UNIT 8

IMAGE CORRECTIONS-RADIOMETRIC

Structure

8.1 Introduction

Expected Learning Outcomes

8.2 Concept of Image Distortion and Correction

Image Distortions

Image Corrections

8.3 Nature of Radiometric Errors

8.4 Systematic Radiometric Errors and their Corrections

Random Bad Pixels (Shot Noise)

Line or Column Dropouts

Line Start Problems

N-Line Striping

8.5 Non-Systematic Radiometric Errors and their Corrections

Atmospheric Modelling

Image Based Methods

Direct Calibration Using Field-Derived Reflectance

8.6 Activity

8.7 Summary

8.8 Terminal Questions

8.9 References

8.10 Further/Suggested Readings

8.11 Answers

8.1 INTRODUCTION

You are aware that remote sensing images are commonly acquired by sensors mounted on remote sensing platforms such as airplanes, unmanned aircraft or satellites. There is no perfect remote sensing system that records absolutely correct, error free view of the ground surface. The complexity of the interaction between earth and atmosphere with energy often introduces errors and noise in the remote sensing image data during the scanning process. Thus, the obtained raw images are susceptible to a variety of distortions, which degrade image quality and finally, reduce accuracy of the image analysis. Therefore, it is required to preprocess the raw images in order to make them suitable for application.

Contributors: Prof. B.K. Mohan and Dr. Omkar Verma

Normally, distortions can affect the values recorded by the sensors differently in different wavelengths. The geometry of the pixel as well as alignment of an image with other images and also with reference maps is affected. It is important to know the effects of these distortions on the images and apply suitable corrections to minimise them. There are two types of errors namely, radiometric and geometric that are present in the raw images and their removal is known as image correction. In this unit, we will discuss the types and causes of radiometric distortions in remote sensing images and methods of their corrections to make images able to represent the terrain more closely. We will discuss geometric corrections in next unit (i.e. Unit 9).

Expected Learning Outcomes

After reading this unit, you should be able to:

❖ describe the concept of distortions suffered by remotely sensed images;

❖ discuss types and causes of radiometric distortions; and

❖ explain the requirements and approaches of radiometric corrections.

8.2 CONCEPT OF IMAGE DISTORTION AND CORRECTION

Radiometric and geometric distortions are two common types of distortions that occur in remotely sensed image data. These distortions are developed due to the variations in solar radiation incident on the curved earth’s surface, imperfect transparency of atmosphere and sensor imperfections. First, let us first get introduced to the concept of image distortion.

8.2.1 Image Distortions

Any kind of errors present in remote sensing images are known as *image distortions*. Any remote sensing images acquired from either space-borne or air-borne platforms are susceptible to a variety of distortions. These distortions occur due to data recording procedure, shape and rotation of the Earth relative to the remote sensor platform and environmental conditions prevailing at the time of data acquisition.

Distortions occurring in remote sensing images can be categorised into two types:

- radiometric distortions and
- geometric distortions.

Sensors record the intensity of electromagnetic radiation as digital numbers (DNs). These digital numbers are specific to the sensor and conditions under which they were measured. However, there are variations in the pixel intensities (digital numbers) irrespective of the object or scene being scanned. The recorded values get distorted due to one or more of the following factors:

- sensor ageing
- random malfunctioning of the sensor elements
- atmospheric interference at the time of image acquisition and

- topographic effects.

The above factors affect radiometry (variation in the pixel intensities) of the images and resultant distortions are known as *radiometric distortions*.

As you know, an image is composed of finite number of pixels. The positions of these pixels are initially referenced by their row and column numbers. However, if you want to use images, you should be able to relate these pixels to their positions on the earth surface. Further, the distance, area, direction and shape properties vary across an image, thus these errors are known as *geometric errors/distortions*. This distortion is inherent in images because we attempt to represent three-dimensional earth surface as a two-dimensional image. Geometric errors originate during the process of data collection and vary in type and magnitude (Wilkie and Finn, 1996). There are several factors causing geometric distortions such as:

- Earth's rotation
- Earth's curvature
- satellite platform instability and
- instrument error.

Let us now learn about the concept of image correction.

8.2.2 Image Corrections

As you now know that raw remote sensing images always contain significant amount of distortions, therefore, they cannot be used directly for further image analysis. The image correction involves image operations which normally precede manipulation and analysis of image data to extract specific information. The primary aim of image correction operations is to correct distorted image data to create a more accurate representation of the original scene. Image corrections are also known as a *pre-processing* of remotely sensed images. It is a preparatory phase that improves quality of images and serves as a basis for further image analysis. It may be noted that modeling of the radiometric and geometric distortions and consequent corrections of distortions falls in the category of preprocessing of remotely sensed imagery.

Depending upon the kinds of errors which are present in images, the image correction functions are comprised of radiometric and geometric corrections. *Radiometric correction* attempts to improve the accuracy of measurements made by remote sensors pertaining to the spectral reflectance or emittance or back-scatter from the objects on the earth surface.

Geometric correction is the process of correcting geometric distortions (pixel position and shape errors) and assigning the properties of a map to an image.

Both of these corrections are made prior to actual use of remote sensing data in resource management, environmental monitoring, disaster mitigation and change detection by application scientists.

A complete chain of processing of remote sensing images is shown in Fig. 8.1. It becomes clear from this figure that image correction forms an integral part of processing of images.

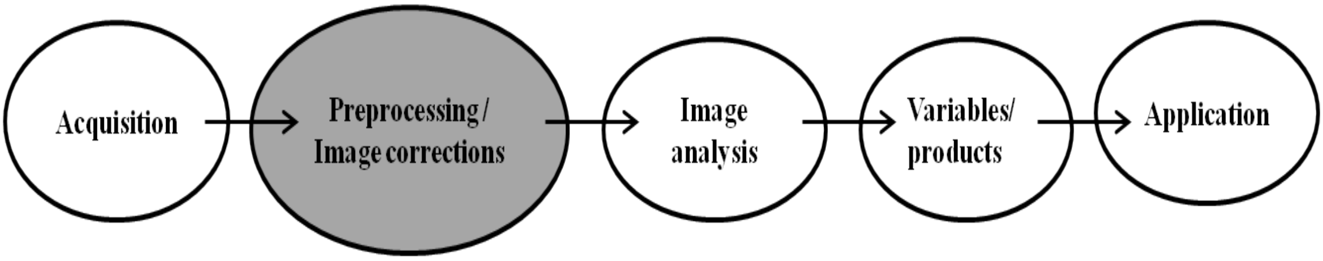


Fig. 8.1: Chain of broad steps in remote sensing data processing.

8.3 NATURE OF RADIOMETRIC ERRORS

You have read earlier that radiometric distortions relate to the distortions suffered by the images in recorded values at different pixel locations. Let us now discuss in detail the types of radiometric errors and their correction procedures. The radiometric errors listed in subsection 8.2.1 can be broadly categorised into the following two categories:

- internal errors and
- external errors.

Internal errors are introduced by the electronics or remote sensing systems themselves. These kinds of errors are also known as *systematic errors* because of their systematic or predictable nature. These errors can be modeled, identified and corrected based on laboratory calibration or in-flight measurements. For example, if a single detector has become uncalibrated, the concerned row (in older satellites such as Landsat) or the column (in pushbroom scanners like SPOT, IRS, IKONOS, WorldView-1-4) would appear like a constant intensity stripe, that does not reflect the terrain changes on the ground.

External errors are a result of phenomena that vary in nature through space and time and hence are also known as *non-systematic errors*. External variables such as atmospheric disturbances, steep terrain undulations can cause remote sensor data to exhibit radiometric and geometric errors. It is important to note that the identification of both internal and external errors is required for correcting the image data.

Correction of radiometric errors requires knowledge about electromagnetic radiation principles and the interactions that take place during data acquisition process. The radiometric correction can benefit from the terrain information such as slope and aspect and advanced information like bi-directional reflectance distribution function (BRDF) characteristics of the scene. The BRDF is a function which describes the magnitude of the upwelling radiance of the target in terms of illumination angle and the angle of view of the sensor. Radiometric correction procedures can be time consuming and at times problematic.

We shall now discuss the two types of radiometric errors and their correction procedures in the next two subsections.

SAQ I

a) List two types of image corrections.

b) What are internal errors?

8.4 SYSTEMATIC RADIOMETRIC ERRORS AND THEIR CORRECTIONS

The systematic radiometric errors are also known as remote sensing system induced radiometric errors. These errors are introduced due to earth rotation, scan skew, velocity variation in platform and mirror scan, malfunctioning of individual scanner/detector, aspect ratio and improper sensor calibration. Some of the commonly observed systematic radiometric errors are listed below (Jensen, 2018):

- Random bad pixels
- Line or column drop-outs
- Line start problems
- N-Line striping

We shall now discuss here these errors and their corrections.

8.4.1 Random Bad Pixels (Shot Noise)

Occasionally, an individual detector does not record received signal for a pixel. This may result in *random bad pixels*. When there are numerous random bad pixels found within the scene, it is called ***shot noise***. Shot noise gives the image an impression of having many dark poke marks. Generally, these bad pixels contain values in the range of 0 or 255 (in 8-bit data) in one or more bands. Shot noise is removed by identifying such pixels in a given band that are either 0 (black) or 255 (white) in the midst of neighbouring pixel values that are radically different. These noise pixels are then replaced by the average pixel value of their immediate eight neighbouring pixels.

Take an example of the Landsat Thematic Mapper band 7 image, which is given in Fig. 8.2. It has two of the pixels having zero gray levels along a bad scan line, which is entirely different from their neighbouring pixels (Fig. 8.2a, b). These are marked as shot noise pixels and are replaced by the average of their eight neighbouring pixels (Fig. 8.2c).

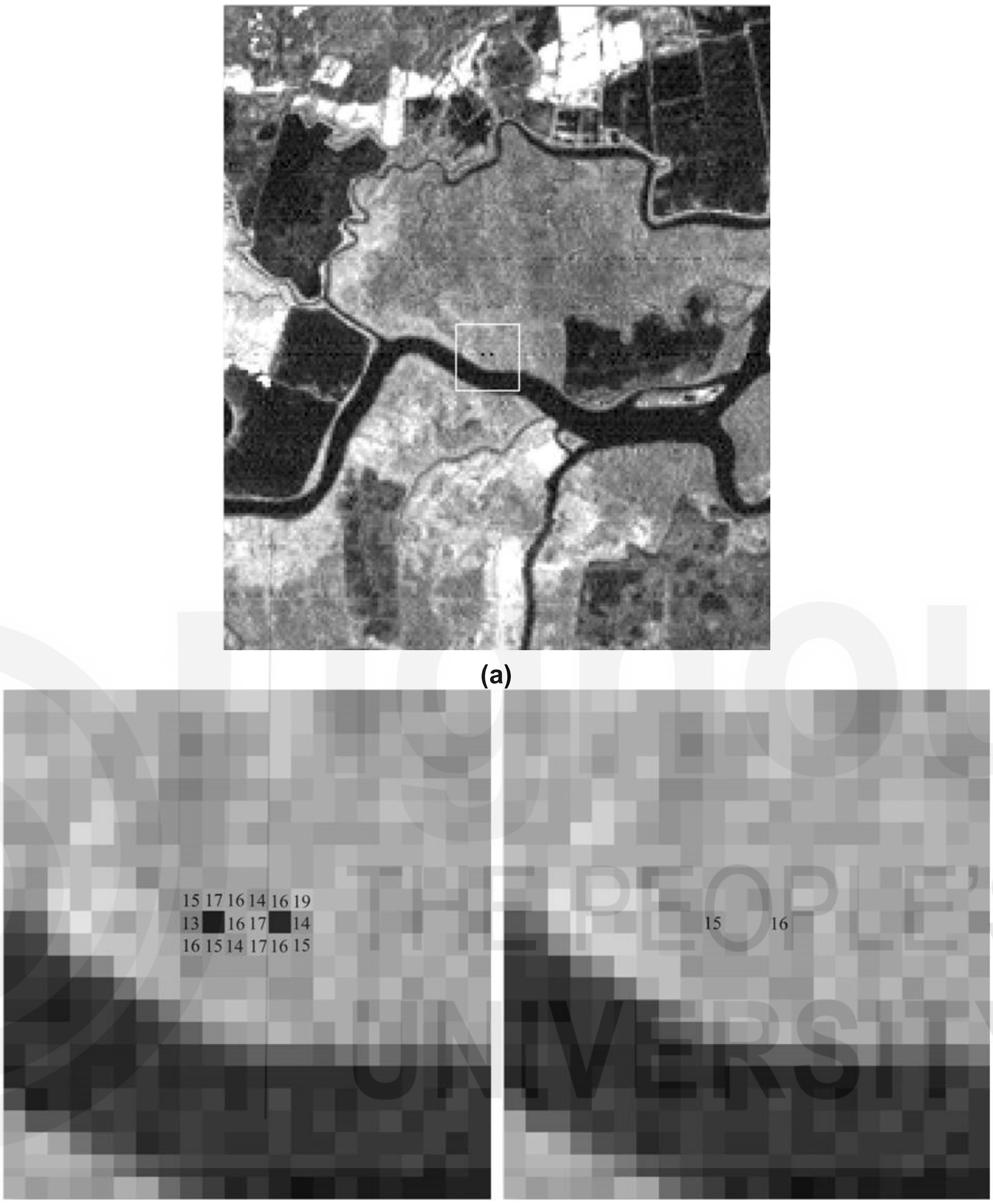
If pixel at location (m, n) is a shot noise pixel, then f(m, n) is corrected as given below:

$$f(m, n) = [f(m-1,n-1) + f(m-1,n) + f(m-1,n+1) + f(m,n-1) + f(m,n+1) + f(m+1,n-1) + f(m+1,n) + f(m+1,n+1)] / 8$$

where,

m and n are pixel locations in x and y coordinates, i.e. columns and rows, respectively.

By replacing with average of neighbouring pixels like (15+17+16+13+16+16+15+14) / 8 = 15 and (14+16+19+17+14+17+16+15) / 8 = 16), shot noise pixels disappear after the correction, as seen in Fig. 8.2c.



(a)

(b) (c)

Fig. 8.2: Illustration of shot noise and its removal. a) a Landsat TM band 7 data with shot noise (two black dots in the region within the white box); b) zoomed image of the box portion showing the bad pixels along with DNs of the neighbouring eight pixels for each bad pixel; and c) the same image portion after the shot noise removal showing the pixel values which has replaced the bad pixels. (Source: Lecture slides of Prof. J. R. Jensen, University of South Carolina; used with permission)

8.4.2 Line or Column Dropouts

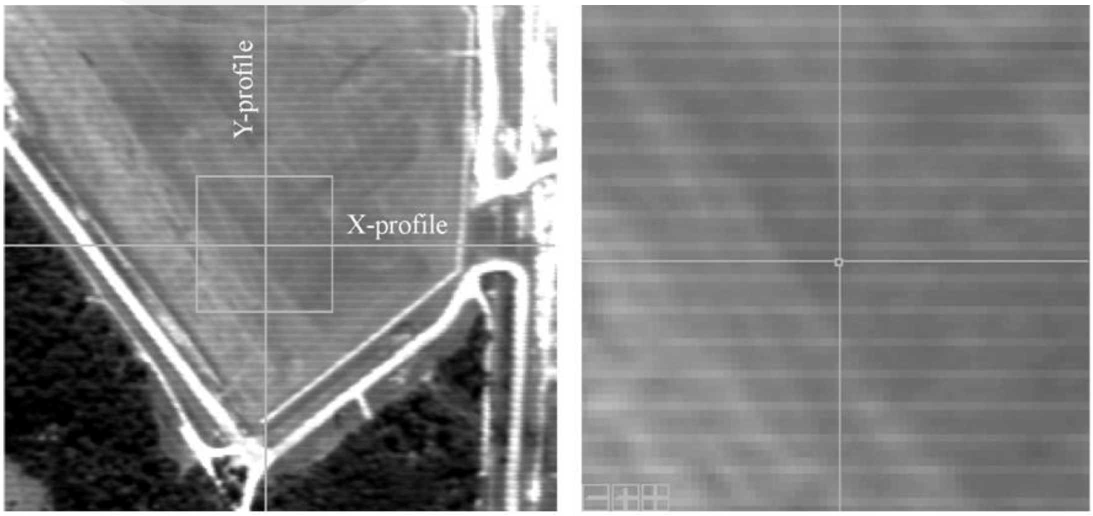
You may have noticed that a blank row containing no details of features on the ground may be seen if an individual detector in an electro-mechanical scanning system (e.g., Landsat MSS or Landsat 7 ETM$^+$) fails to function properly. If a detector in a pushbroom linear array (e.g., IRS-1C, QuickBird) fails to function, this can result in an entire column of data with no spectral information. The bad line or column is commonly called a *line* or *column drop-out* and contains brightness values equal to zero or some constant value, independent of the terrain changes. Generally, this is an irretrievable loss of information because there is no way to restore data that were never acquired. However, it is possible to improve visual interpretability of data by introducing estimated brightness values for each bad scan row (or column) by replacing them with the average of rows (or columns) above and below (or to the left and right). This concept works because adjacent pixels often have similar pixel values.

8.4.3 Line Start Problems

There is another kind of problem encountered in earlier satellites in which the scanner fails to start recording as soon as a new row starts. It may also happen that the sensors place pixel data at inappropriate locations (with shift) along the scan line. For example, all of the pixels in a scan line might be systematically shifted just one pixel to the right. This is called a *line-start* problem. If line start problem is always associated with a horizontal bias of a fixed number (say 50) of columns, it can be corrected using a simple horizontal adjustment. It is found difficult to restore the image data, if the quantity of the line start displacement is random (Jensen, 2018).

8.4.4 N-Line Striping

Occasionally, a detector does not fail entirely but its calibration parameters (gain and offset/bias) are disturbed. For example, a detector might record signals over a dark, deep body of water that are almost uniformly 20 or 30 gray levels higher than the other detectors for the same band. The result would be an image with systematic, noticeable lines that are brighter than adjacent lines. This is referred to as *n-line striping.* The affected line contains valuable information but should be corrected to have approximately the same radiometric quality as data collected by properly calibrated detectors associated with the same band (Fig. 8.3).



(a) **(b)**

(c) (d)

Fig. 8.3: Illustration of image destriping on a sample remote sensing data. a) Original image data containing bad lines (stripes); b) zoomed portion of the box region of the image (a) showing the stripes; c) sample data after destriping; and d) zoomed portion of the box region of image c. (Source: Lecture slides of Prof. J.R. Jensen, University of South Carolina; used with permission)

To repair systematic n-line striping, it is necessary to identify mis-calibrated scan lines in the scene. This is usually accomplished by computing a histogram of values for each of the *n* detectors that collected data over the entire scene (ideally, this would take place over a homogeneous area like a water body). If one detector's mean or median DN value is significantly different from the others, there is a probability that this detector is out of adjustment. Consequently, every line and pixel in the scene recorded by the maladjusted detector may require a correction. This type of n-line striping correction:

- adjusts all the bad scan lines so that they have approximately the same radiometric scale as the correctly collected data and
- improves visual interpretability of the data.

Let us now discuss non-systematic errors and their correction in the next section.

8.5 NON-SYSTEMATIC RADIOMETRIC ERRORS AND THEIR CORRECTIONS

It is noted that the radiometric errors also enter into the remotely sensing data even when remote sensing systems work properly. These errors constitute non-systematic errors and are developed due to i) atmospheric scattering and absorption and ii) topographic attenuation. It is essential to carry out corrections for non-systematic errors in the following circumstances:

- if you are trying to compare remote sensing images which have been acquired at different times
- if you are modelling interactions between electromagnetic radiation and a surface feature, or
- using band ratios for image analysis.

Correction of non-systematic errors include following three steps (Fig. 8.4):

Step 1: Involves the conversion of DNs to sensor spectral radiance. This step requires information on the 'gain' and 'bias' of the sensor in each image band. The 'gain' and 'bias' are the sensor calibration information. *Bias* is the spectral radiance of the sensor for a DN of zero and *gain* represents the gradient of the calibration. The sensor calibration is carried out before the launch of the sensor. *Sensor calibration* includes procedures that convert digital numbers to physical values of radiance. The relationship between DN recorded at a given location and reflectance of the material making up the surface of pixel area changes with time hence the coefficient values that are used to calibrate image data also vary with time.

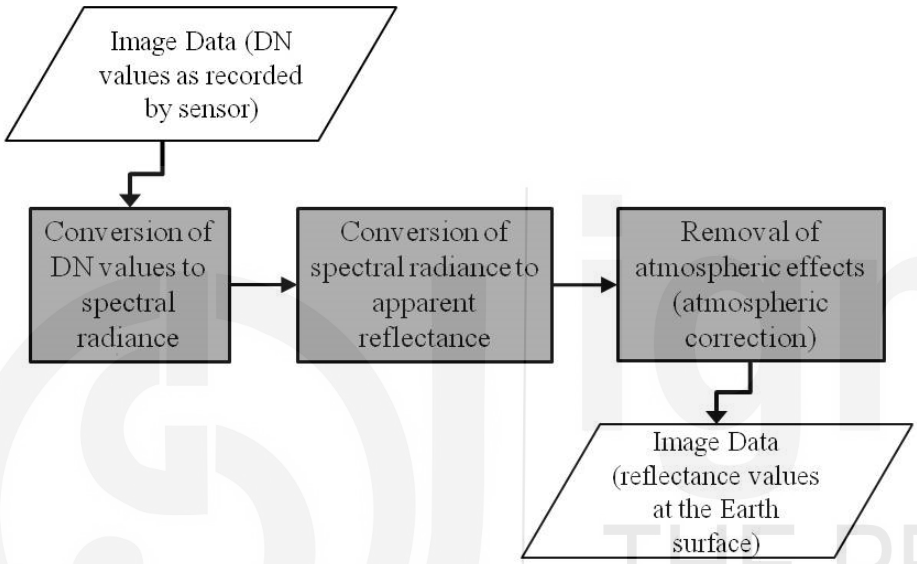


Fig. 8.4: Steps in non-systematic radiometric error correction process.

Step 2: Is the conversion of spectral radiance to apparent reflectance. It converts DN values from radiance units to apparent reflectance. Apparent reflectance defines as the reflectance at the top of the atmosphere.

Step 3: Involves the removal of atmospheric effects due to the absorption and scattering of light (atmospheric correction). There are several methods for atmospheric correction of the remotely sensed data. Some methods are relatively straight forward while others are based on the physical principles of interaction of radiation with atmosphere, and require a significant amount of information pertaining to the atmospheric conditions to be effective. For your convenience we can categorise atmospheric correction procedures into the following three:

- atmospheric modelling
- image based methods and
- direct calibration using field-derived reflectance (empirical line method).

8.5.1 Atmospheric Modelling

In this approach, atmospheric radiative transfer codes (models) are used that can provide realistic estimates of the effects of atmospheric scattering and absorption on satellite imagery. Once these effects have been identified for a specific date of imagery, each band and/or pixel in the scene can be adjusted to remove the effects of scattering and/or absorption. The image is then considered to be *atmospherically corrected.* Unfortunately, application of these codes to a specific scene and date also requires knowledge of both the sensor spectral profile and atmospheric properties at the same time. And, for most of the historic satellite data, they are not available. Ideally, this approach is used when scene specific atmosphere data (such as aerosol content, atmospheric visibility) are available.

Most current radiative transfer based atmospheric correction algorithms can compute much of the required information, if

- the user provides fundamental atmospheric characteristic information to the programme or
- certain atmospheric absorption bands are present in the remote sensing dataset.

For example, most radiative transfer based atmospheric correction algorithms require that the user provides

- latitude and longitude of the image scene
- date and exact time of the image
- image acquisition altitude (e.g., 600 km above the ground level)
- mean elevation of the scene (e.g., 450 m above the mean sea level)
- an atmospheric model (e.g., polar summer, mid-latitude winter, tropical)
- radiometrically calibrated image radiance data
- data about each specific band (mean and full width at half-maximum (FWHM)). The FWHM is the wavelength range defined by the two points at which the intensity level is 50% of its peak value.
- local atmospheric visibility at the time of remote sensing data collection

These parameters are then input to the atmospheric model selected and used to compute the absorption and scattering characteristics of the atmosphere at the time of remote sensing data collection. These atmospheric characteristics are then used to invert the remote sensing radiance to *scaled surface reflectance.* Many of these atmospheric correction programmes derive the scattering and absorption information they require from robust atmosphere radiative transfer code such as

- MODTRAN 4
- ACORN
- ATCOR
- ATREM and
- FLAASH

8.5.2 Image Based Methods

One of the commonly used methods is known as *dark pixel subtraction method* (Chavez, 1988). This method is generally used prior to band-ratioing a single image and is not generally employed for image to image comparisons. This method of radiometric correction is based on simple heuristics, used to reduce the effect of haze in the image. The underlying assumption is that some image pixels have a reflectance of zero and DN values of these “zero” pixels recorded by the sensor result from atmospheric scattering (path radiance; see Fig. 8.5). To remove path radiance, minimum pixel value for each band is subtracted from all other pixels in different bands. DNs in pixels representing deep clear water in near-infrared (NIR) band and dark shadows in visible bands are assumed to result from atmospheric path radiance. Since histogram offset can be used as a measure of path radiance, it is also known as *histogram minimum method*. Bi-plots of NIR band against the other bands are generated for pixels of dark regions and then regression techniques are used to calculate the y-intercept which represents path radiance in other bands. The y-intercept value is then subtracted from all pixels in the image.

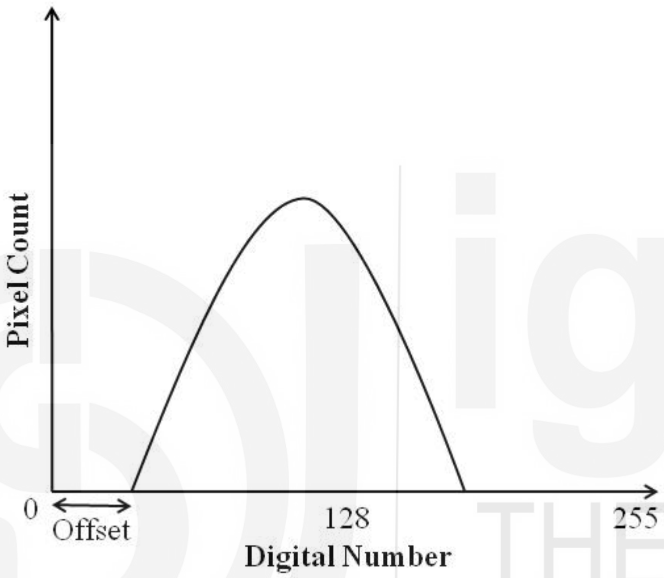


Fig. 8.5: Histogram with an offset (DN = 31) in brightness values.

When multi-temporal imagery is being used for studying changes taking place in a study area, common radiometric quality is required for quantitative analysis of multiple satellite images of a scene acquired on different dates with same or different sensors. The radiometric quality could also be rectified using one image as a reference image. Transformed images appear to have been acquired with the reference image sensor, under atmospheric and illumination conditions nearly identical to those in the reference scene.

In order to achieve this, a few sets of scene landscape elements with a mean reflectance which is (almost) time invariant are identified. These elements are also known as *pseudo-invariant features*. The average gray level values of these reference sets are used to calculate a mathematical mapping relating the gray levels between the reference and the remaining images.

8.5.3 Direct Calibration Using Field-Derived Reflectance

This method is based on the assumption that reflectance measured in one region for a particular feature is directly applicable to the same feature occurring in other regions. The method requires some field work to measure true ground reflectance of at least two regions/targets of area covered by the image. The ground measurements are made using a spectral radiometer.

Sometimes, large areas on the ground are painted in white and black as seen in Fig. 8.6 and recorded values over these areas are examined in different bands and calibration values are computed based on the relation between expected and recorded values in different bands.

Fig. 8.6: Preparation of test sites for calibration purposes. (Source: Lecture slides of Prof. J.R. Jensen, University of South Carolina; used with permission)

Besides atmosphere, topography of the Earth surface also induces errors, which requires correction. The effects of topographic slope are:

- local variation in view and illumination angles and
- identical surface objects might be represented by totally different intensity values.

The goal of topographic correction is to remove all topographically caused variance, so that areas with same reflectance have same radiance or reflectance. Ideal slope-aspect correction removes all topographically induced illumination variation so that two objects having the same reflectance properties show the same gray levels despite their different orientation to the Sun's position. This requires digital elevation data of the area covered by the entire image as well as satellite heading along with Sun elevation and azimuth details.

SAQ II

a) List operations used for the elimination of the systematic radiometric errors occurring in a satellite image.

b) What is FWHM?

8.6 ACTIVITY

- Prepare an illustration showing the various steps involved in non-systematic radiometric error correction process.

8.7 SUMMARY

Let us summarise what we have learnt in this unit:

- There is no perfect remote sensing system that records absolutely correct, noise free remotely sensed data.
- The raw images obtained from remote sensing sensors are susceptible to a variety of distortions, which degrade image quality and finally, reduce accuracy of the image analysis.
- Radiometric and geometric are two common types of distortions that occur in remotely sensed image data.
- Any kind of errors present in remote sensing images are known as image distortions.
- The image correction involves image operations which normally precede manipulation and analysis of image data to extract specific information.
- The primary aim of image correction operations is to correct distorted image data to create a more accurate representation of the original scene.
- Internal errors are introduced by the electronics or remote sensing systems themselves and are known as systematic errors.
- External errors are a result of phenomena that vary in nature through space and time and hence are also known as non-systematic errors.
- The removal of the systematic radiometric errors involves random bad pixels, line or column drop-outs, line start problems and n-line striping operations.
- The removal of the non-systematic radiometric errors involves atmospheric modeling, image-based methods and direct calibration using field-derived reflectance on the remotely sensed data.
- Radiometric corrections are the most important operations that help to utilise information contained in the remotely sensed images in a standard reference framework along with other geospatial datasets.
- Radiometric correction is extremely important for data processing and analysis steps.

8.8 TERMINAL QUESTIONS

1. Differentiate between systematic and non-systematic radiometric errors occurring in remotely sensed data.
2. Describe the operations used for eliminating systematic radiometric errors in remotely sensed data.

3. Describe the process used for elimination of non-systematic radiometric errors in remotely sensed data.

8.9 REFERENCES

- Chavez, P. S. Jr, (1988), An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. *Remote Sensing of Environment*, Vol 24, pp 459-479.
- Jensen, J. R., (2005), *Introductory Digital Image Processing: A Remote Sensing Perspective*, Prentice Hall, New Jersey (for lecture slides of Prof. J. R. Jensen, University of South Carolina).
- Jensen, J. R., (2018), *Introductory Digital Image Processing: A Remote Sensing Perspective*, 4th Edition, Pearson India Education Services Pvt. Ltd.
- Wilkie, D. S. and Finn, J. T. (1996), *Remote Sensing Imagery for Natural Resources Monitoring: A Guide for First-Time Users,* Columbia University Press, USA.

8.10 FURTHER/SUGGESTED READINGS

- Jensen, J. R., (2005), Digital Image Processing: A Remote Sensing Perspective, Prentice-Hall, New Jersey.
- Mather, P. M., (2004), Computer Processing of Remotely Sensed Images- An Introduction, John Wiley & Sons Ltd, New Delhi.
- Schowengerdt, R., (2007), Remote Sensing: Models and Methods for Image Processing, Academic Press, Burlington.

8.11 ANSWERS

SAQ I

a) The two types of image corrections are radiometric and geometric.

b) Internal errors are introduced by the electronics or remote sensing systems themselves. These kinds of errors are also known as *systematic errors* because of their systematic or predictable nature.

SAQ II

a) The removal of the systematic radiometric errors involves random bad pixels, line or column drop-outs, line start problems and n-line striping operations.

b) FWHM is the wavelength range defined by the two points at which the intensity level is 50% of its peak value.

Terminal Questions

1. Please refer to section 8.3.
2. Please refer to section 8.4.
3. Please refer to section 8.5.