A Guide for Teachers

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Introduction

The web is a major resource for information on remote sensing. There are many educational sites, tutorials, overviews of remote sensing agencies—companies—research programs, and most of all data. However, the volume and variety of this information is often overwhelming. Below I have selected some key sites targeting those wanting to obtain basic data and information on remote sensing for educational purposes. My intent is to provide beginners with a manageable list of particularly useful sites. These are my picks and I would be happy to receive comments and suggestions.

Hot Links to Get You Started

- The **GLOBE** program home page http://www.globe.gov
- **MULTISPEC** home page at Purdue University http:// dynamo.ecn.purdue.edu/~biehl/MultiSpec/
- **PACES** home page at UTEP http://paces.geo.utep.edu/index.html
- **Virtual library of Remote Sensing** http://www.vtt.fi/aut/rs/virtual/
- An Excellent Tutorial at the **Canadian Center for Remote Sensing** http://www.ccrs.nrcan.gc.ca/ccrs/eduref/tutorial/ tutore.html
- NASA's **Remote Sensing Tutorial—**very good but a little technical http://rst.gsfc.nasa.gov/
- **Virually Hawaii**— a nice tutorial and a variety of images http://hawaii.ivv.nasa.gov:80/space/hawaii/index. html
- A very nice tutorial prepared by the **ASPRS** http://www.research.umbc.edu/~tbenja1/

The Big Picture is Important AND Straight Forward

A Definition

> Remote sensing is the science of acquiring, processing and interpreting measurements acquired from aircraft and satellites (Sabins, 1997).

The Tricks of the Trade of Applied Remote Sensing

1. *Know the physics of the problem!* This is not all that complicated. We are dealing with electromagnetic energy (light, heat, radar), and we are all familiar with visible light. Much of the physical intuition needed comes naturally because we deal with light every day (i.e., bright means high energy). As you look at images constructed from remote sensing data, do not be afraid to use your physical intuition to understand terms such as:

   See—Resolve—Recognize—Detect—Signature Contrast—Brightness—Tone—Texture

2. *Know the numerical aspects of the problem!* Here again, the basics are not all that complicated. However, it is crucial to understand the digital nature of modern data. The digital values of these data represent the average energy of the electromagnetic energy reflected or emitted from a pixel covering a small area of the Earth's surface (~30m square in the case of Landsat). The mathematical operations are not complex, but the numerical manipulations of these data are. One has to beware of the "garbage in garbage out" rule. Be sure you have some idea of what a good result of a process would look like before applying it to your data.

3. *Get to know one of the popular software packages!* Processing of digital data to make images is an essential part of remote sensing. The main processing steps are standard, and if you can execute these using one software package, you will be able to quickly learn how to use another. Getting the data into a processing package can be a challenge that involves moving files from one computer system to another. Bite the bullet and learn how to do this yourself.

4. *Know the problem you are trying to solve!* Generic remote sensing means little. You have to be knowledgeable about a problem before you can do much to solve it. **Ground truth is always important!**

5. *Know the sources of data!* There is a huge amount of free and low-cost data in the public domain. It is a challenge just to keep up with what is available. Those who know where to find data quickly and cheaply are always valuable to their organization.

6. *The web is your friend!* The web is a major tool in remote sensing. It is the primary source of data, information on new developments, and educational materials.

An Introduction to Remote Sensing

Notes by Randy Keller

Remote sensing has been defined in many ways. It can be thought of as including traditional aerial photography, geophysical measurements such as surveys of the Earth's gravity and magnetic fields, and even seismic and sonar surveys. However, in a modern context, the term remote sensing really implies digital measurements of electromagnetic energy often for wavelengths that are not visible to the human eye. A big advantage in remote sensing is that the final product is usually an image ("picture") of the Earth's surface which we can visualize and interpret as if it were as picture. Thus, many of the terms and concepts (e.g., brightness, contrast, color, intensity) are familiar, and we have a physical intuition for their meaning. Very often the ultimate goal of a remote sensing study is simply to be able to "see" some feature or changes in it well. Thus, the definition of a good result can be as subjective as deciding which of a series of photographs is best. However, one must be careful to remember that remote sensing images are usually more than just digital pictures, and we need to have a good understanding of their physical meaning. Remote sensing techniques measure the interaction of the Earth's surface (or at most the upper few meters) with electromagnetic energy from the sun and therefore are inherently a form of geographic information. Thus, the use of geographic information systems (GIS) to store and display remote sensing information is so common that the terms remote sensing and GIS are almost synonymous. The use and generation of digital elevation models is an example of how these two fields are merging. When properly geographically referenced (ie., the location of each measurement is carefully determined), images ("pictures") created from remote sensing measurements become maps of the Earth's response to various wavelengths of electromagnetic energy.

Basic Principals of Electromagnetic Wave Propagation

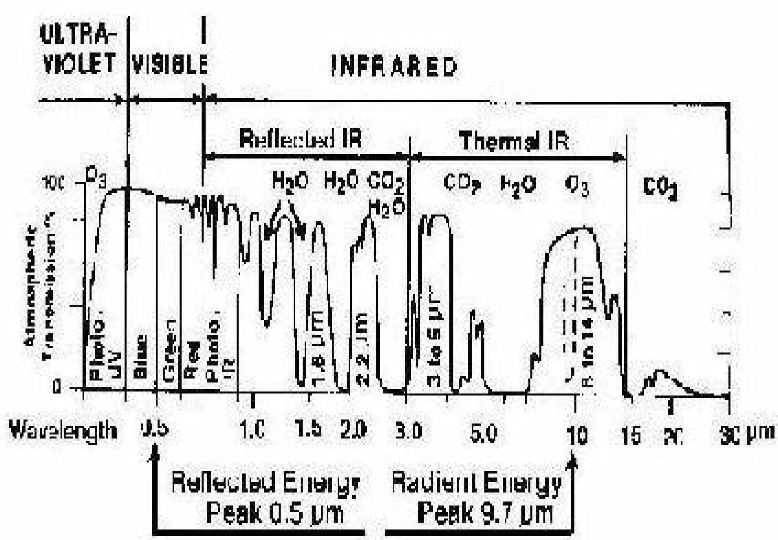
Most of the key physical principals we need to formulate a basic understanding of electromagnetic energy are familiar to us. In remote sensing, we classify electromagnetic energy by its wavelength. Visible light is the type of electromagnetic energy with which we are most familiar, but there is much to be learned from waves whose wavelengths are longer or shorter that those of visible light. The basic theory needed to understand electromagnetic energy well enough to use remote sensing techniques intelligently is surprisingly simple. The mathematics needed is not difficult, and the physical principles are straightforward. The trick is to link your training in mathematics and physics with your practical knowledge of physical phenomena (like light, x-rays, radar, and radio waves) to develop an intuitive understanding of the propagation of electromagnetic waves through the atmosphere and their interaction with the Earth's surface. One advantage is that many terms used in remote sensing are familiar and have the same meaning as in every day life (i.e.., bright, dark, high and low contrast, and intensity). In physics, one learns that light (and electromagnetic energy of similar wavelengths) can be thought of as either a propagating wave or a stream of particles. In remote sensing, we usually think in terms of waves.

Basic Concepts, Equations and Terms:

There are a number of basic equations (and the terms involved in them) which form the basis for an understanding of electromagnetic waves and how to use them in practical applications.

1. Electromagnetic energy has been classified by wavelength and arranged to form the electromagnetic spectrum.

are false color in nature and are not pictures in the sense that humans would never see the Earth in this particular fashion. The images in fact detect objects and phenomena which could never be "seen" by the human eye. Primarily as the result of ozone (O_3), CO_2, and water vapor, the atmosphere absorbs energy in several discrete bands so sensors are designed to avoid these bands since little energy survives transmission through the atmosphere. Most remote sensing devices are passive in that they merely measure the intensity of the Sun's electromagnetic energy which is reflected off the surface of the Earth or is emitted (radiated) as heat. However, some systems (radar in particular) are active in that the energy that is measured is generated by the measuring system not the Sun.



This spectrum shows that visible light occupies only a very narrow band of wavelengths. Gamma rays, x-rays, and most ultra-violet energy do not penetrate the atmosphere so they are not used in remote sensing. However, infrared and microwave (radar) energy is measured regularly and is very useful in addition to energy at visible wavelengths. Thus, we must remember that almost all images made from remote sensing data

2. As electromagnetic energy interacts with the atmosphere and the surface of the Earth, the most important concept to remember is the conservation of energy (i.e., the total energy is constant). Our main concern is the fate of the energy that makes it through the atmosphere to hit the surface of the Earth. The three main processes are reflection (scattering is a form of reflection), absorption (this energy is converted

to heat and some is emitted with a change in wavelength and a time delay) , and transmission. Each of these phenomena are a function of wavelength (l), and conservation of energy leads to the following equation:

Ei(l) = Er(l) + Ea(l) + Et(l),

where,
Ei(l) = the incident energy
Er(l) = the reflected energy
Ea(l) = the absorbed energy
Et(l) = the transmitted energy.

In the case of a lens, almost all of the energy is transmitted. However, the case of the Earth's surface most energy is reflected or absorbed. At a particular location, the ratio of the reflected energy to the incident energy as a function of wavelength (expressed as a %) is called the **reflectance spectra**, and is expressed as:

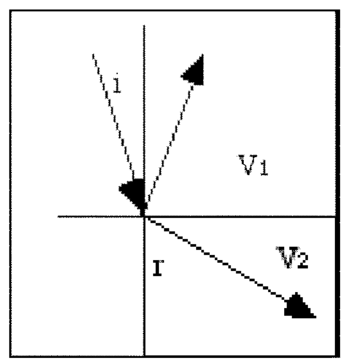
R(l) = Er(l) / Ei(l)

The interaction of the incident energy with the atomic structure of soil, rocks, plants, bodies of water, man-made objects, etc. governs how much energy is absorbed and thus how much is reflected. Materials such as minerals and leaves have a (at least somewhat) distinctive reflectance spectra which can be measured by a laboratory or field-portable spectrometer. These values can then be compared to remote sensing data in order to identify which materials are present in the area of an image.

3. As electromagnetic waves travel , they encounter discontinuities in velocity (objects) which reflect some energy like a mirror and transmit some energy after changing the travel path (refract - like a lens). The basic principles of optics apply here in particular

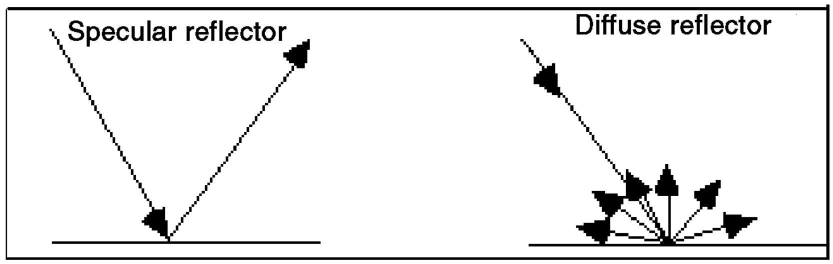
Snell's law: $\sin\theta \, {}^{1}\!/_{C_1} = \sin\theta \, {}^{2}\!/_{C_2}$

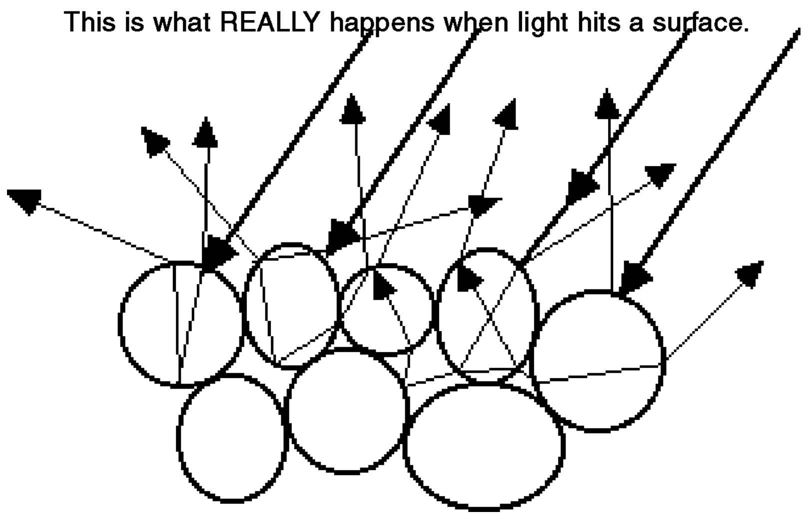
The ratio of the velocities is called the index of refraction - n.



Snell’s Law of Refraction

This type of reflection (technically called **specular** reflection) is what we usually think of when we consider physical processes in optics, seismology, or billiards. However, it only occurs when the surface is smooth (irregularities are very small relative to the wavelength of the incident electromagnetic energy); examples are the reflection of objects in a mirror or a body of quiet water. However, in the case of the Sun's energy reflecting off the Earth, this only partly describes the processes that occur. Specular reflection is a function of wavelength, the size of the reflecting particle, and the index of refraction of the particle. In addition, some energy usually is transmitted through a few particles very near the surface and is thus effected by their absorptive properties (which are function of wavelength) as well as adjacent particles that are encountered (see below). The end result is that reflected energy leaves the surface at all angles (**diffuse** reflection) after interacting with particles near the surface. The resulting variations in reflectance with wavelength are the process which gives us color as we see it visually and the energy that we study in remote sensing. Thus, reflectance is basically a simple concept, but we must remember that it is a function of the wavelength of the incident energy (and to some extent the angle of incidence), the index of refraction and absorption of the materials which make up the reflecting surface, and the size of the particles which make of the surface.

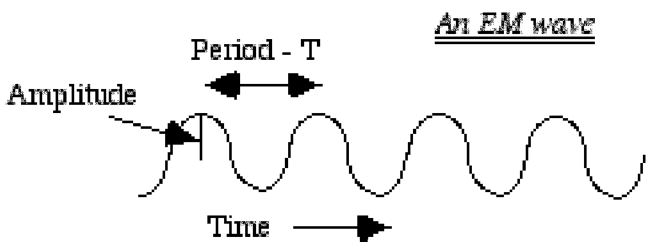




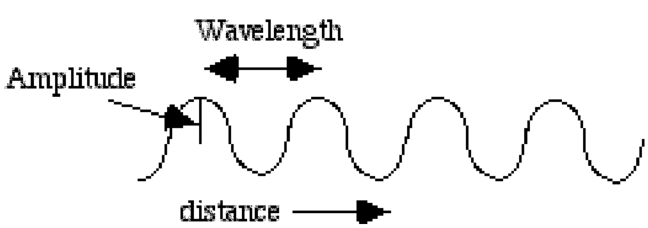
4. The distance (d) a electromagnetic wave travels in a certain time (t) depends on the velocity of the material (v) through which the wave is traveling; **d = v t**. Since all electromagnetic energy travels at the speed of light (usually denoted by c) this is equation is very simple to apply. For example, we can generate radar waves and time their return after reflection from the Earth's surface. The distance to the reflecting object can be obtained from this simple equation.

5. The **velocity** (c), **frequency** (f), and **wavelength** (l) of a electromagnetic wave are related by the equation: **c = f l**. Strictly speaking, this equation applies to simple harmonic motion in which we are dealing with a wave which consists of motion with a single frequency (i.e. a sine wave), but in remote sensing, one usually treats measurements which are made for a narrow band of frequencies as represent a single frequency at the middle of the band.

$$T = {}^{1}/_{f}$$



In the picture above, the wave is depicted as what happens to a particular point as the wave passes so the horizontal axis in this diagram is in units of time and the distance between two peaks is the period. We can also think of depicting the wave as if we could take a snapshot of it at one instant of time. In this case, we are looking at a spatial picture in which the horizontal axis is in units of distance and the distance between two peaks on the wave form is the wavelength.



We usually think of electromagnetic waves as a constant stream of energy from the Sun for a particular frequency. Thus, the depictions above apply. In radar applications, we generate our own energy, and in this case, it is appropriate to think of these waves as a pulse (wavelet) of energy which is as short as possible in time. Strictly speaking, it is no longer simple to think of the wavelength or frequency of this wave although such terms are still commonly used in radar studies. One reason for this usage is the utility of wavelength as a measure of the spatial dimension of a electromagnetic wave relative to some object whose interaction with the wave is of interest.

6. We can draw on the analogy of a rock dropped into a pond to define **wavefront**. The circular ripples on which the wave motion is the same (a particular peak or trough) are wavefronts. In the case of most remote sensing applications, these fronts are spherical and spread out in three dimensions from the source (the Sun). Because of our great distance from the Sun, we think of the incoming wavefront as being planar, and in radar, we go to great lengths to generate a planar wavefront (we call this synthetic aperture radar and almost all modern data is of this type). In this way, one can think of the propagating electromagnetic energy as being very organized. When a wavefront encounters discontinuities which are large relative to a wavelength, the energy is reflected (and refracted for example through a lens) also in an organized fashion (Snell's law above). Thus, light whose wavelength is such that it is red looks red to us when it is reflected.

7. It is quite appropriate to look at the amplitude of a electromagnetic wave and think of it as a measure of the energy in that wave. Obviously, the larger the amplitude the more energetic the wave. However, technically we must remember that introductory physical treatments of simple harmonic motion show that energy is proportional to the square of the amplitude.

8. Electromagnetic waves lose energy (amplitude) as they travel because of several phenomena:
   - *Spherical spreading*—This phenomena is simply the fact that the amplitude dies off with distance traveled (i.e., the further you are from the source, the weaker the signal). This obvious physical effect is no different than observing that as one gets farther and farther from a source of sound, a weaker and weaker sound is heard. Technically, as the wave travels, the wavefront is a sphere whose radius gets larger and larger. Since the area of a sphere is $\mathbf{4\pi r^{2}}$, at some radius (distance traveled), the energy per unit area on the wavefront is equal to the original energy divided by $\mathbf{4\pi r^{2}}$. Since the energy is proportional to the square of the amplitude, the amplitude is proportional to $^{1}/_{r}$. Strictly speaking, the energy is not diminished by this effect, it is just spread over the surface of larger and larger spheres.
   - *Absorptio*—It is appropriate to think of absorption as the tendency for materials to simply soak up electromagnetic energy and convert it to heat. We can measure some of this energy as radiated (emitted) heat which is at a longer wavelength than the original energy.
   - *Scatterin*—The interaction of electromagnetic waves with objects which are small relative to a wavelength (i..e., molecules in the atmosphere) leads to energy being reflected (scattered) in an unorganized fashion. This term is very intuitive, and we can just think of the energy being randomly dispersed in three dimensions. The primary scattering process at work is called **Rayleigh scattering** which proportional to 1 over the wavelength to the 4 power. Thus in the atmosphere, short wavelengths are subject to selective scattering which is basically due to the fact that many particles and molecules are too small to effect the longer wavelengths significantly. Short wavelength energy like UV and blue light are in fact scattered about twice as strongly as red light. For wavelengths in the visible light range, selective scattering causes us to see that color. Blue sky which is the effect of selective scattering of blue light is the classic example of this effect. This effect (along with absorption) is a fundamental restriction in remote sensing and limits the range of wavelengths which can be employed. When large particles like water droplets are encountered, the scattering effects a broad range of wavelengths (non-selective), and then we simply see unorganized white light. Classic examples of this effect are clouds and fog.

9. **Resolution** —A question which constantly arises in electromagnetic studies is whether the target of a remote sensing study can actually be "seen" (resolved) in the data. When one looks at a printed copy of a particular image or picture, resolution can be quantified to some extent but is really no more complex than determining if the interpreter can see the object, pattern, signature, texture, etc. which is of interest. In the case of digital images, resolution is a technical issue in two ways. First of all by its very nature, a digital image is composed of pixels (ground resolution cells) of finite size. The measurement for each cell is the intensity of the reflected energy for a particular band of wavelengths, and the size of the pixel is a measure of spatial resolution. The simple fact is the smaller the pixels, the better the resolution . Good resolution is of course desirable, and as new satellites and airborne systems become available, the tendency is for the pixel size to decrease (30 m for Thematic Mapper, 10 m for SPOT, 5 m for IRS). There is also the question of spectral resolution. In this case, the question is how well have we determined the variation of reflectance with wavelength (the reflectance spectra). As a practical matter, this simply a question of how many bands is a particular device capable of measuring and what is their width (i.e., what is the range of wavelengths). A large number of narrow bands is desirable and

again technology is providing data with better resolution. For example, Landsat Thematic Mapper makes measurements for 7 bands while the AVIRIS airborne system makes measurements for 224 bands. Thus in digital terms, the denser the measurement, the better the resolution. However, the data volume also increases greatly as the sampling rate (spatially or in wavelength) increases, and this will effect the speed and ease of the data processing.

Image Analysis vs Spectral Analysis—Two ways to employ remote sensing data

The first step in analyzing remote sensing data is image analysis. This step involves some amount of data processing, but its initial goal is to produce an image of the Earth's surface that "shows" features of interest. One can then either directly or indirectly (e.g. image classification schemes) "map" the distribution and/or characteristics of these features. In this case, the desire is to have the smallest pixels possible so that the clearest and most detailed image possible is obtained. The analysis may stop here because the image or map provides the information needed.

Another way to examine remote sensing data is by analyzing the spectral reflectance of individual pixels or groups of pixels. Here the attempt is to identify the specific materials (minerals, pollutants, vegetation, etc.) that are present in the surface area represented by the pixels. This approach requires careful comparison with known reflectance spectra for materials of interest. In this case, the desire to have data from as many spectral bands as possible so that the material identification can be as exact as possible.

References

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