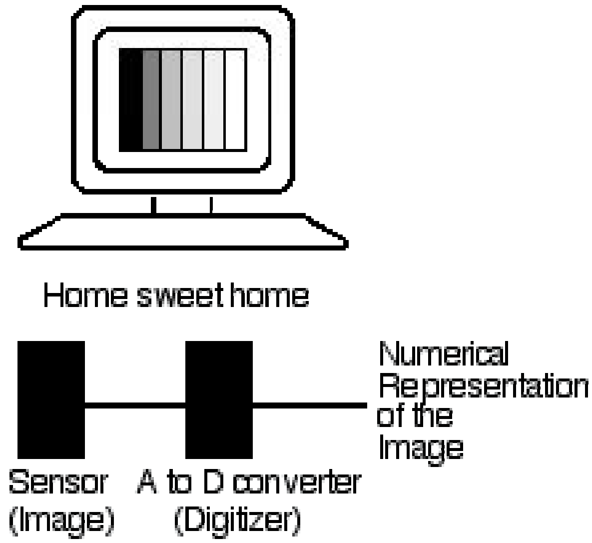
Chapter 8

Digital Image Processing



Digital processing involves many possible procedures in which the numbers which represent the image are manipulated. Many computer processes involve resampling which must keep in mind the basic resolution of the data. Most modern data is processing so that geometrical effects are corrected prior to delivery to the user. However, the **basic steps in processing** are:

- **Image restoration**
  This step involves repairing flaws in the image, and most importantly, adjusting the image so that it is an accurate cartographic product.
- **Image enhancement**
  This step involves a wide variety of processes which make various aspects of the image clearer. Examples of processes which are commonly applied are improving (increasing) the contrast ratios on the image (contrast stretch), mosaiking adjacent images, spatial filtering, and enhancing edges in the data.
- **Information extraction**
  This step generally consists of statistical processes which often automatically extract information and present it in either image or graphical form.
- **Linkage to a data base and a GIS system**
  The job is not really complete until the data are stored in a structured system and geographic information is added to the image to help the user locate features in a map sense.

Some Rules to Remember

- Garbage in; garbage out (i.e., always look at your data first).
- Never apply a process unless you are sure that you would recognize a good result if you saw one. If it does not look right, it probably isn’t right.
- Do not hesitate to try different processes or several values of parameters required for a certain process. You cannot hurt anything and you will develop an experience base and learn what parameters are most important. Remember that, from an image analysis point of view, the processing steps that produce an image that provides the information you need are, by definition, the right steps.

Image Restoration

- **Noise Removal**

  There are several possible sources of noise in scanning systems. Since the data are so dense, simple moving window operators can usually spot spurious values and replace them with some sort of average of neighboring values. Examples of such operations include restoring periodic line dropouts, removal of banding, removal of random noise. Such operations are generally foolproof and simply viewing the image after application of the process can assure that it worked properly. Most modern data come with such problems already fixed.

- **Correction for Atmospheric Scattering**

  The effect of haze is to reduce contrast. In a digital image, the effect is to make all the values in a band high relative to an IR band where atmospheric effects are minimal. The cure for this is simply a DC shift (i.e., subtraction of a constant) to the hazy data. More sophisticated approaches exist which involve models of the atmosphere's response to the incoming EM energy from the Sun.

- **Geometric Restoration**

  Images usually include geometric distortions due changes in the attitude and altitude of the spacecraft. These distortions are not systematic and must be dealt with on a image by image basis. The procedure is to pick a series of ground control points which are places on the ground that can be clearly seen on the image. The coordinates of these points are determined from maps or Global Positioning System (GPS) surveys. A surface is then fitted to these points mathematically, and this surface is then used to predict corrected locations for the pixels in the distorted image. The process of moving the pixels to these new locations is often referred to as warping the image. This process can also require resampling of the digital values since a given pixel in the original image may overlap several pixel locations in the corrected image. The "nearest neighbor" approach avoids this procedure by taking each new pixel location and assigning it the digital value of the pixel from the original image that come closest to overlying it after correction.

Image Enhancement

- **Contrast Enhancement**

  This is a very common procedure whose goal is to increase the contrast ratio on an image. The process is simply one of looking at a histogram of the digital values for an image and resampling them after stretching the values which made up the bulk of the variation on the image over the full range of possible values. There are a number of approaches available in most software packages, but a simple linear stretch is usually sufficient.

  A major cause of low contrast in images is **scattering**, which is due to multiple collisions with particles and gases in the atmosphere. However, some terranes inherently have low contrast. For example, polar areas covered with snow are uniformly bright and a basaltic volcano is uniformly dark. The key control on the nature and amount of scattering is the relationship between the wavelength of the energy and the size of the particles and molecules being encountered.

- **Selective Scattering**

  Short wavelengths are scattered more producing blue sky for example.

- **Nonselective**

  Due to large particles - all wavelengths are scattered producing random white light. For example, water droplets produce white clouds. Scattering produces *illumination* but reduces contrast ratio. In the case of film, contrast is increased by using filters (haze filter or IR film). In the case of digital images, contrast stretching (transformation) is a basic step in image processing that is applied to almost every data set. The concept is simple in that for most images a histogram showing the number of pixels which assume a certain digital value reveals that the values span a limited range of the radiometric resolution available (usually 0 to 255). Thus, the contrast is reduced. The most common approach to employ is the **linear contrast stretch** (often with the highest 1-2% and lowest 1-2% of the values excluded) where the highest recorded value is transformed to the highest value possible and the lowest values recorded transformed to the lowest value possible. Everything in between is adjusted in a linear fashion. A **gaussian stretch** is a similar transformation but assumes the digital values should have a bell-shaped curve distribution. A **histogram equalization** approach attempts to put a similar number of digital values in every portion of the distribution.

- **Density Slicing**
  This process is nothing more than assigning a single color or shade of gray to a whole range of digital values. This makes a map appear terraced, and the idea is that each level of the slice corresponds to a some aspect of the image.
- **Edge Enhancement**
  The fact that a digital image is composed of resolution cells which have finite dimensions tends to blur edges (i.e., faults, roads, land use boundaries, etc.). Thus, edge enhance is a process which attempts to sharpen up the edges in an image. Mathematically this process amounts to taking spatial derivatives (gradients). Where there is only a small change in the image there will be little effect. Areas with changes will be sharpened. This approach can be applied so that edges with any geographic trend will be enhanced (non-directional filter) or so that only edges with a certain trend will be enhanced (directional filter).
- **HS Transformation**
  The intensity, hue, and saturation approach is an alternative way to think of the colors in an image. This approach can be used to enhance an image by for instance contrast stretching the saturation component and then transforming back to the RGB system. (see Plate 11 of Sabins, 1987). Another reason to employ this simple transformation is to replace the intensity with some other sort of data such as SPOT or IRS-C and then do the inverse transformation to obtain the RGB color image at a higher resolution.
- **Digital Mosaics**
  It always seems that one's area of interest lies near the boundary between two scenes. Thus, it is necessary to merge the data from these scenes into a mosaic. This process involves spatially merging the data sets and then matching their histograms so that the color schemes match and the seam between the two scenes is not visible.
- **Stereo Pairs and Perspective Images**
  With the emergence of readily available digital elevation data, many new approaches to enhancing images are emerging. For example, the digital elevation data can be used to create synthetic stereo pairs and to create perspective views by draping the image over the topography.

Information Extraction

Principal Component Images

In this approach, the goal is to make linear combinations of data from multiple bands so that most of the variation (i.e., independent data) can be expressed in a small number (ideally 3) of components of transformed data. The mathematics is messy but straightforward.

Any three principal components can be displayed as an RGB image and interpreted. A subset of the n principal components can be thought of as reducing the dimensionality of the data set thus simplifying further analysis.

A challenge with multispectral data is finding an efficient way to extract the information it contains. One consideration is that multispectral data sets usually contain certain bands that are highly correlated (Figure 1). This implies that the data from these two bands provide essentially the same information, and principal component analysis is a technique commonly employed to exploit this fact. The mathematics behind this approach is simple when the case of two or three bands is considered but gets more abstract as one tries to imagine the process in n-dimensions. In the case of two bands (Figure 1), one finds a linear transformation that defines a new set of axes one of which displays the maximum variation. This first principal component thus becomes the basis for a new set of orthogonal axes each of which in turn contain decreasing amounts of variance.

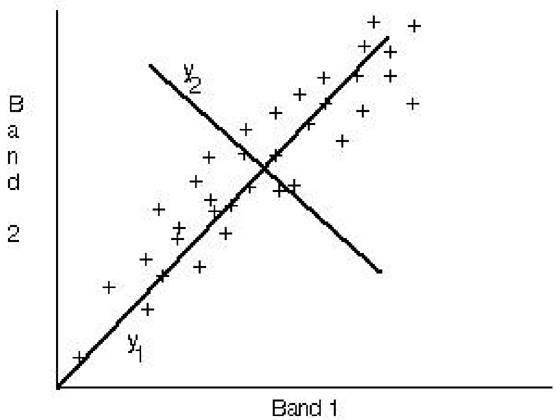


Figure 1. Two correlative bands and the principal components y_1 and y_2.

Ratio Images

Ratio images are derived by simple pixel-by-pixel division of digital values. One advantage of ratio images is that they minimize differences in illumination (reduce the effects of shadows. Another advantage is that they emphasize differences in spectral reflectance (Figure 2).

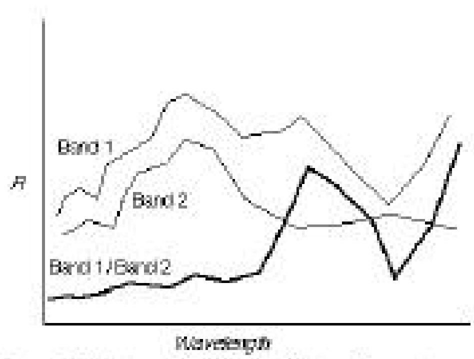


Figure 2. A ratio image tends to emphasize differences in reflectance at specific wavelengths.

One disadvantage is that they lose the information contained in the absolute values of reflectance data especially in the overall reflectivity or albedo of a region of an image (Figure 3). Another disadvantage is that they tend to amplify noise (Figure 4).

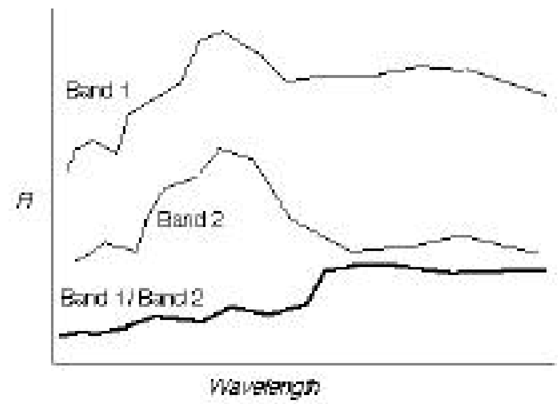


Figure 3. A ratio image tends to deemphasize differences in overall reflectance (albedo).

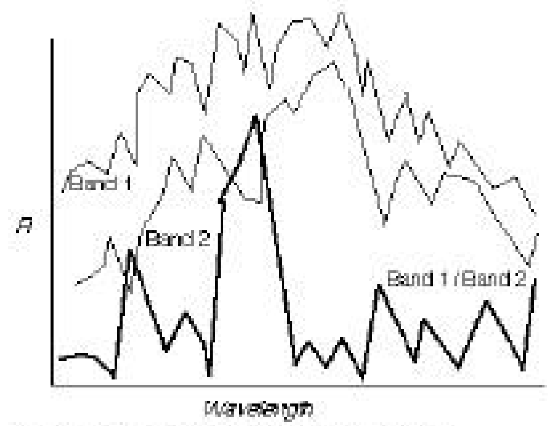


Figure 4. A ratio image tends to emphasize noise.

There are many possible combinations of ratios that can be calculated. With the 6 bands of TM data alone there are dozens. One can combine any three ratios to form an RGB color image or even combine ratioed data with standard data. An example of thinking through what one might expect would be to use a TM3/TM4 which would make water and roads bright because they absorb energy in band 4 while making vegetation dark because its is strongly reflective of energy in band 4. On the other hand, vegetation in a TM5/TM2 ratio image would appear bright because the reflectivity in band 2 is relatively low.

Multispectral Classification

In general, classification schemes involve some form of pattern recognition in an effort to compress all of the information in a multispectral data set into a single image which depicts the majors types of surface reflectivity in a manageable number of colors (shades of gray, symbols, etc.). For example, a few types of rocks and vegetation, urban areas, and water might be identified as representing the classes. The basis for the classification is the spectral signature of each class. This procedure takes many forms, but the goal is to extract from the image or measure in the field the spectral signature of a particular rock type, vegetation type, etc. and then search the image for this signature. These approaches can be supervised (human intervention involved) or unsupervised (automatic).

Supervised

In supervised classification schemes, a series of sites which represent known classes (i. e., you know that a certain field recognizable on an image was filled by well developed corn plants or that a certain rock outcrop is composed of sandstone). The spectral signature of each class (a pattern) is then used as the basis for a search for pixels which have this signature. The process employs all of the bands (or principal components) so it is n-dimensional. The 2-D example given Figure 5 shows what the process is generally like with idealized data. The process requires some work to choose classes that are distinct and meaningful. There are many different statistical approaches which can be used in classification schemes, but one needs to consider basic aspects of the data such as whether they are tightly grouped (A and D, Figure 5) or dispersed (B and C, Figure 5) or whether they are correlated strongly (A and B).

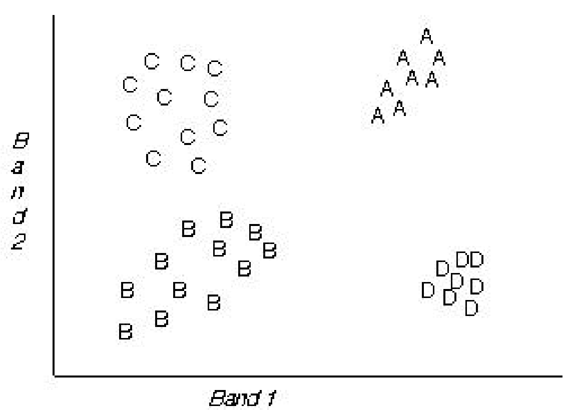


Figure 5. Examples of classes having different statistical properties.

Unsupervised

Unsupervised classification schemes proceed in a similar manner as supervised ones. However, the classes are assigned automatically by the computer. This as the advantage of being unbiased by the interpreter and may turn up patterns that would have been missed. On the other hand, it may produce unlikely class groupings.

Change Detection

With today’s emphasis on global change and environmental impacts, the detection of change between images acquired at two different times is a common procedure. There are several approaches to this procedure, but the most simple is simply to carefully correct two images for effects of differences in sun angle, distance to the sun (anniversary images are ideal), atmospheric conditions, and sensor variations. Then one does a careful georeferencing of the images and simply subtracts the pixel values in one from the other. The differences can then be contrast stretched and displayed.