

Geos 492/692 Fundamentals of Planetary Remote Sensing

Review of 1st 3 lectures, especially Fourier series.

1. go over parts of cos wave: $a \cos (bx + c)$
2. show that phase shift is same as sum of cos and sin
3. Taylor series for sin, cos, exp., relationship
4. Fourier transform for cos, sin.
5. Fourier transform with exponentials.
6. Some things to note:
 1. if integral of $f(x)$ nonzero, must have DC component.
 2. the delta function has energy at all wavelengths (not same as periodic function)
 3. discuss Nyquist frequency, which is half the sampling frequency (i.e., two per wavelength).

So, to sum up, wave behavior of light says we can describe light hitting us as a sum of light waves and multiple frequencies hitting us. Black body is a function for the relative amplitudes of the waves in the spectral domain.

Lectures 4 and 5

Topic: Photographic systems, using film cameras and then using the camera as a radiometer.

How does black and white film work?

Plastic transparent base of support. On top of this base is a gelatin (called an emulsion layer) that contains crystals of silver halide (a compound of silver and ion of bromine, chlorine, or iodine, e.g. AgBr). A photon whacks the crystal and busts the halide into silver and bromine, and if a bunch of silver atoms are in close proximity, then the silver is stable and forms a “development centre”. A chemical reducing agent applied to the film reduces Ag⁺ ions to Ag in the presence of these development centers, while the rest of the silver ions get washed away. The end result is that areas of film that were exposed to light are converted to solid silver, while the rest is transparent, thus making a negative.

Some details:

Crystals of silver halide are typically 1 micrometer across, meaning on order of 35,000 grains in a typical negative. Not exactly correct, but you get the idea.

An exposure to light sufficient to cause only a few atoms of silver to form in a grain of halide will allow the entire grain (10^{10} ions) to become silver in the development process. So, photographic detection involves huge amplification.

The minimum energy required to bust up the halide dictates the maximum wavelength to

which the film can respond, which should be blue and shorter (out to x-ray, with the opacity of the lens and film eliminating the shorter wavelengths). Various chemical modifications allow the material to be made sensitive out to the red or even infrared wavelengths.

Increasing light sensitivity of the film (so the shutter speed can be decreased) requires using larger halide grains, which is why fast film (ISO 800, etc.) can produce grainy photos.

The spectral sensitivity of panchromatic film is decidedly nonuniform.

How does color film work?

Three layers of emulsion: upper most is sensitive to blue, middle-blue and green, bottom-red and blue, then yellow filter (removes blue light) between upper and middle layer. Then, in processing the yellow filter is removed, and the activated regions are processed to form dyes that are, respectively, yellow (red + green), magenta (red and yellow), and cyan (blue + green), or the negatives of rgb.

Using clever color processing, can “shift” colors for color IR film, so G-R-IR → B-G-R. Good for detecting camouflage in WW2.

Parameters of film: spectral sensitivity-not necessarily like the eye; speed-how long an exposure to achieve opacity after processing (ASA, ISO, or DIN, with larger numbers meaning less exposure time); contrast-how gradations in light translate to gradations in final picture (high contrast means high sensitivity, but easy to overexpose); spatial resolution (returning to this, measured as distinguishable line-pairs on negative, typically a few thousand for 35 mm, 7000 for aerial recon work).

note: instead of using special dyes and chemicals in the film and processing to divide up the spectra, we can put filters in front of the camera.

define focal length f :

with lens, $1/u + 1/v = 1/f$, where u and v are distance from lens. For object of height x , image is height $v \tan(\theta)$, where θ is angle through center of image where object is in focus on opposite side. As u gets very large, v tends to f and image size to fx/u . Thus, if we have a camera with lens at a vertical height H above the ground and focal length f , then the scale s , the ratio of the size of something on the ground to something in the image, is defined as f/H . If the width of the negative is w , then the ground coverage is wH/f .

returning to resolution, see that all other things being equal, resolution increases with focal length, so there is a trade-off of ground coverage with resolution.

Photogrammetry

If we now set H as some datum, then the scale of a point h above the datum is $s=f/H-h$.

If we know the topography, then we can “correct” the image to a datum if we'd like.

Also, for aerial photos with relief displacement, $h = Hd/r$, where d is base-to-top in image, and r is radial distance to top (fig. 2.11a). That only works for straight up and down objects.

Now consider another image of the same object, taken at the same H , with same camera (focal length f), but a distance B away in the x direction.

$x_1 = -fx/(H-h)$, where x_1 is image coord., x is horiz. coord., h is obj. height.

$x_2 = -f(x-B)/(H-h)$

$x_2 - x_1 = Bf/(H-h)$

While measuring topography can be done precisely using photographs, getting a property like reflectance (or what we really want, soil content, etc.) is much more problematic with photographs. We need a series of functions to go from one to the other, and this often requires a lot of ground truth with analog instruments. With digital systems we can do things more cheaply and with more precision.

Photoclinometry

A method for determining the shape of a surface from its image

"Shape from shading" (also known as photoclinometry) is a method for determining the shape of a surface from its image. For a surface of constant albedo, the brightness at a point (x,y) in the image is related to the gradients (p,q) by the following expression:

$$i(x,y) = a R[p(x,y),q(x,y)]$$

where R is the reflectance map, $p = dz/dx$ and $q = dz/dy$ are the partial derivatives of the surface in the x - and y -directions, and a is a constant that depends on the albedo, the gain of the imaging system and other factors. The above expression also assumes that any additive offsets, for example, because of atmospheric scattering, have been removed.

A variety of methods have been developed for inverting the above equation (see Horn 1990). The next section describes a simple method that provides satisfactory results in many planetary imaging scenarios. It is based on some early ideas described by Horn (1977).

Row Integration - The reflectance map depends on the position of the light source, the observer, and the type of surface material (Horn 1981). It can be thought of as a lookup table that gives the brightness as a function of the gradients. This is known as a photometric function, or a model of the intrinsic reflectivity of a surface F :

$$B/J = F(I, E, G, w, \dots)$$

where:

B	is the observed reflected surface brightness,
J	is the brightness incident on the surface,
I	is the angle of incidence (i.e., of the sun),
E	is the angle of emission (i.e., of the observer),
G	is the phase,
w	is the albedo of surface particles, and

... denotes any other quantities which may contribute to the functional relationship of B/J.

For Lambertian surfaces the brightness is proportional to the cosine of the angle between the vector that is normal (perpendicular) to the surface and the vector in the direction of the light source. As noted by Pentland (1988), if the angle between the vector in the direction of the light source and the vector in the direction of the observer are more than 30 degrees apart and the surface is not too rough the reflectance map can be approximated by a linear relationship. If the image is rotated so that the vector that points to the sun is in the x-z plane, it can be shown that

$$i(x,y) \sim a [\sin(s) p(x,y) + \cos(s)]$$

where s is the zenith angle (angle wrt vertical) of the sun. The constant scale factor a is difficult to determine directly without ground truth (that is, ground targets with known albedo and slope). However, because in most images the gradients are more-or-less uniformly distributed in all directions, the expected value of the gradient in the x-direction $E[p] \sim 0$ and so the average image brightness

$$E[i] \sim a \cos(s).$$

This then allows us to estimate the scale factor

$$a = E[i] / \cos(s).$$

The elevation map $z(x,y)$ can be obtained iteratively, row-by-row as

$$z(x,y) = z(x-1,y) + [i(x,y) - a \cos(s)] / a \sin(s)$$

where $z(0,y)$ are the boundary values. If the boundary values $z(0,y)$ are unknown, we can minimize the mean-squared elevation difference between rows by subtracting the average row elevation from the elevations in the row.

When stereo imagery does exist, shape from shading provides an alternative method for extracting terrain data. Although its use has been limited primarily to constant-albedo planetary mapping applications (that is, where the surface is covered more-or-less by the same material) a new algorithm under development by PSR will extend to the general case in terrestrial imaging applications where the albedo is not constant.

Some examples:

the [Minnaert](#) function: $F=B_0*(\text{COS}(I)**k*\text{COS}(E)**(k-1))$,

(the Lambert function is equivalent to [Minnaert](#) for $k=1$)

three [Hapke](#) functions (1978 version, [Cook](#) modification, and 1984 version),

the [Veeverka](#) function, and

the [Mosher](#) function (a variant of the [Veeverka](#) function).

the [Buratti-Veeverka](#) function.

the [Irvine](#) function.