Image Processing for Remote Sensing Course 2023-2024

Course leader: Asst.Prof. Dr. Dleen Al-Shrafany
email: dleen.alshrafany@su.edu.krd

Principles and Practice of Digital Image Processing (DIP)

1- Introduction

2- Areas of DIP

Overview – Course Description

- This course extends remote sensing concepts and data analysis towards digital image processing topics with natural resources applications.
- **Topics such as**:

- Radiometric and atmospheric corrections,

- Image formation,

- Image enhancement, and

- Classification are presented.

- Special emphasis is given to hyperspectral and LiDAR data collection/analysis and machine learning algorithms for image classification.

Overview – Course Resources

TEXT BOOKS:

1- Required:

- John Jensen (2016). "**Introductory Digital Image processing: A Remote Sensing Perspective**" (4th edition.). Prentice-Hall - ISBN: 0-13-145361-0

2- Recommended:

- Robert Schowengerdt (2007). "**Remote Sensing: Models and Methods for Image processing**" (3rd edition). Elsevier. ISBN: 0-12-369407-8

3- ADDITIONAL MATERIALS:

- Research article handouts.
- Links to websites covering different topics.

DIP – Introduction

- The primary interest in transmitting and handling images in digital forms goes back to 1920's. However, due to lack of adequate computer systems and vast storage requirements the interest in this area was not fully explored until mid 1960's .
- The serious work in the area of digital image processing (DIP) originally established to analyse and improve satellite images is rapidly growing into a wealth of new applications, due to the enormous progress made in both algorithm development and computer engineering.
- The most important fields of growth appear to emerge in the areas of:

  1- medical image processing (e.g. surgical simulators)

  2- data communication and compression

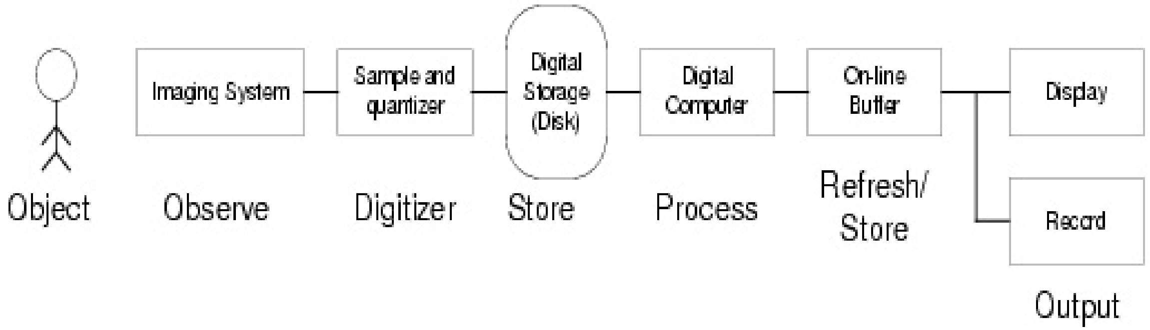
  3- remote sensing (e.g., meteorological, environmental and UAVs)

  4- computer vision (e.g., robotics, autonomous systems)

What is DIP ?

- Digital Image: A sampled and quantized version of a 2-D function that has been acquired by optical or other means, sampled at equally spaced rectangular grid pattern, and quantized in equal intervals of amplitudes.

- A typical image processing system is:



- DIP involves handling, transmitting, enhancing and analyzing digital images with the aid of digital computers. This calls for manipulation of 2-D signals. There are generally three types of processing applied to an image, namely:
  1- low-level,
  2- intermediate-level, and
  3- high-level processing,:

What is DIP Idea ?

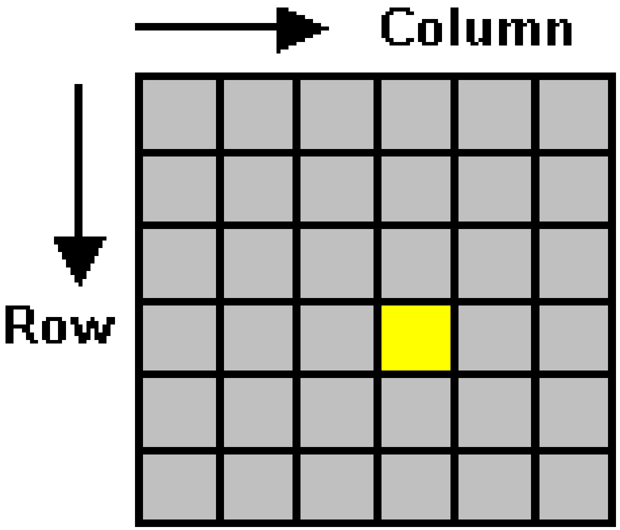
- The central idea behind digital image processing is quite simple. One or more images are loaded into a computer. The computer is programmed to perform calculations using an equation, or series of equations, that take pixel values from the raw image as input.

- In most cases, the output will be a new digital image whose pixel values are the result of those calculations.
- This output image may be displayed or recorded in pictorial format or may itself be further manipulated by additional software.

- The possible forms of digital image manipulation are categorized into one (or more) of the following types of computer-assisted operations: pre-processing; Image enhancement; Image classifications; etc .....

Digital Image

- Digital image is a discrete, 2D array recording of target radiometric response.
  - x,y collection of picture elements (pixels) indexed by column (sample) and row (line).
  - pixel value is digital number (DN)
  - NOT physical value when recorded - simply response of detector electronics.
  - Single value (per band) per pixel, no matter the surface



DIP Ideas

1- Image pre-processing.

- These operations aim to correct distorted or degraded image data to create a more faithful representation of the original scene and to improve an image's utility for further manipulation later on.
- This typically involves the initial processing of raw image data to:

1- eliminate noise present in the data,

2- to calibrate the data radiometrically,

3- to correct for geometric distortions, and

4- to expand or contract the extent of an image via mosaicking or sub-setting.

These procedures are often termed pre-processing operations

DIP Ideas

2- Image enhancement.

- These procedures are applied to image data in order to more effectively render the data for subsequent interpretation.
- In many cases, image enhancement involves techniques for :

1- heightening the visual distinctions among features in a scene,

2- increasing the amount of information that can be interpreted from the data.

DIP Ideas

3- Image classification.

The objective of image classification is to replace visual interpretation of image data with quantitative techniques for automating the identification of features in a scene.

- This normally involves the:

1- analysis of multiple bands of image data (typically multispectral, multi temporal, and Polarimetric)

2- and the application of statistically based decision rules for determining the land cover identity of each pixel in an image

DIP Ideas

4- Analysis of change over time.

- Many remote sensing projects involve the analysis of two or more images from different points in time,
- to determine the extent and nature of changes over time.

5- Data fusion and GIS integration.

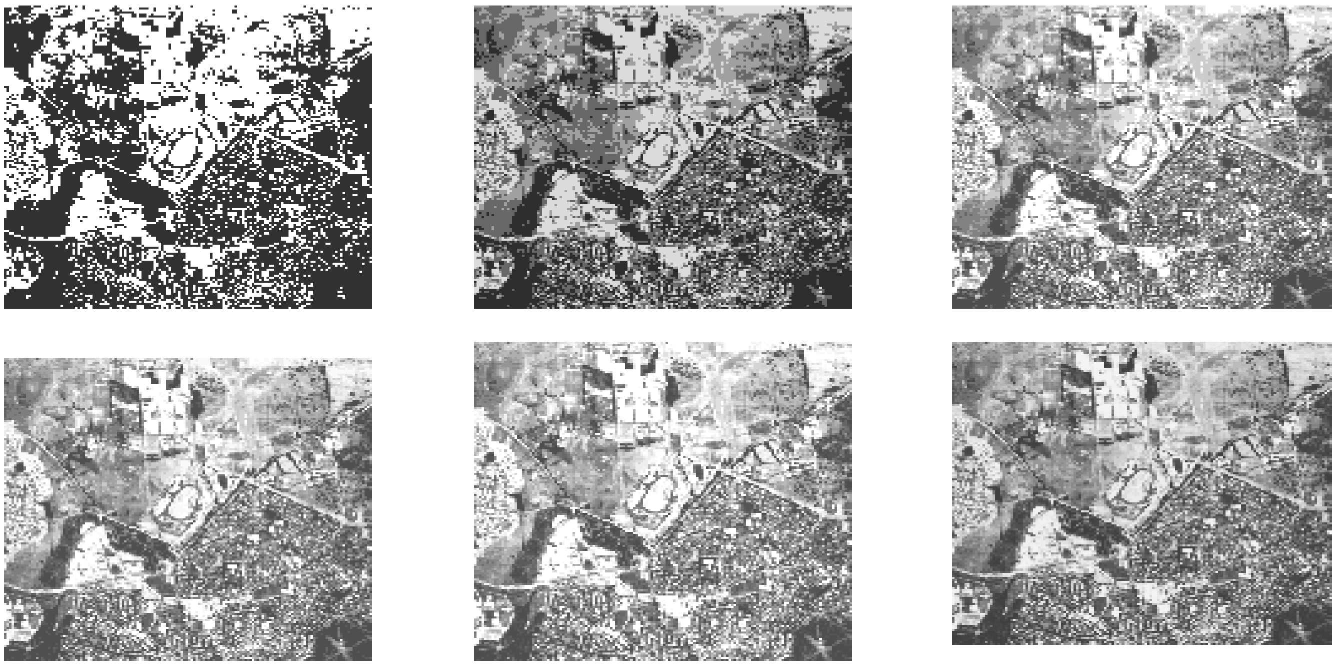
These procedures are used to combine image data for a given geographic area with other geographically referenced data sets for the same area.

Resolution Levels

- **Bits per pixel**

– 1 bit (0,1); 2bits (0, 1, 2, 3); 3 bits (0, 1, 2, 3, 4, 5, 6, 7) etc.

– 8 bits in a byte so 1 byte can record 2^8 (256) different DNs (0-255)



- 1 to 6 bits (left to right)

– black/white (2^1) up to 64 gray levels (2^6) (DN values)

– human eye cannot distinguish more than 20-30 DN levels in grayscale i.e. ‘radiometric resolution’ of human eye 4-5 bits

Pre-processing of Satellite Image

- In nearly every case, there are certain pre-processing operations that are performed on the raw data of an image prior to its use in any further enhancement, interpretation, or analysis.
- Some of these operations are designed to correct flaws in the data, while others make the data more amenable to further processing.

we will discuss these pre-processing operations under the general headings of :

1- noise removal,

2- radiometric correction,

3- geometric correction, and

4- image sub-setting and mosaicking.

- Some of these operations may be performed by the data provider, before the imagery is provided to the analysts.
- In other cases, the users may need to perform one or more of these pre-processing steps themselves.

1- Noise Removal

- **Image noise** is any unwanted disturbance in image data that is due to limitations in the sensing, signal digitization, or data recording process.

- The potential sources of noise range from periodic drift or malfunction of a detector, to electronic interference between sensor components, to intermittent "hiccups" in the data transmission and recording sequence.

- Noise can degrade or totally mask the true radiometric information content of a digital image.

- Hence, noise removal usually precedes any subsequent enhancement or classification of the image data.

- The objective is to restore an image to as close an approximation of the original scene as possible.

Noise Removal- Types

The nature of noise correction required in any given situation depends upon whether the noise is :

- systematic (periodic),
- random, or
- some combination of the two.

For example, multispectral sensors that sweep multiple scan lines simultaneously often produce data containing systematic striping or banding. This stems from variations in the response of the individual detectors used within each band.

Such problems were particularly prevalent in the collection of early Landsat data. While the multiple detectors used for each band were carefully calibrated and matched prior to launch, the radiometric response of one or more tended to drift over time, resulting in relatively higher or lower values along every sixth line in the image data.

In this case valid data are present in the defective lines, but they must be normalized with respect to their neighbouring observations.

Noise Removal- Systematic Noise

- Several **de-striping procedures** have been developed to deal with the type of problem described above.

- **One method is** to compile a set of histograms for the image—one for each detector involved in a given band. These histograms are then compared in terms of their descriptive statistics (mean, median, standard deviation, and so on) to identify radiometric differences or among the detectors.

An empirical correction model can then be calculated to adjust the histograms for the differences detectors' lines to resemble those for the normal data lines.

This adjustment factor is applied to each pixel in the problem lines while the others are not altered (Figure 1)

Noise Removal- Systematic Noise

- Another line-oriented noise problem sometimes encountered in digital data is **line drop**. In this situation, a number of adjacent pixels along a line (or an entire line) may contain spurious DNs, often values of 0 or "no data."

This problem is normally addressed by replacing the defective DNs with the average of the values for the pixels occurring in the lines just above and below (as in Figure 2).

- **Random noise problems** in digital data are handled somewhat differently than striping or line drops. This type of noise is characterized by non-systematic variations in gray levels from pixel to pixel called(bit errors) or (salt and pepper) noise.

- Such noise is often referred to as being **"spiky"** in character, and it causes images to have a "**salt and pepper**" or "**snowy**" appearance with anomalously bright and/or dark pixels scattered across the imagery.

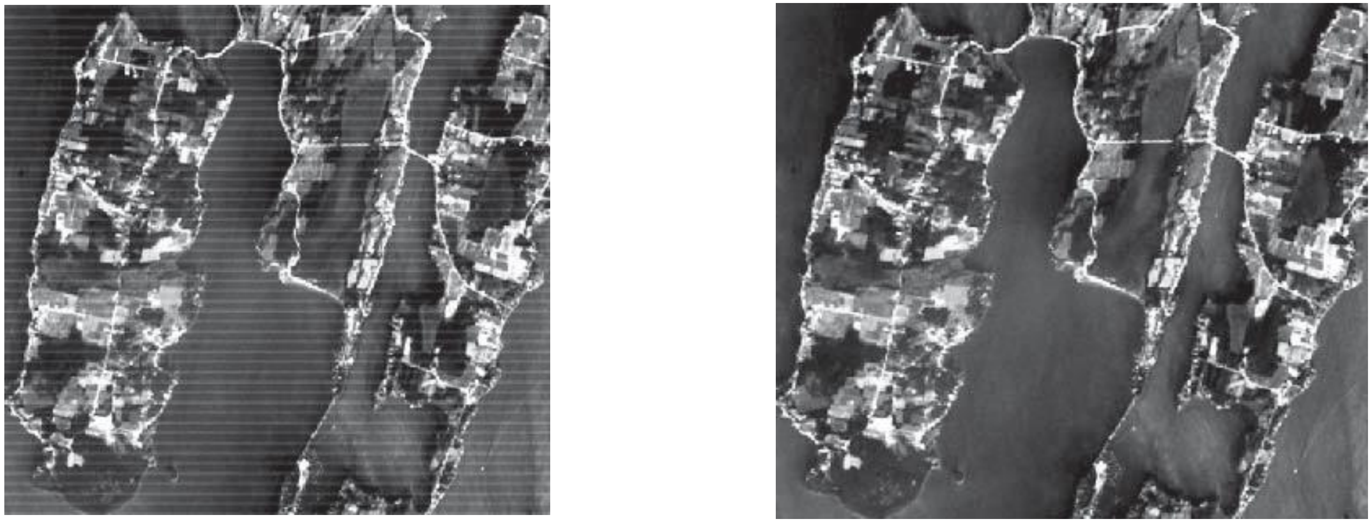


Figure 1 Destriping algorithm illustration: (*a*) original image manifesting striping with a six-line frequency; (*b*) restored image resulting from applying histogram algorithm. (Author-prepared figure.)

Figure 2 Line drop correction: (*a*) original image containing two line drops; (*b*) restored image resulting from averaging pixel values above and below defective line. (Author-prepared figure.)

Noise Removal- Random Noise

- **Bit errors** are handled by recognizing that noise values normally change much more abruptly than true image values.

- Thus, noise can be identified by comparing each pixel in an image with its neighbours. If the difference between a given pixel value and its surrounding values exceeds an analyst-specified threshold, the pixel is assumed to contain noise.

- The noisy pixel value can then be replaced by the average of its neighbouring values. Moving neighbourhoods or windows of 333 or 535 pixels are typically used in such procedures.

- Figure 3 illustrates the results of applying a noise reduction algorithm to an image with salt-and-pepper noise.

- **Figure 7.3** Result of applying noise reduction algorithm: (*a*) original image data with noiseinduced “salt-and-pepper” appearance; (*b*) image resulting from application of noise reduction algorithm. (Author-prepared figure.)

Radiometric Corrections

- Assuming that any striping, line drops, or other noise has been removed, the radiance measured by any given system over a given object is influenced by such factors:

- as changes in scene illumination, atmospheric conditions, viewing geometry, and instrument response characteristics. Some of these effects, such as viewing geometry variations, are greater in the case of airborne data collection than in satellite image acquisition.

- Also, the need to perform correction for any or all of these influences depends directly upon the particular application at hand.

Radiometric Corrections

- Over the course of the year, there are **systematic**, **seasonal** changes in the intensity of solar irradiance incident on the earth's surface.

- If remotely sensed images taken at different times of the year, then it is usually necessary to apply:

  1- sun elevation correction and

  2- earth–sun distance correction.

- The sun elevation correction accounts for the seasonal position of the sun relative to the earth (as in next figure).

Radiometric Corrections

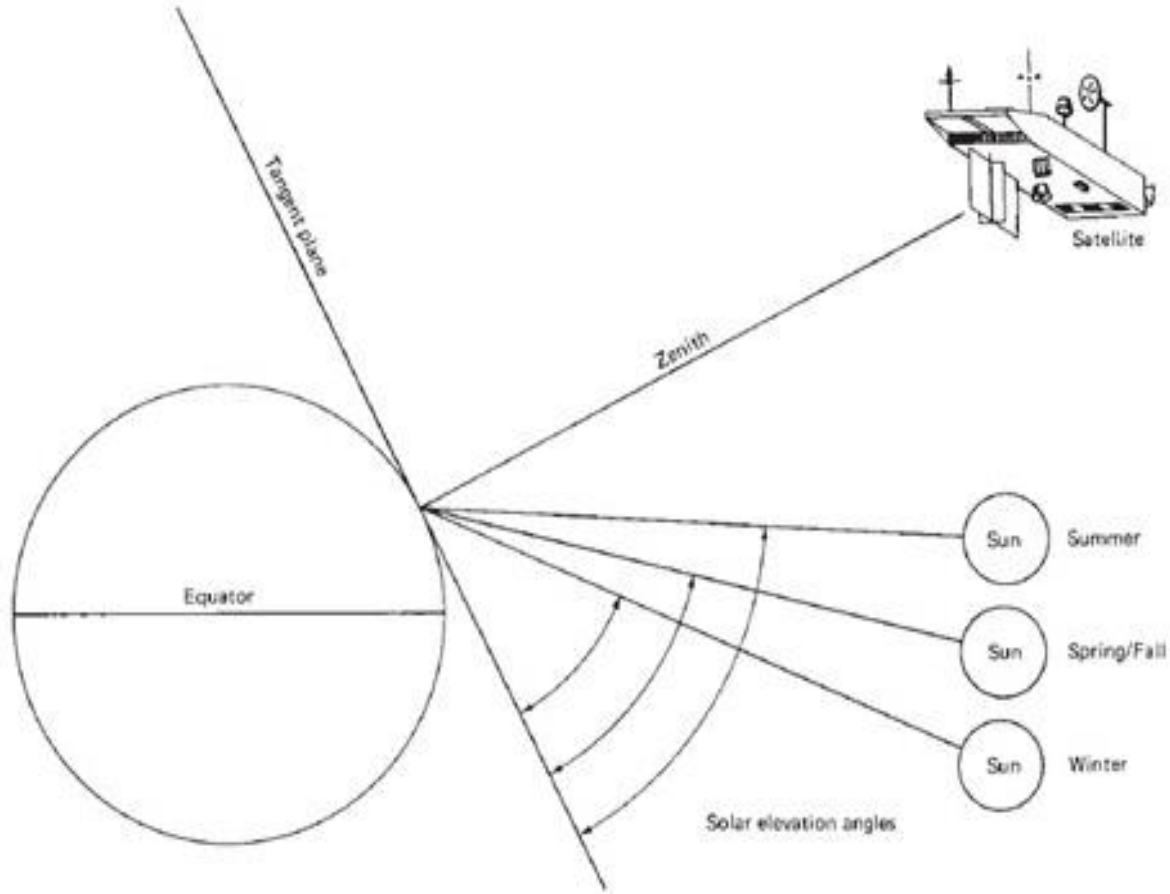


Figure 7.4 Effects of seasonal change on solar elevation angle. (The solar zenith angle is equal to 90° minus the solar elevation angle.)

Radiometric Corrections

- Through this process, image data acquired under different solar illumination angles are normalized by calculating pixel brightness values.

- By assuming the sun was at the zenith on each date of sensing. The correction is usually applied by **:**

(dividing each pixel value in a scene by the sine of the solar elevation angle (or cosine of the solar zenith angle) for the particular time and location of imaging.)

Radiometric Corrections

- Ignoring atmospheric effects, the combined influence of solar zenith angle
- and earth–sun distance on the irradiance incident on the earth's surface can be
- expressed as:

$$E = \frac{E_0 \cos \theta_0}{d^2}$$

where
E = normalized solar irradiance
E_0 = solar irradiance at mean earth–sun distance
y_0 = sun's angle from the zenith
d = earth–sun distance, in astronomical units

Geometric Corrections

- Raw digital images usually contain geometric distortions so significant that they cannot be used directly as a map base without subsequent processing.

- **The sources of these distortions range**:

from (variations in the altitude, attitude, and velocity of the sensor platform) to factors such as

(panoramic distortion, earth curvature, atmospheric refraction, relief displacement, and nonlinearities in the sweep of a sensor's IFOV).

Geometric Distortions Types

1- Systematic distortions

are well understood and easily corrected by applying formulas derived by modelling the sources of the distortions mathematically. For example, a highly systematic source of distortion involved in multispectral scanning from satellite altitudes is the eastward rotation of the earth beneath the satellite during imaging.

- This causes each optical sweep of the scanner to cover an area slightly shifts to the west of the previous sweep.

(**This is known as skew distortion**)

- The process of de-skewing the resulting imagery involves **offsetting each successive scan line slightly to the west**.
- The skewed-parallelogram appearance of satellite multispectral scanner data is a result of this correction.

Geometric Distortions Types

2- Random distortions and residual unknown systematic distortions are corrected by analysing well-distributed ground control points (GCPs) occurring in an image.

- As with their counterparts on aerial photographs, GCPs are features of known ground location that can be accurately located on the digital imagery.
- Some features that might make good control points are highway intersections and distinct shoreline features.
- **In the correction process:**

1- numerous GCPs are located both in terms of their two-image coordinates (column, row numbers) on the distorted image and in terms of their ground coordinates (typically measured from a map or GPS located in the field, in terms of UTM coordinates or latitude and longitude).

Geometric Distortions Types

2- These values are then submitted to a least squares regression analysis to determine coefficients for two coordinate transformation equations that can be used to interrelate the geometrically correct (map) coordinates and the distorted-image coordinates. (Appendix B.)

- Once the coefficients for these equations are determined, the distorted-image coordinates for any map position can be precisely estimated. Expressing this in mathematic notation,

$$x = f1(X,Y) \qquad y = f2(X,Y)$$

- Where

(x,y)= distorted-image coordinates (column; row)

(X,Y)= correct (map) coordinates

f1, f2 = transformation functions

Geometric Corrections Apply

- Practically , it might seems though these equations are stated backward!
- That is, they specify how to determine the distorted-image positions corresponding to correct, or undistorted, map positions.
- But that is exactly what is done during the geometric correction process.

It is important to mention that

- We first define an undistorted output matrix of "empty" map cells and then fill in each cell with the gray level of the corresponding pixel, or pixels, in the distorted image. This process is illustrated in the following Figure.

Geometric Corrections Apply

This figure shows the geometrically correct output matrix of cells (solid lines) superimposed over the original, distorted matrix of image pixels (dashed lines).

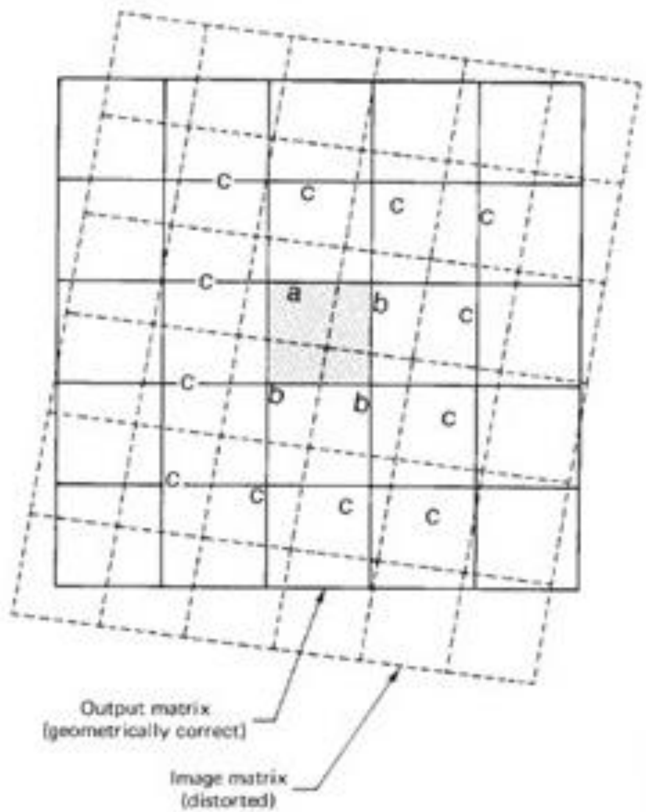


Figure 7.6 Matrix of geometrically correct output pixels superimposed on matrix of original, distorted input pixels.

Geometric Corrections Apply

After producing the transformation function, a process called **resampling** is used to determine the pixel values to fill into the output matrix from the original image matrix. This process is performed using the following operations:

1- The coordinates of each element in the undistorted output matrix are transformed to determine their corresponding location in the original input (distorted-image) matrix.

2- In general, a cell in the output matrix will not directly overlay a pixel in the input matrix. Accordingly, the intensity value or digital number (DN) eventually assigned to a cell in the output matrix is determined on the basis of the pixel values that surround its transformed position in the original input matrix.

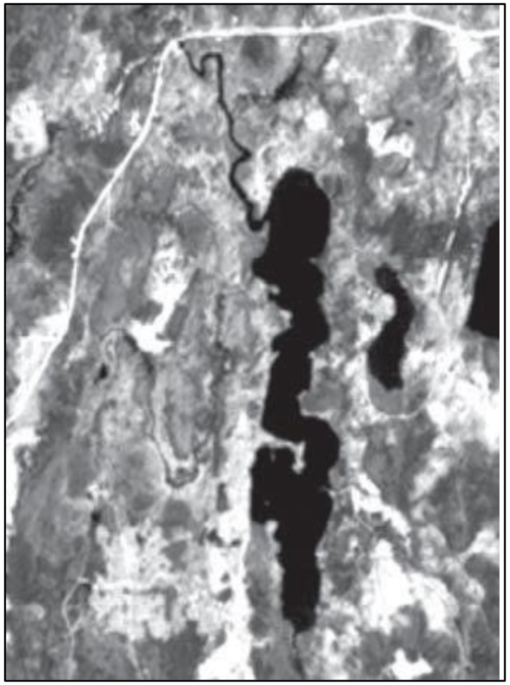
Resampling Schemes

A number of different resampling schemes can be used to assign the appropriate DN to an output cell or pixel. To illustrate this:

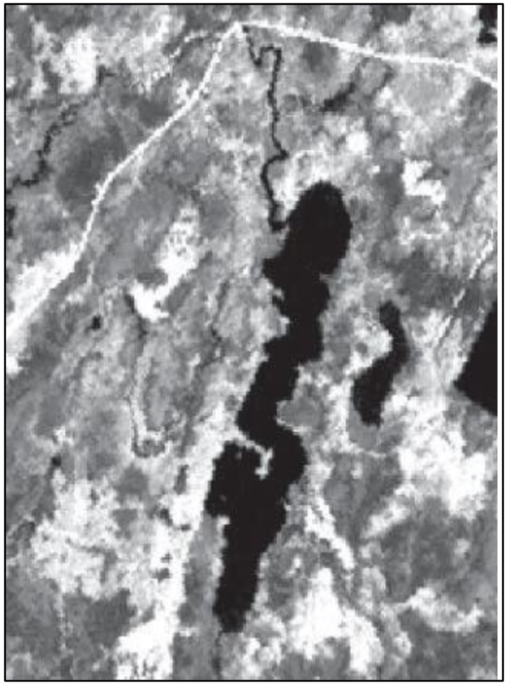
- consider the shaded output pixel shown in previous figure.
- The DN for this pixel could be assigned simply on the basis of the DN of the closest pixel in the input matrix, disregarding the slight offset.
- In our example, the DN of the input pixel labelled (*a*) would be transferred to the shaded output pixel.
- This approach is called (**Nearest Neighbour**) **resampling**. It offers the advantage of computational simplicity and avoids having to alter the original input pixel values.

Resampling Schemes

- However, features in the output matrix may be offset spatially by up to one-half pixel. This can cause a disjointed appearance in the output image product. Following Figure is an example of a **Nearest Neighbour** resampled Landsat TM image.



Original Image



Nearest neighbour resampled Image

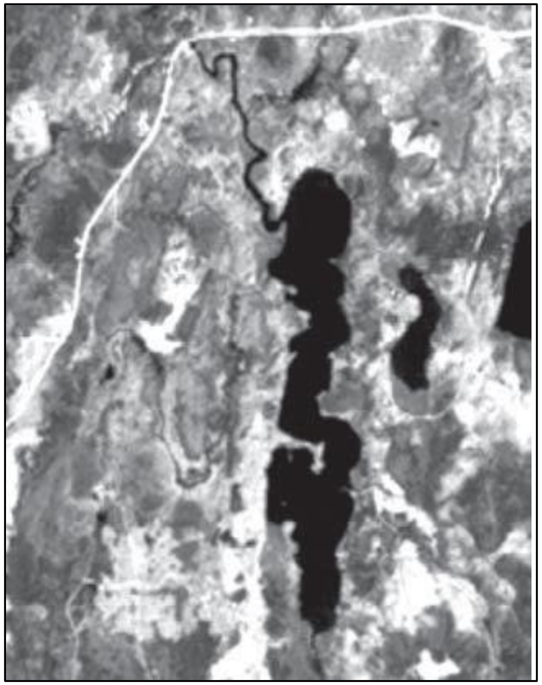
Resampling Schemes

- More sophisticated methods of resampling evaluate the values of several pixels surrounding a given pixel in the input image to establish a “synthetic” DN to be assigned to its corresponding pixel in the output image.

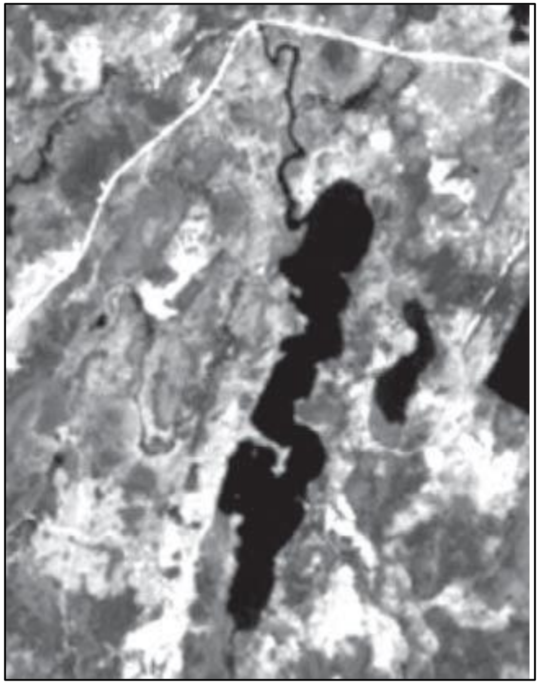
- The (**Bilinear Interpolation**) technique takes a distance-weighted average of the DNs of the four nearest pixels (labelled a and b in the distorted-image matrix in previous Figure).

- This process is simply the two-dimensional equivalent to linear interpolation. As shown in the next Figure, this technique generates a smoother-appearing resampled image.

Resampling Schemes



Original Image



Bilinear Interpolation
resampled Image

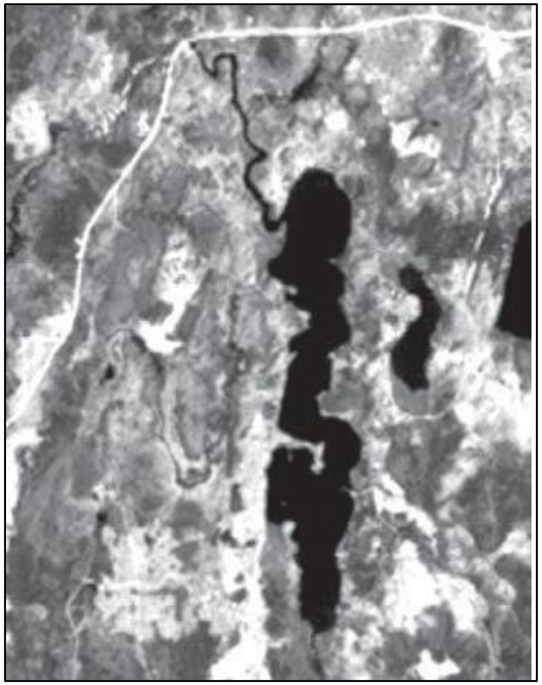
Resampling Schemes

- An improved restoration of the image is provided by the (**bi-cubic interpolation**) or (**cubic convolution**) method of resampling.

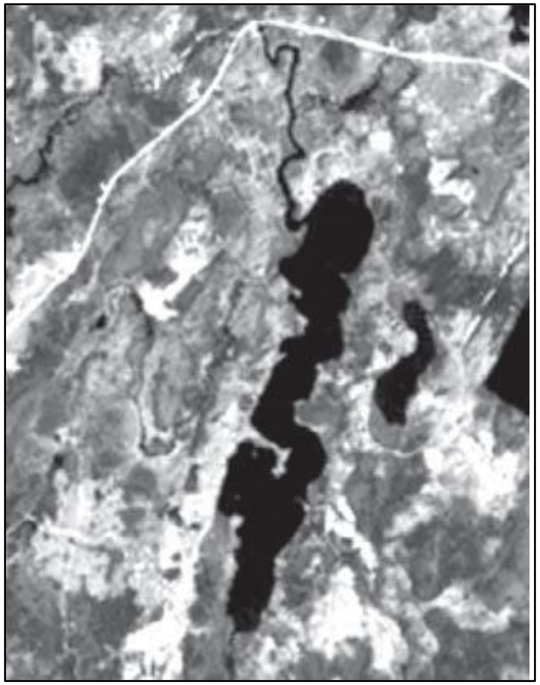
- In this approach, the transferred synthetic pixel values are determined by evaluating the block of 16 pixels in the input matrix that surrounds each output pixel (labelled a, b, and c in previous Figure).

- Cubic convolution resampling (next Figure) avoids the disjointed appearance of the **nearest neighbour** method and provides a slightly sharper image than the **bilinear interpolation** method.

Resampling Schemes



Original Image



Cubic Conolution resampled Image