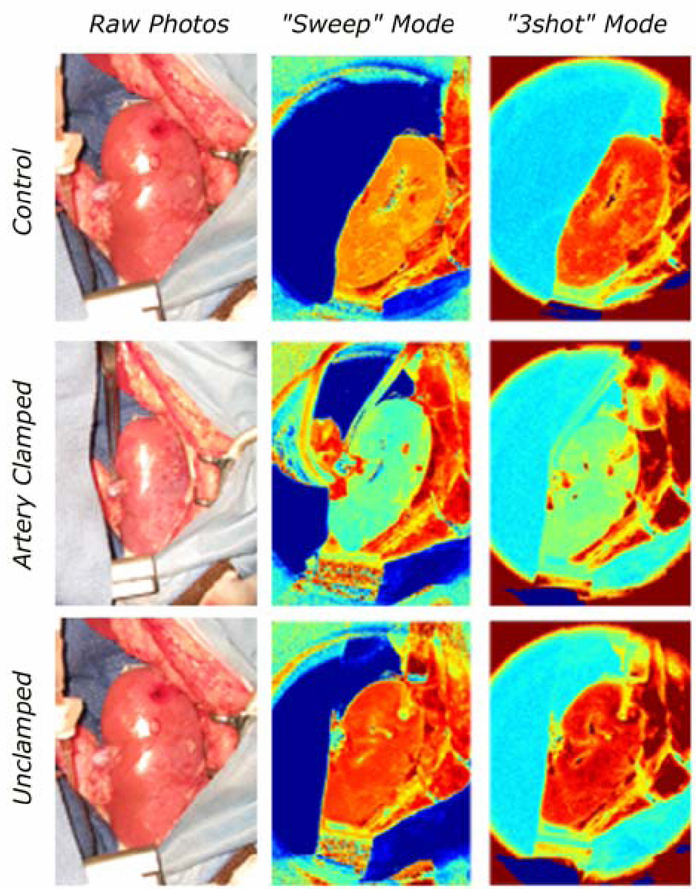
http://www.cri-inc.com/products/maestro-2.asp





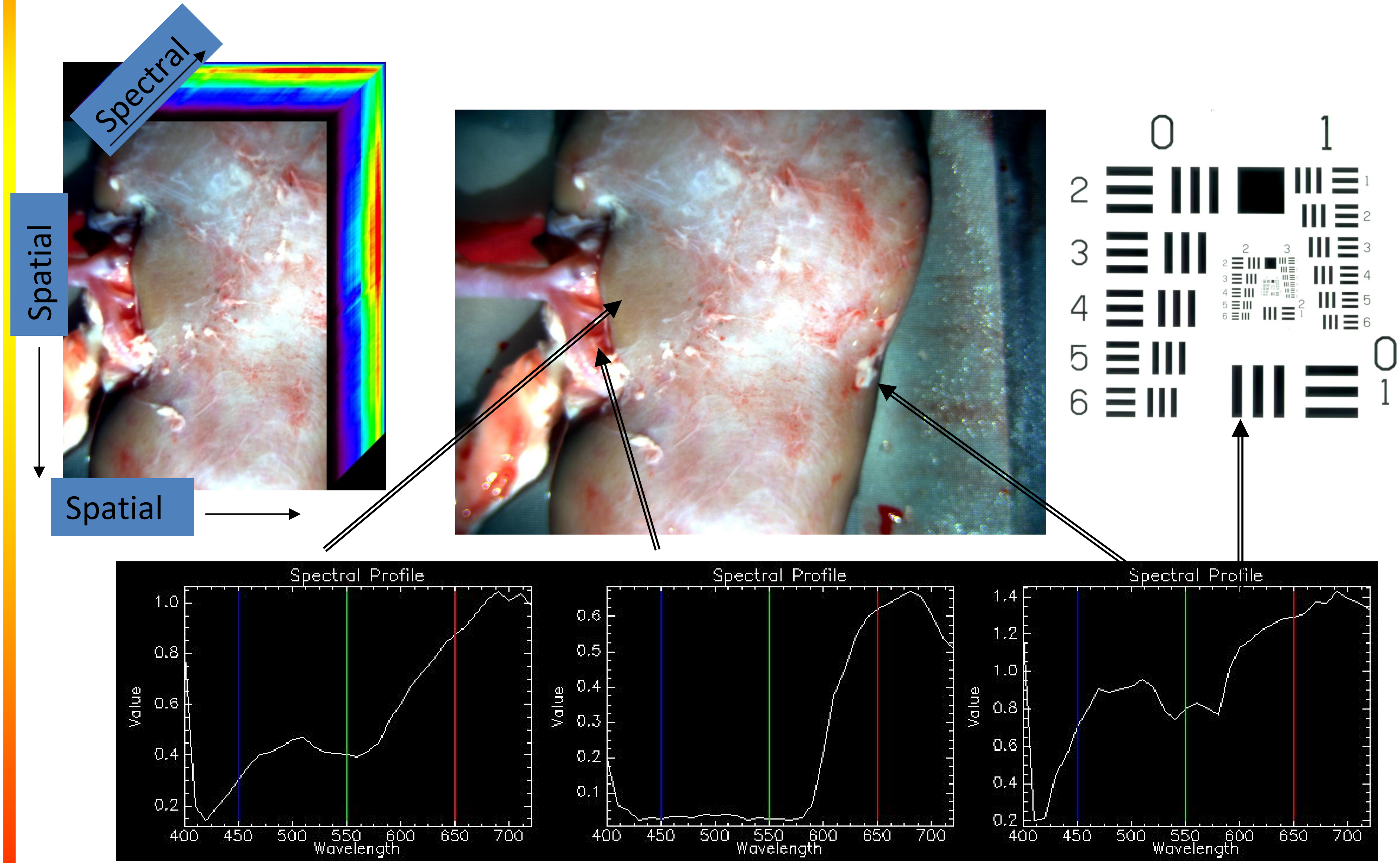
Hyperspectral Chemometrics
Zuzak (UTA) and Texas Instruments



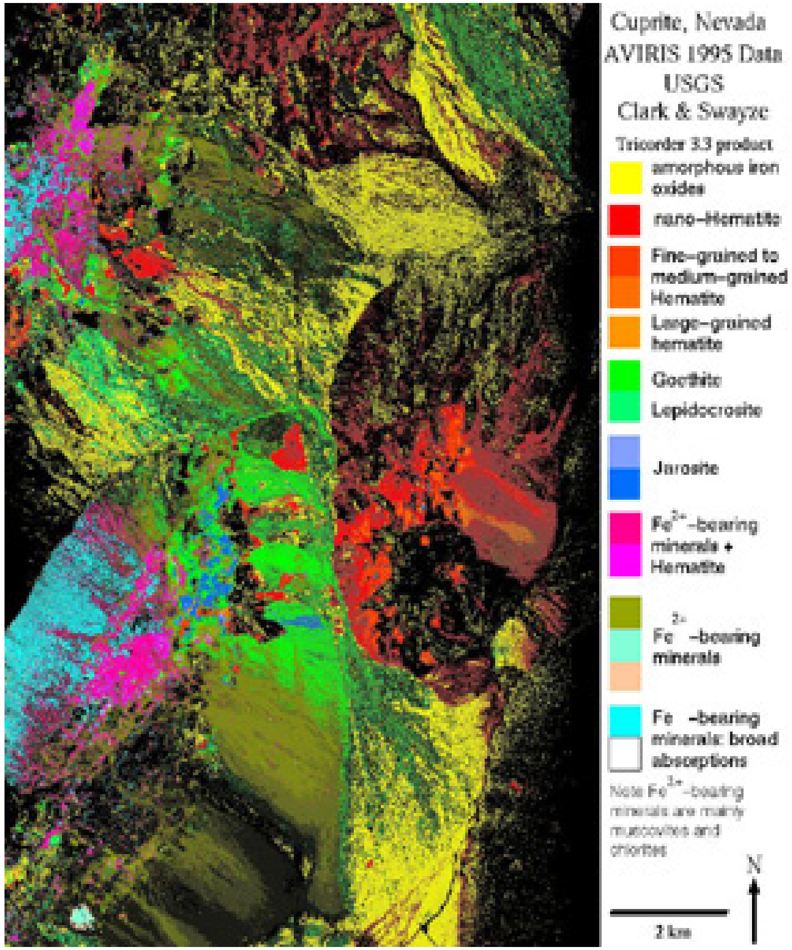


http://www.olinet.com/content/library/1225477024R37_DLP_PRODUCTS_MAKE_SURGERY_EASIER_10-08.pdf

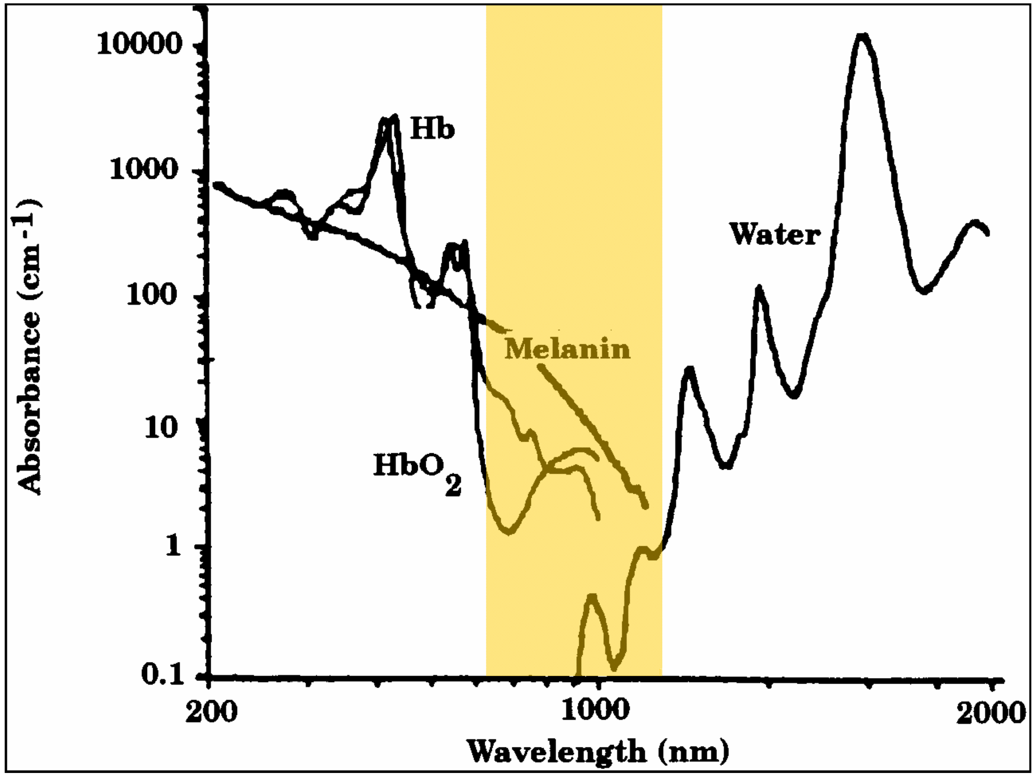
Hyperspectral Image and Distinct Spectra



Material Classification



Tissue spectral window



Kortum, R.R., Sevick Muraca, E. Ann. Rev. Phys. Chem. 1996: 47, 555
Lim and Soter, Clinical Photomedicine 1993

"therapeutic window"

$600<\lambda<1200$ nm

Primary chromogen in reflectance measurements is blood (hemoglobin)

Visible region: accesses surface blood vessels
Near IR region: deeper penetration, larger blood vessels