Slide 1 – Title Slide

Hello and welcome to Week 2, Part 1 of EGM703: Spectral Properties. In this lesson, we'll refresh our knowledge of spectral properties, and discuss what it is that makes hyperspectral data, well… so hyper.

Slide 2 – Week 2 Outline

Over the rest of this week's lecture, we'll cover a number of different methods of hyperspectral image analysis, before looking at some different applications of hyperspectral remote sensing.

Slide 3 – Spectral Properties

Recall that the reflectance of an object, or the ratio of the energy that it reflects to the energy that falls on it, depends on its surface properties such as its roughness. It also depends on the chemical composition, or what molecules make up the surface, but also the viewing angle and angle of illumination. For example, leaves on healthy, chlorophyll-producing plants absorb light in the red and blue visible wavelengths, leaving mostly green light to be reflected – as a result, most plants appear green to our eyes. We can also see absorption and transmission in action with the color of water. At the shore of the lake here, water is mostly clear. As the depth increases, though, we see a shift in color to green and then dark blue. Water molecules preferentially absorb longer wavelengths like red light, so the light that gets scattered back toward the sensor is at shorter wavelengths. As the water gets deeper, more of the light is absorbed, and so the water appears darker and darker – less of it is reflected back. Scattering by suspended sediments and other particles in the water also plays a role – because most of the light that is transmitted into the water column is preferentially shorter wavelengths, the light scattered back appears more green and blue, depending again on the depth. All of this is to say – objects or surfaces reflect differently at different wavelengths.

Slide 4 – Some definitions

Before we start, we have to lay out some definitions. First, the spectral reflectance of an object or a surface, ρ_λ, is the reflectance of an object for a given wavelength λ – this is similar to how we defined the spectral radiance or irradiance of an object as the radiance or irradiance for a given wavelength. The spectral signature of an object or surface is just the pattern of spectral reflectance across the electromagnetic spectrum. We can display an object's spectral signature as a spectral response curve, several examples of which are shown here. We see here that in the visible wavelengths, these different plants, oak, lawn grass, and conifer, all have similar spectral signatures, just perhaps at different brightness levels. But, the plants all look quite different to the concrete, or the snow, which have somewhat similar reflectances across red, green, and blue wavelengths. Moving into the infrared wavelengths, we see that concrete has a fairly even reflection, while the pattern of our different vegetation types is quite distinctive. We can also see that water has a pretty low reflection across the electromagnetic spectrum. We can use spectral signatures to help differentiate between surfaces and objects, potentially allowing us to map things like vegetation, or snow, or water bodies, or anything else we might be interested in.

Slide 5 – Measuring spectral properties

In order to use the spectral properties of different objects, though, we have to measure them. In the field, or in the lab, we use an instrument called a spectrometer. A spectrometer, seen here in action somewhere in Arizona, takes the incoming light and breaks it into its individual spectral components, similar to how a prism works. It then records the reflectance of the object at those different wavelengths – in other words, it records a bunch of spectral reflectances. We often need to take multiple measurements of multiple samples, as even the same material can have variable spectral signatures – remember again that the amount of energy reflected depends on surface properties, as well as illumination angle or viewing angle. Instead of a field spectrometer, we can also use a hyperspectral camera – an instrument that records radiation in a large number of wavelengths. We can also use some satellite images – some sensors record in a large number of wavelength ranges, or bands – if we know exactly what we're looking at in a given image, we can use this information to estimate the object's spectral signature.

Slide 6 – What is hyperspectral?

In this course so far, we've primarily studied multispectral sensors – these are sensors with more than one band. For example, we've looked at a number of different Landsat sensors, including the Multispectral Scanner, or MSS; Thematic Mapper, Enhanced Thematic Mapper plus, and so on. One characteristic of most multispectral systems is that the bands have a varied width – if we look at the band widths on this plot here, we see that they aren't all the same size – not only that, but they also aren't continuous – there are gaps between successive bands where the sensor doesn't actually record data. Hyperspectral systems, on the other hand, are also known by another name: imaging spectrometers. They are characterized by narrow, continuous bands – note that it's not necessarily the number of bands that makes a sensors "hyperspectral", but rather the fact that the bands are typically of a uniform width, and that they are continuous. Some examples of hyperspectral sensors that we'll learn a bit more about are the Airborne Visible and Infrared Imaging Specrometer, or AVIRIS, or the Hyperion sensor carried by the Earth Observing-1 satellite – on the plot here, you can see the 220 bands of this sensor, ranging from 357 nm all the way up to 2576 nm in 10 nm increments.

Slide 7 – Hyperspectral data: an example

If we take a minute to look at this plot here, we see a spectral signature for some type of vegetation (I think it's an oak leaf) in black, as well as what the Landsat 8/9 OLI and Sentinel-2 MSI sensors would see. Note that these multispectral sensors capture the general shape of the curve, but a number of the pronounced absorption bands, for example at about 1400 nm and 1900 nm, are missing. The coarse spectral resolution of multispectral sensors can make it significantly more difficult to correctly identify objects. If we look at what a hyperspectral sensor sees, on the other hand, we see the difference, and also why hyperspectral sensors are also called imaging spectrometers. Because they record in many narrow, continuous bands, they are able to faithfully capture the spectral signature of surfaces.

Slide 8 – Some hyperspectral systems

Next up, we'll look at the characteristics of a few different hyperspectral systems. The first of these, the airborne imaging spectrometer, records in 128 bands with a bandwidth of 9.3 nm. It operates in two different modes – a "tree mode", between 400 and 1200 nm, and a "rock mode", between 1200 and 2400 nm. The reason for the names here is that for most vegetation, visible and near infrared wavelengths are more important for identification, while for rocks and minerals it's often the shortwave infrared that is more useful. This sensor was typically flown at an altitude of about 4200 m, which gives it a ground sampling distance of 8 m.

Next up, we have the Airborne Visible and Infrared Imaging Spectrometer, or AVIRIS. You can see what this sensor looks like in the photo provided by NASA's Jet Propulsion Laboratory here, and an example of one of the images taken by AVIRIS, over Mauna Kea, Hawai'i, here. AVIRIS has 224 bands with a bandwidth of 9.6 nm, recording between 400 and 2450 nm. At a typical flying altitude of 20 km, AVIRIS has a normal ground sampling distance of 20 m. The AVIRIS homepage linked here has additional information about AVIRIS, as well as access to the images that have been acquired by NASA during flights.

Finally, we'll talk about EO-1 Hyperion, which is a spaceborne hyperspectral sensor. As mentioned previously, it has 220 bands with a 10 nm bandwidth, and a similar spectral range as AVIRIS. It also has a 30 m GSD, which is directly comparable to most Landsat bands. The example image shown here shows a Hyperion scene acquired over Mt Fuji, Japan, alongside an artist's rendering of the EO-1 satellite.

Slide 9 – Summary

In this lesson, we've reviewed how we can use spectral properties and signatures to help identify or distinguish objects and surfaces using remote sensing.

We discussed how hyperspectral systems work like spectrometers: they collect data in continuous, narrow bands, which means that we can use hyperspectral images to directly identify surfaces by comparing to known spectral signatures.

Finally, there are a number of hyperspectral sensors with data available for us to use, even if we don't have access to our own hyperspectral camera.

Slide 10 – Additional resources

You can read more about the topics we've discussed here in the textbooks – Lillesand, Kiefer & Chipman, Chapters 4.13 and 5.13, or Cambpell & Wynne, Chapter 2.6. I've also included a link to the AVIRIS homepage from NASA, which has additional information about not just AVIRIS, but also hyperspectral remote sensing more generally. This video, from the National Ecological Observatory

Network, provides a good additional introduction to hyperspectral remote sensing. Finally, this article provides a good history and overview of hyperspectral remote sensing. That’s all for this lesson – I hope you found it interesting, and you have any questions, please don’t hesitate to e-mail me or post in the discussion forum on blackboard. Bye!