What Is Spectral Imaging?  
An Introduction

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Ricardus Dialogue (University of Rochester, D.460 1000-003) before and after spectral image processing
What is Spectral Imaging?

• Over time (passive) imaging systems have improved their spectral (i.e., color) response, range, and sensitivity
  – B&W (1 spectral band)
  – Color (RGB, 3 spectral bands)
  – “Multispectral” (typically a filtered or colored illumination system)
  – “Hyperspectral” (use of a diffraction element such as a prism or grating)

• Why more bands?
  – more spectral information leads to greater material separability
Why Use Spectral Imaging?
Basic Outline of Talk

• Definitions: light, wavelength, and color
• Overview of imaging systems
  – What the camera sees
  – How to collect color imagery
  – Difference between multi- & hyperspectral
  – Calibration, registration
• Basic image processing concept
  – Spatial processing
  – Spectral processing
• Questions
Definitions

• Wavelength: related to the energy of light and color; typically written as $\lambda$
Definitions

- **Color**: optical property of materials; how it selectively reflects light
- **Reflectance**: efficiency with which an object reflects light as a function of wavelength
- **Fluorescence**: material property by which light is emitted at a different wavelength that it is illuminated with
- **Spectral band / channel**: a specific color in an imaging system
- **Resolution**: the projected area of each pixel on the detector onto the object
- **Spectral response**: how sensitive the detector is to each wavelength of light

**Important**: If we say anything that you don’t understand or know the meaning of speak up!
Reflectance imaging is collecting light reflecting off the surface (mostly) of the object.

Reflectance vs.
Transmission vs.
Fluorescence
Imaging System: What the Camera Sees

Transmissive imaging is collecting light being transmitted through the object from behind.

Reflectance vs. Transmission vs. Fluorescence
Fluorescence imaging is collecting light fluorescing from the object after illumination in the Ultra-Violet.

Reflectance vs. Transmission vs. Fluorescence

Note that the fluorescence is at a different wavelength than the illumination.
Imaging System: Your Cell Phone

In this case, the set of filters is fixed at time of construction.

A “spectral filter” limits the wavelengths of light that pass through it to isolate them.

Table to hold object
Using a filter wheel allows us to customize and even change the filters used.
**Imaging System: Colored Illuminant**

- Table to hold object
- Camera

**Must be done in the dark!**

Advantage is that you can limit the exposure of light onto object

- Color of light source is modified
Multi- vs. Hyper- Spectral

• My definitions

• MSI
  – Spectral imaging system that uses filters or colored illumination
  – Generally has 10’s of spectral bands without continuous spectral coverage
  – Generally has higher spatial resolution

• HSI
  – Uses a dispersion element to project “rainbow” onto detector (i.e., a prism)
  – Either the object or the camera has to move
  – Produces continuous spectrum per pixel
  – Generally lower spatial resolution
Basic Hyperspectral Imaging System

• For spectroscopy, we need to spread the light out using a diffraction grating or a prism

• Image is collected **one line at a time**, but full spectral information is collected for each line on **2D array**

• Second spatial dimension collected by platform or object motion
Calibration

• Camera records digital counts – raw data
  – Basically the electrical signal off the detector
  – Contains desired signal plus any sources of noise

• Can be converted to radiance (physical units) with calibration coefficients

• Can be converted to reflectance with known target in scene
  – Gold standard: this is the inherent physical property of the object in each pixel

• Different from color balancing
Image Registration

Two images of same object at different wavelengths but slightly offset

Images simply overlaid in pixel space

Images registered by content
Spatial Image Processing

• Uses information contained in the spatial domain
  – Pixels are next to each other

• Typically (but not always) done on a single band image

• Examples
  – Sharpening and filtering, attempting to remove blur
  – Edge detection

Hyperspectral fluorescence imaging at Bodleian Library, Univ. of Oxford
Spatial Image Processing Example

RGB from hyperspectral

PC band 1

The “high pass” filter enhances sharp edges

High Pass Filtered
Spectral Imaging Processing: Signatures

• The actual measurement in each band

• How “bright” is this object in this band relative to the other bands?

• Useful for identifying bands of high contrast and for assessing spectral similarity
Hyperspectral Pixel Signatures

Spectral measurement (reflectance) as a function of wavelength for three different materials
Spectral Signatures in the Color Space

- We think of pixels as points in a space where the axes are the various colors.

- Specific colors fall on the axes, mixtures fall in the space in between.

- Provides a mathematical description of the data that is useful.
Principal Components Analysis (PCA)

- Consider this collection of pixels in two colors
- They represent two different materials, but their color differences are subtle
- Looking at them in either red or blue alone makes it difficult to distinguish
Principal Components Analysis (PCA)

• PCA provides a way to represent them with new axes

• New axes are derived to maximize separation in first PCA dimension (band)

• Now materials are easy to separate
Spectral Similarity Measures

• We measure how similar pixels are to each other based on their spectral similarity

• Pixels of similar material will have similar spectral signatures
  – And will appear of similar color in original image and in transformed images such as PCA

• Spectral angle is one measure, but there are others
  – In the case of spectral angle, smaller values indicate more similar
Summary

• Spectral imagery is becoming a much more useful tool for digitization, preservation, and discovery

• Leverages differences in material properties in every pixel across the image to highlight sometimes subtle differences

• Tasks of interest:
  – Faded text enhancement
  – Erased / damaged text enhancement
  – Pigment analysis
Questions?

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