APPENDIX 18-1: Initial Spectral Data Processing

Initial spectral data processing involves the calibration issues discussed in Chapter 7 and the correction for non-uniformity of response of the various detectors in the Focal Plane Array (FPA) discussed in Chapters 7 and 14. Additionally, for most spectral applications, the data must be corrected for atmospheric effects, and the resulting measured radiance values for the ground pixels making up the scene must be converted to spectral reflectance values. It is at this point that the spectral data is amenable for spectral analysis algorithms.

Recall that calibration involves determining both the quantum efficiency, or responsivity (sometimes referred to as the gain), and the dark current (sometimes referred to as the offset) of every detector in the FPA. Not all the detectors in the FPA will have the same values of quantum efficiency and dark current. As previously discussed in Chapter 14, the first step is to determine those detectors which are totally non-functional: the so-called "dead" detectors (no output for any value of incident radiation) and the "happy" detectors (saturated output for any value of incident radiation). Such detectors will produce data drop-outs in spectral imagery: No coverage of a ground pixel, if a staring sensor is used, or a missing spectral band of data from rows of ground pixels if a scanning sensor is used. To adjust the variable quantum efficiency and dark current values for the rest of the detectors, so that they are the same when viewing a uniform scene, all of whose ground pixels have the same spectral signature, several calibration procedures were introduced in Chapters 7 and 14. These include pointing the sensor at an on-board calibration source, at a well measured region on the ground (all of whose ground pixels have the same spectral signature) or at a portion of the night sky having few stars. If the output from all the detectors has been adjusted as discussed above, then the spectral imagery collected by that FPA is said to have been flat-field or non-uniformity corrected, or had a non-uniformity correction applied. If actual calibration values for the detector quantum efficiency and dark current are known for every detector, then the spectral imagery produced is said to have absolute radiometric calibration. In this case, the spectrum measured by each detector can be given in units of spectral irradiance, such as Watts/m^2-μm.

The atmospheric correction is then used to take these spectral images in irradiance and convert them into ground pixel spectral radiances. Atmospheric correction algorithms make use of some of the standard atmospheric radiative transport codes, such as Moderate Resolution Atmospheric Transmission (MODTRAN) (refer back to Chapter 5), Fast Atmospheric Signature Code (FASCODE), and Second Simulation of the Satellite Signature in the Solar Spectrum (6S). As was pointed out in Chapter 5, the results of these codes depend strongly on the atmospheric characteristics at a given location, date of year, and time of day. In particular, the most important of these characteristics for the Visible-Shortwave Infrared (visible-SWIR) are the water vapor density profile (values as a function of altitude), aerosol density and size-distribution profiles, and aerosol type (for example, rural, urban, tropical, etc). The situation in the Mid-Wave Infrared – Long-Wave Infrared (MWIR-LWIR) will be discussed in Chapter 19. Input information can be selected from options provided by the code itself or by in-scene measurements. For example, MODTRAN provides the user a choice of atmospheric models, such as US standard, mid-latitude summer, tropical, etc, as well as aerosol models, such as 23-km visibility rural, 5-km visibility urban, etc. These models represent average values based on years of surface and airborne measurements, but they obviously don't reflect the possible variation seen at a particular location, date, and time.

Some specific measurements are routinely made using surface observations, weather balloons, or satellite sensors. For any desired location, date, and time, an interpolation can be made using the values measured at nearby locations, dates, and times. For example, the Air Force Weather Service (now part of Air Combat Command) can be tasked to provide interpolated values based on either actual measurements or their predicted values. The results of these interpolations are the most accurate in regions of the world, such the United State and Europe, where the number of weather reporting sites and frequency of measurement are highest. Elsewhere in the world, the interpolated values may suffer in accuracy because of the lack of nearby reporting stations.

Some examples of currently used atmospheric codes are the following:

- Atmosphere REMoval (ATREM) program, among the first such codes,
- Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH), developed by Air Force Research Lab,
- MODtran - H2O (Mod-H2O), developed by NASIC and evaluates only water vapor effects,
- MODtran - Full (Mod-Full), developed by NASIC and evaluates all atmospheric constituent effects, and
- Quick Atmospheric Correction (QUAC), currently used in ENVI.

Once the spectral images have been converted to a scene of ground pixels, each with a spectrum given by radiance values, these radiance values must be converted to reflectivity values. For most objects, Lambertian reflectivity (See Chapter 4) can be assumed, and a form of Eq 4-24 applies:

$$L_\lambda = \frac{\rho \mathrm{E}_{\lambda,INC}}{\pi} \tag{1}$$

assuming each pixel is only reflecting incident solar radiation $\mathrm{E}_{\lambda,INC}$. This assumption is usually valid in the visible thru SWIR portion of the spectrum. Longer wavelengths and pixels emitting thermal radiation will be discussed in Chapter 19. Also, the possibility of non-Lambertian reflectivity will be discussed in Chapter 21.

While the approach given above is rigorous, although laborious, sometimes a shorter approximate approach may be applied to gain reasonable results. Suppose there are one or more ground pixels in the scene whose spectral reflectance are known. The more pixels there are, and the wider the range of pixel reflectance values, the better the results of this approximation. These pixels could be carefully manufactured calibration panels which can be deployed in controlled areas. Note that bare earth is not an option, because there are too many types of minerals that can make up soil at a particular location (for example, dark loam soil versus sand).

To see how this approximate approach can produce useful results, consider the following example: Suppose a Landsat scene contains an area of healthy dense tree foliage and in the Near Infrared (NIR) band (λ= 0.76 to 0.90 μm), these foliage pixels are known to give a digital unit (DU) value of $\tilde{N}$ = 130. From other measurements, it is known that ρ = 0.4 (which is typical for foliage in the NIR). What are the reflectivity values in the NIR of every other ground pixel in the scene if Landsat DN values have been measured? An easy solution results with these reasonable assumptions:

Atmospheric spectral radiance is small.

Detector quantum efficiency across the NIR is constant.

There is no thermal emission contribution to ground pixel radiance.

The dark current level from each detector gives a $\tilde{N}$ value of 4.

Recall the end-to-end equation (See Chapter 10). For each ground pixel in the NIR to good approximation,

$$\begin{aligned}
\tilde{N} &\approx A/D \left\{ \frac{\mathrm{E}_\lambda}{hc} A_R \tau_{OPT} \eta\, \lambda\, \Delta\lambda\, \Delta t_{INT} \right\} + 4 \\
&\approx A/D \left\{ \frac{L_{OBJECT} \tau_{ATM} \Omega_{PIX}}{hc} A_R \tau_{OPT} \eta\, \lambda\, \Delta\lambda\, \Delta t_{INT} \right\} + 4 \qquad (2) \\
&\approx A/D \left\{ \left(\frac{\rho \mathrm{E}_{\lambda,INC}}{\pi} \right) \frac{\tau_{ATM} \Omega_{PIX}}{hc} A_R \tau_{OPT} \eta\, \lambda\, \Delta\lambda\, \Delta t_{INT} \right\} + 4 \quad [\mathrm{DU}]
\end{aligned}$$

If foliage (ρ = 0.4) ground pixels in the scene produce $\tilde{N}$ = 130 values, taking ratios gives

$$\frac{\tilde{N} - 4}{130 - 4} = \frac{\rho}{0.4} \qquad (3)$$

because all the other parameters are the SAME for the collected radiation from all the ground pixels in the scene. Hence

$$\rho = 0.4 \left(\frac{\tilde{N} - 4}{126} \right), \qquad (4)$$

and the reflectance value of every pixel reflectance can now be determined from its $\tilde{N}$ value. Note that in using this approximation, virtually nothing about the Landsat sensor, its viewing geometry, or the atmospheric conditions during the collection had to be known.