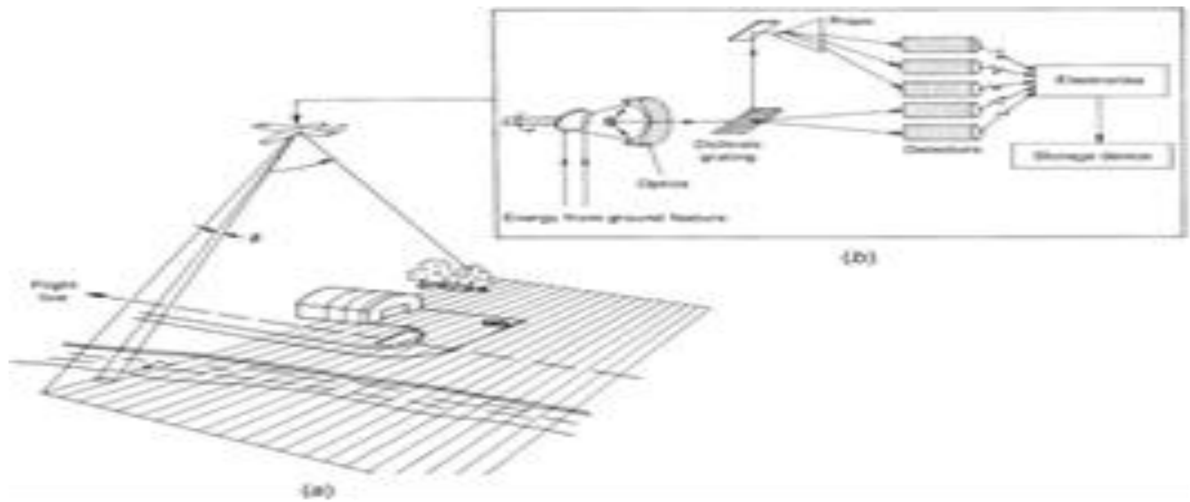
Chapter 3: "Image Rectification & Restoration"

Part 1 out of 3



Introduction:

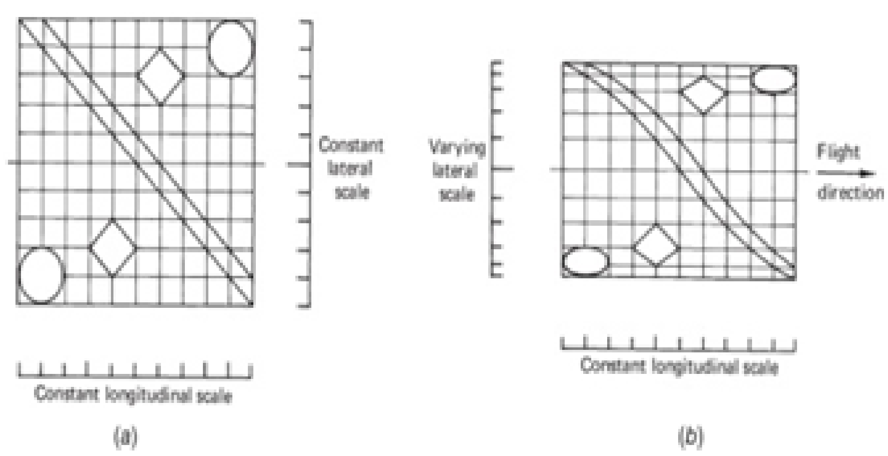
The goal of image rectification & restoration, often termed preprocessing, is to correct image data for distortions or degradations which stems from the image acquisition process.

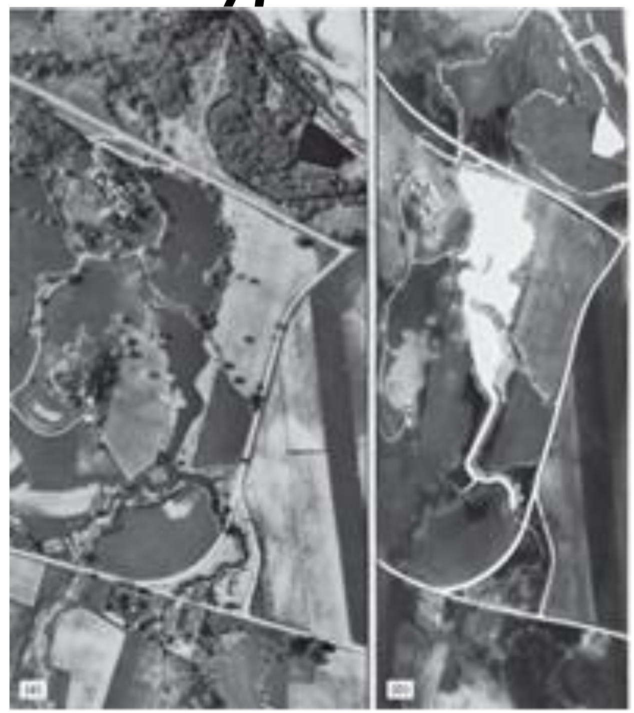
Chapter 2: "Image Rectification & Restoration"

Introduction: *(continue)*

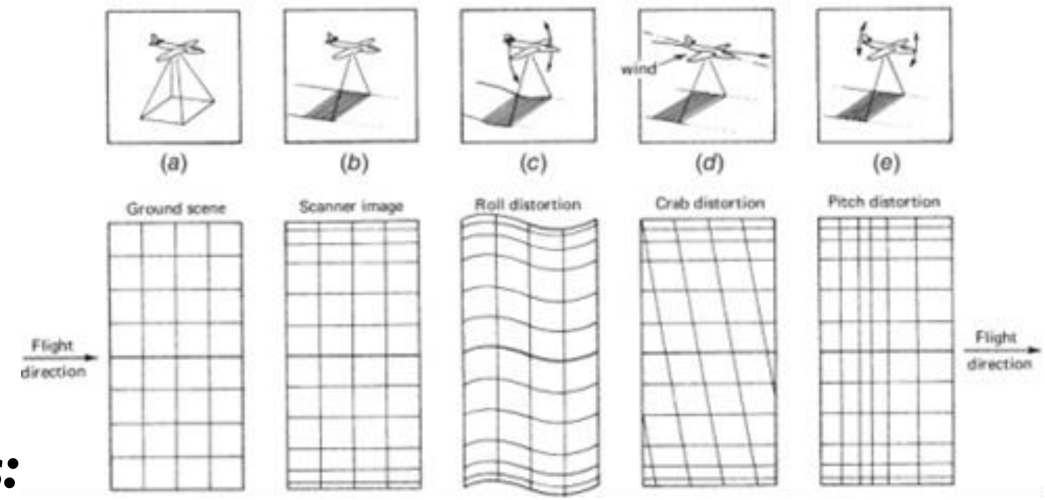
The nature of any particular image restoration process is highly dependent upon the sensor & the craft used to collect the data. The generic types of corrections can be categorized in one of the three types below:

1. ***Geometric corrections.***
2. ***Radiometric corrections, &,***
3. ***Noise removal.***





Chapter 2: "Image Rectification & Restoration"



Geometric Corrections:

- *Raw digital image usually contain geometric distortions so significant that it cannot be used as a map.These errors can be either of systematic or random nature.*
- *The goal of geometric corrections is to compensate for the distortions introduced by these errors so that the corrected image will have the geometric integrity of a map screen.*

Chapter 2: "Image Rectification & Restoration"

Geometric Corrections*: (continue)*

- *The geometric correction process is usually implemented in a two stages procedure; first systematic errors are corrected, then the random errors.*
- *This is because of two reasons: the first of which is that systematic errors can be approximated by mathematical model, & these mathematical model can only be applied to the original data.*
- *Secondly is that these mathematical model can create some residuals of their own which can be fixed by the random errors correction.*

Chapter 2: "Image Rectification & Restoration"

Systematic errors corrections:

- *To correct for systematic distortions, we have to model the nature & the magnitude of the sources of the distortions & use the model to establish the correction formula.*
- *These are effective when the types of distortion is well characterized such as that caused by earth rotation during satellite imaging.*
- *In such effort, line scan sensor take a finite time to acquire a frame of an image data. During that time, the earth rotates from west to east so that a point imaged at the end of the frame would have been further to the west when recording started.*

Chapter 2: "Image Rectification & Restoration"

Systematic errors corrections: (continue)

- *To give a pixel its correct position relative to the ground, it is necessary to offset the image to the west by the amount of movement of the ground during image acquisition.*
- *The amount of image skewed at the end of the frame depends upon the relative velocity of the satellite to earth & the length of the image recorded frame.*
- *For example, the angular velocity of Landsat satellite,* ω_0 = *1.014* $* 10^{-3}$ *rad/s. So that a nominal 185 km frame length, L, is scanned in a time,* $\mathbf{t_s}$ *= 28.6 s, based on the earth radius,* $\mathbf{r_e}$ *= 6,378,160 m, & the following formula;*

$$\mathbf{t_s} = L /(re * \omega_0)$$

Chapter 2: "Image Rectification & Restoration"

Systematic errors corrections: (continue)

- *The surface velocity of the earth,* $\mathbf{v_e}$, *is a function of the latitude of the data imaged,* Φ, *& the earth rotational velocity,* ω_e, *of* $7.272 * 10^{-5}$ *rad/s, & is given by the following formula;*

$$\mathbf{v_e} = w_e * r_e \cos \Phi .$$

- *Therefore, the surface velocity of the earth,* $\mathbf{v_e}$, *at a latitude,* Φ, *of* 60^o *can be given as;*

$$\mathbf{v_e} = 7.272 * 10^{-5} * 6{,}378{,}160 \ \cos 60^o = 231.91 \ m/s$$

- *Which means that the earth could cross a distance of 6632.6 m in 28.6 s needed to image a frame length of 185 km. That means that the last line of the image have to be skewed back by this distance, or the number of pixels equivalent to it, in order to get the image to its right location.*

Chapter 2: “Image Rectification & Restoration”

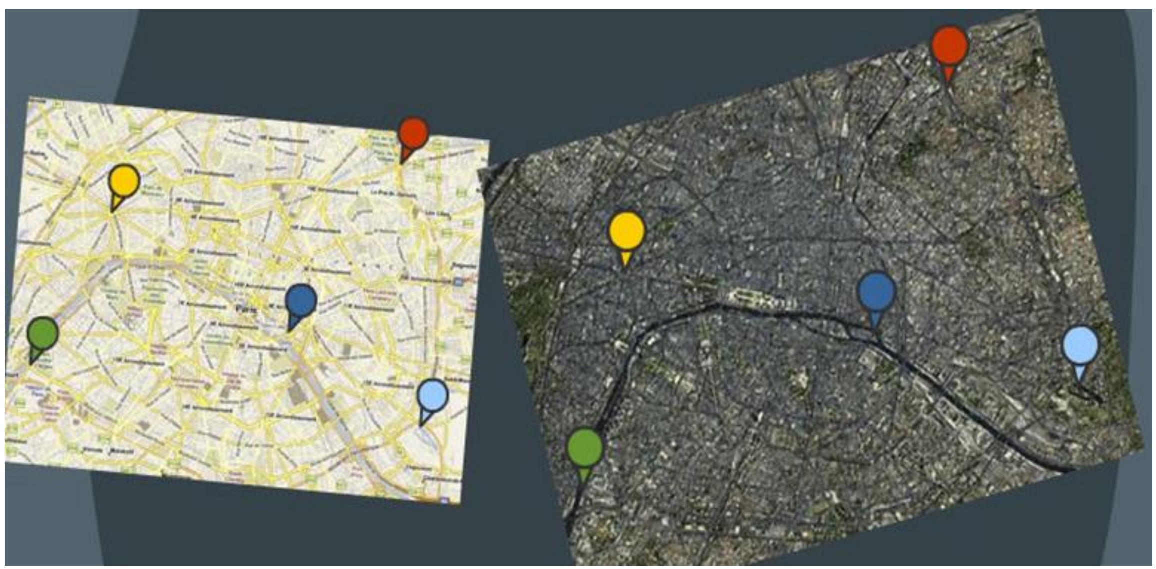
Random errors corrections:

- *Unlike systematic distortions, we cannot apply derived formulas to fixe random distortions.*
- *Random distortions, residuals from previous systematic errors corrections along with small systematic errors that we choose not to fix by derived formulas can all be corrected to a an acceptable level by analyzing well distributed ground control points (GCP) occurring both on a map & on the distorted image.*

Chapter 2: "Image Rectification & Restoration"

Random errors corrections*: (continue)*

- *Coordinates of GCPs, both on a map & on the distorted image, are submitted to a least-squares regression analysis to determine coefficients that can be used to interrelate the geometrically corrected (map) coordinates & the distorted image coordinates.*



Chapter 2: "Image Rectification & Restoration"

Random errors corrections*: (continue)*

- *The distorted image coordinates for any map position can then be precisely estimated by;*

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

Where, x, & y are the distorted image coordinate in row & column,

X, & Y are the corrected map coordinates, Northern & Eastern, &

f1, & f2 are the transformation functions.

Chapter 2: "Image Rectification & Restoration"

Random errors corrections: (continue)

The Affine transformation is a good example of the transformation function

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

Where, x, & y can be computed as;

$$x = a0 + a1\ X + a2\ Y, \ \&$$

$$y = b0 + b1\ X + b2\ Y,$$

But first we have to determine formula coefficients, the a's & b's.

So we need 6 equations for 6 unknowns, but each GCP give as 2 equations, 1 for x & 1 for y .Therefore we need, at least 3 GCP to get a unique solution, or more than that for least square adjustment.

Chapter 2: "Image Rectification & Restoration"

Random errors corrections: *(continue)*

For 2nd order polynomial, with much complicated transformation function, we need 12 equations for 12 unknowns, but each GCP give as 2 equations, 1 for x & 1 for y . Therefore we need, at least 6 GCP to get a unique solution, or more than that for least square adjustment.

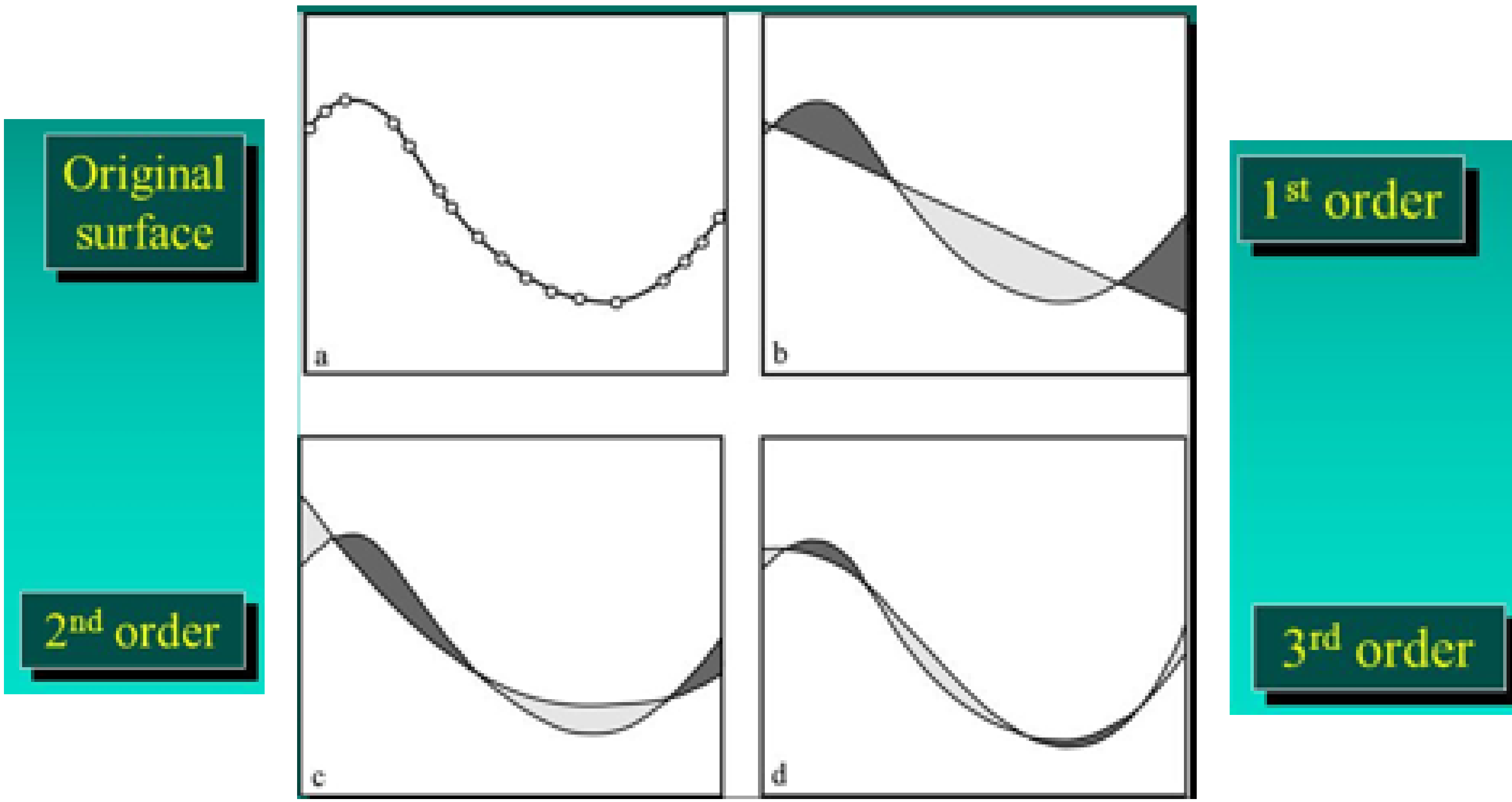
1st-order polynomial equations	2nd-order polynomial equations
$x' = a_0 + a_1 x + a_2 y$	$x' = c_0 + c_1 x + c_2 y + c_3 xy + c_4 x^2 + c_5 y^2$
$y' = b_0 + b_1 x + b_2 y$	$y' = d_0 + d_1 x + d_2 y + d_3 xy + d_4 x^2 + d_5 y^2$

The rule of thumb for the minimum amount of GCP needed is given by this formula, where t is the order of the polynomial;

Minimum # of GCP needed = (t+1)(t+2) / 2.*

Chapter 2: "Image Rectification & Restoration"

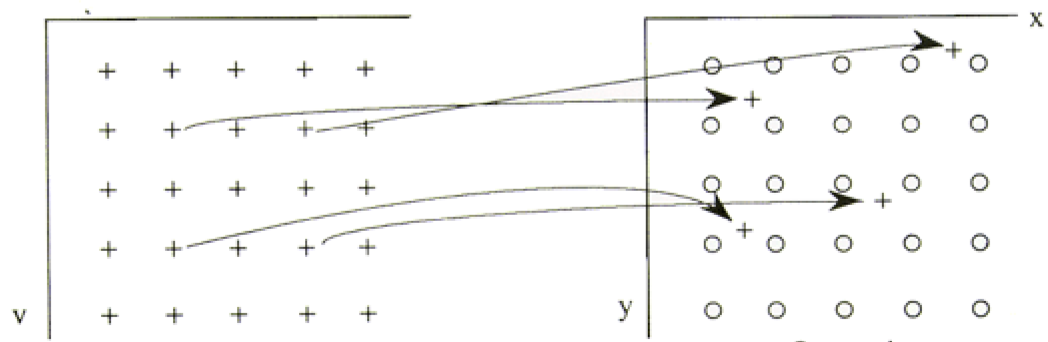
Random errors corrections: *(continue)*



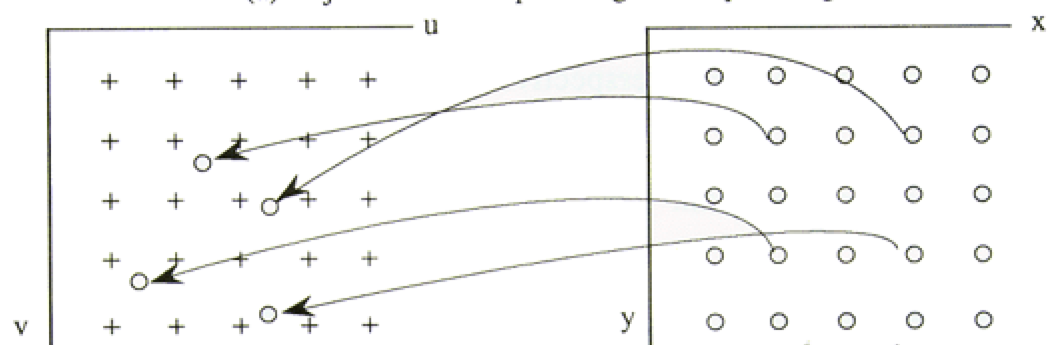
Differences among Affine (1st order), 2nd & 3rd order transformation.

Chapter 2: "Image Rectification & Restoration"

Random errors corrections: (continue)



(a)Projection from input image to output image

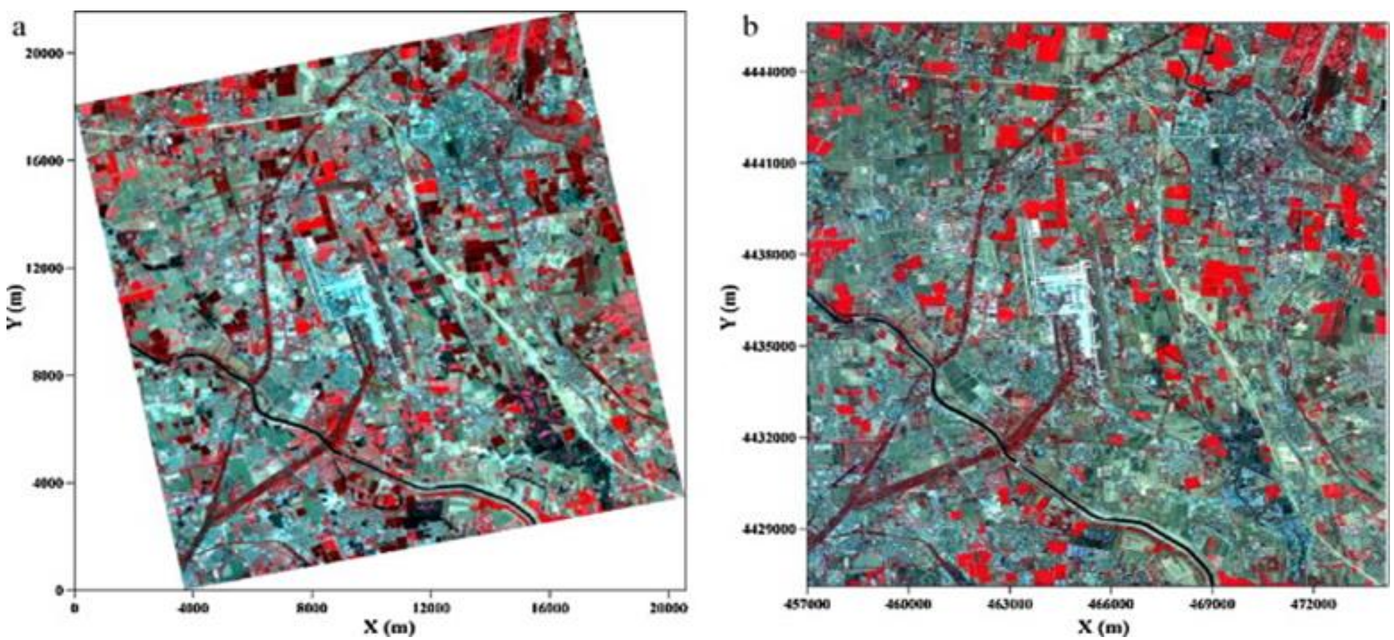


(b)Projection from output image to input image

Chapter 2: "Image Rectification & Restoration"

Random errors corrections***: (continue)***

- *In the above formula, we first define an undistorted output matrix of "empty" map cells. Then fill in each cell with a gray level of the corresponding pixel, or pixels, on the distorted image.*



Chapter 2: "Image Rectification & Restoration"

Random errors corrections*: (continue)*

- *But before we rectify the image & determine the DN's for each pixel on the output image, it is important to determine how well the derived coefficients of the initial GCPs.*
- *To do this, we have to compute the Root Mean Square, RMS, error for each point, then compute the overall RMS of the entire model & compare it to a preset threshold.*
- *If it is below this preset threshold, then we can continue with the transformation process.*

Chapter 2: “Image Rectification & Restoration”

Random errors corrections*:* *(continue)*

- *Otherwise, we eliminate the GCP with the highest RMSE, & repeat the process again until we satisfy the required accuracy.*
- *Good distribution of GCPs should be maintain all the time, we can add more GCPs if needed.*

$$\text{RMS (in X)} = \sqrt{\sum_{i=1}^{n} (\Delta X_i)^2}$$

$$\text{RMS (in Y)} = \sqrt{\sum_{i=1}^{n} (\Delta Y_i)^2}$$

$$\text{RMS (T)} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} \left(\Delta X^2{}_i + \Delta Y^2{}_i\right)}$$

where:

ΔX_i , ΔY_i = residuals of point (i) in X and Y directions.
T = total RMS error
n = number of GCPs
i = GCP number

- *We can compute the RMS for each GCP by computing the square roots of the sum of the square of the difference between the original & computed coordinate of this GCP.*

Chapter 2: "Image Rectification & Restoration"

Random errors corrections: *(continue)*

- *The output digital number, DN, or gray level, for each pixel, can be fill in by a process called resampling.*
- *Different resampling methods can be used to assign the appropriate DN to an output cell or pixel. One of the following three methods is most likely to be used.*
- *Three of the most used resampling methods are:*

  1. *The nearest neighbor resampling method,*
  2. *The bilinear interpolation resampling method,*
  3. *The cubic convolution resampling method.*

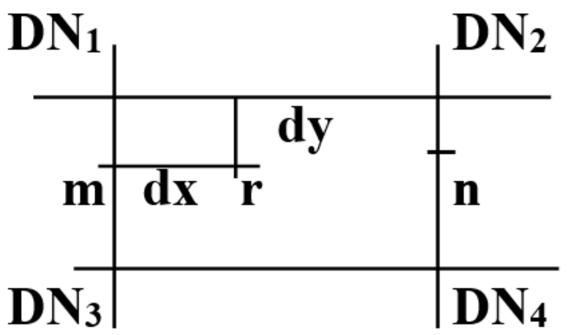
Chapter 2: "Image Rectification & Restoration"

The nearest neighbor resampling method:

- *In such a method the DN for the output pixel is simply assigned to the DN of the closest pixel in the input matrix disregarding the slight offset.*
- *This method is computationally simple & does not alter the original values.*
- *On the other hand, features on the output matrix may be spatially offset by up to a half pixel.*

Chapter 2: "Image Rectification & Restoration"

The bilinear interpolation resampling method:



- *This method takes a distance weighted average of the DNs of the four nearest pixels, it is the 2D equivalent to linear interpolation method.*
- *This method is implemented in two steps procedures. First each two points on top of each other are linearly interpolated in the y direction; the results of these interpolation is stored in a temporary variables.*
- *Next, the output pixel value is linearly interpolated between the values of these temporary variables in the x direction.*

Chapter 2: "Image Rectification & Restoration"

$$DN_m = [DN_3 - DN_1] * dy + DN_1$$
$$DN_n = [DN_4 - DN_2] * dy + DN_2$$

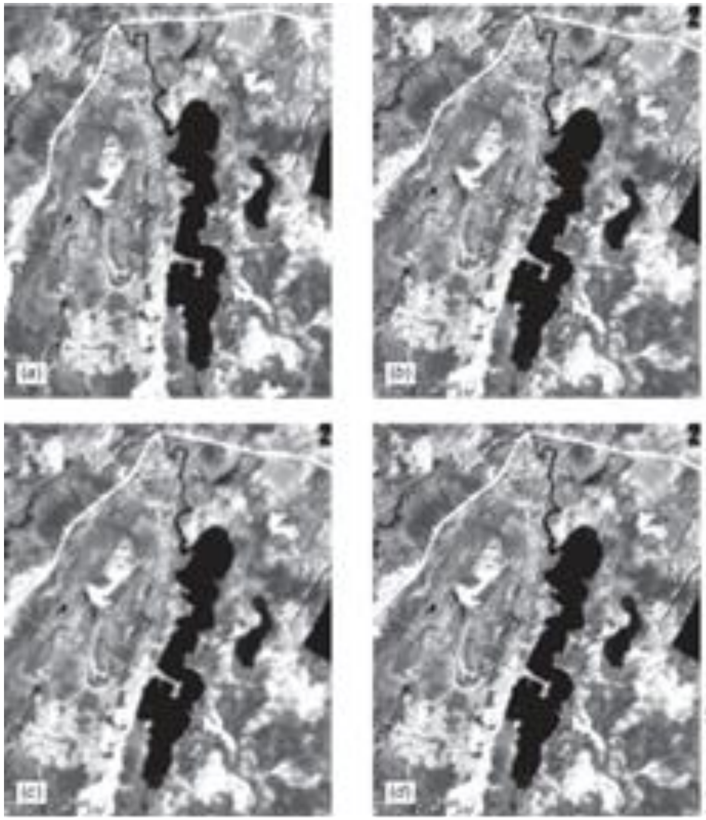
$$DN_r = [DN_n - DN_m] * dx + DN_m$$

- *This method will give a much smoother output.*
- *However, this method has little pit of more computation than the nearest neighbor beside it will alters the gray values of the original image.*

Chapter 2: "Image Rectification & Restoration"

The cubic convolution resampling method:

- *In this method the output DN value are determined by evaluating a block of 16 pixel in the input matrix that surround each output pixel.*
- *This method will give the best output, (i.e., the smoothest).*
- *Nevertheless, it is alters the gray level of the input pixels values & it is heavily computation method.*



Resampling techniques are important in several other processing operations as well, besides the geometric corrections of raw images.

Chapter 2: "Image Rectification & Restoration"
Part 2 out of 3

Radiometric Corrections:

- *The type of radiometric correction applied to any given digital image data set varies widely among sensors.*
- *The radiance measured by any given system over a given object is influenced by such features as change in scene illumination, atmospheric conditions, viewing geometry & instruments response characteristics.*
- *The need to perform correction for any or all of the radiometric influences depends directly upon the particular application at hand.*

NASA image

Chapter 2: "Image Rectification & Restoration"

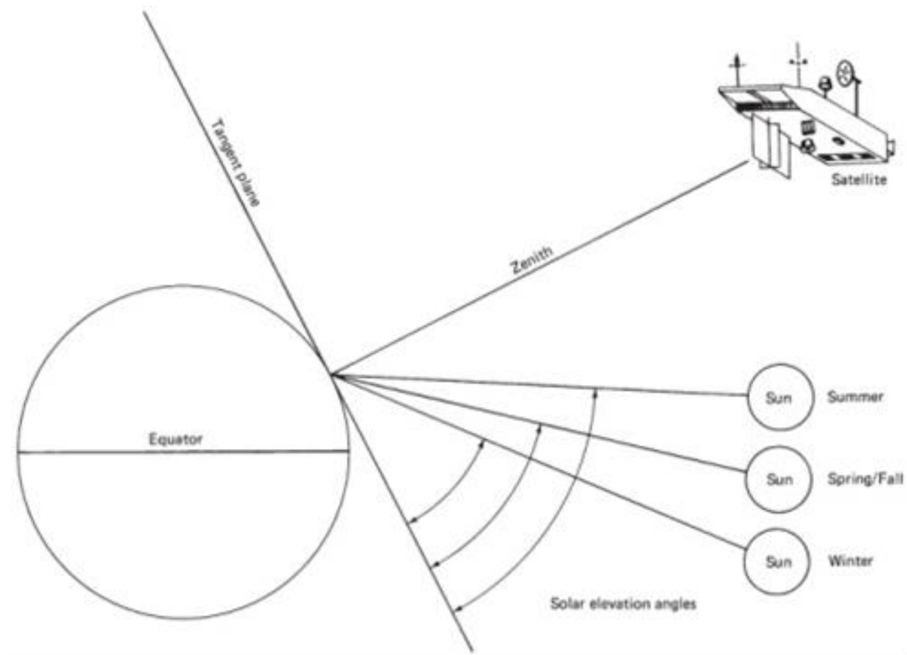
Radiometric Corrections: *(continue)*

- *For example, scene illumination is different in case of mosaics of images taken at different times, or in the case of reflectance changes of ground features at different times or locations.*

Chapter 2: "Image Rectification & Restoration"

Radiometric Corrections*: (continue)*

- *Therefore, it is necessary to apply a sun elevation angle correction & earth-sun distance corrections.*
- *Image acquired under different solar illumination angles are normalized by calculating pixel brightness values assuming that the san was at the zenith of each date of sensing.*



Chapter 2: "Image Rectification & Restoration"

Radiometric Corrections: (continue)

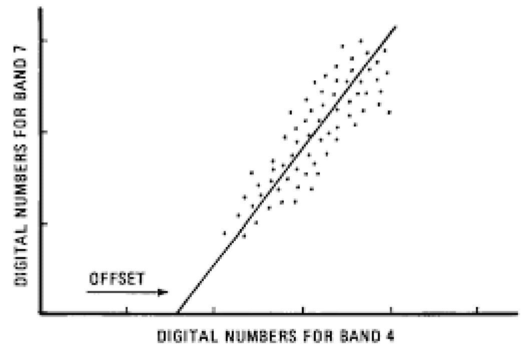
- *Ignoring atmospheric affects, the combined influence of solar zenith angle, θ, & earth-sun distance in astronomical units, d, on the irradiance incident on the earth's surface can be expressed as;*

$$E = E0 * (\cos \theta_0) / d^2$$

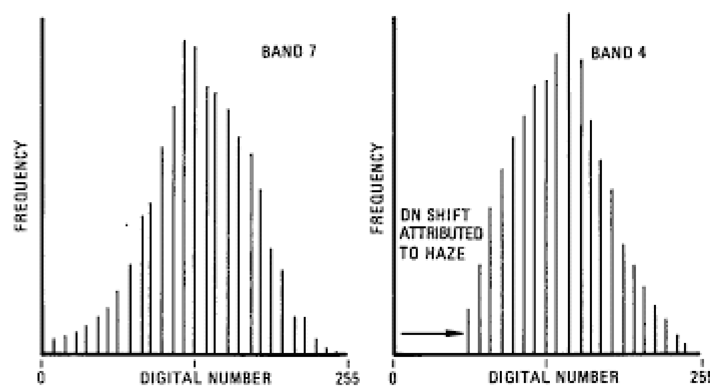
Where, E & E0 are normalized solar irradiance & solar irradiance at mean earth-sun distance.

- *The atmospheric effects the radiance measured at any point in the scene in two contradictory ways; it reduces the energy illuminating a ground object because of the absorption of energy of some cases, & It acts as a reflector by itself adding scattered to the signal detected by a sensor.*

Scattering correction:



A. PLOT OF BAND 7 VERSUS BAND 4 FOR AN AREA WITHIN THE IMAGE THAT HAS SHADOWS. OFFSET OF THE LINE OF LEAST–SQUARES FIT ALONG THE BAND 4 AXIS IS ATTRIBUTED TO ATMOSPHERIC SCATTERING IN THAT BAND.



B. HISTOGRAMS FOR BANDS 7 AND 4. THE LACK OF LOW DN'S ON BAND 4 IS CAUSED BY ILLUMINATION FROM LIGHT SCATTERED BY THE ATMOSPHERE (HAZE).

Chapter 2: "Image Rectification & Restoration" Part 3 out of 3

Noise Removal:

- *Image noise is any unwanted disturbance in image data that is due to limitations in sensing, signal digitization, or data recording process.*
- *The potential sources of noise range from periodic drafts or malfunction of a detector to electronic interference between sensor components.*
- *Noise removal usually precedes any subsequent image enhancement or classification.*
- *As with geometric restoration procedures, the correction required depends upon whether the noise is systematic (periodic), random, or some combination of the two.*

Chapter 2: "Image Rectification & Restoration"

Periodic or Line-Oriented Noise Removal:

- *For each spectral band, detectors were careful calibrated & matched before launched.*
- *However, the radiometric response of one, or more, detectors tend to drift over time resulting in relatively higher or lower values along every certain lines.*
- *Two forms of line-oriented noise problems are presented here, namely; line drop, line striping.*

Chapter 2: “Image Rectification & Restoration”

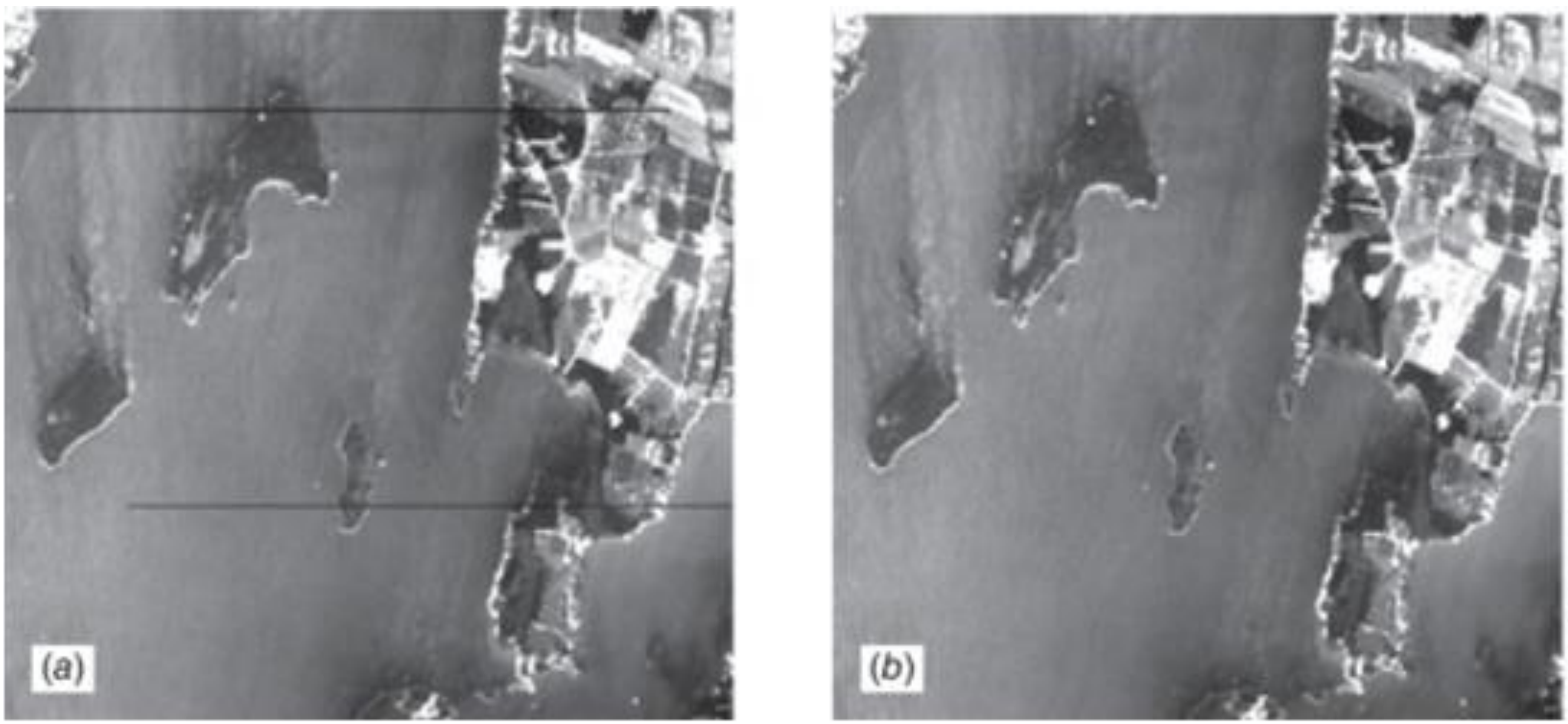
1. Line Drop:

- *In this types of problems, a number of adjacent pixels along a line can contain spurious DNs.*
- *To restore these lines, we have to calculate a replacement for the spurious DNs.*
- *To do this, the average DN values for each line for the entire scene is computed & compared to the overall average of the scene.*
- *A line is identification defected if it is deviating from the overall average by more than a designed threshold value.*

Chapter 2: “Image Rectification & Restoration”

1. Line Drop: (continue)

- Next, defected lines are fixed by taken the average value of the pixels above & below each defected pixel on the defected line.



Author-prepared figure.

Chapter 2: “Image Rectification & Restoration”

I. Line Drop: *(continue)*

Line Dropout

43	47	51	57
40	46	50	54
0	0	0	0
38	40	42	50

Solution: Mean from above and below pixels

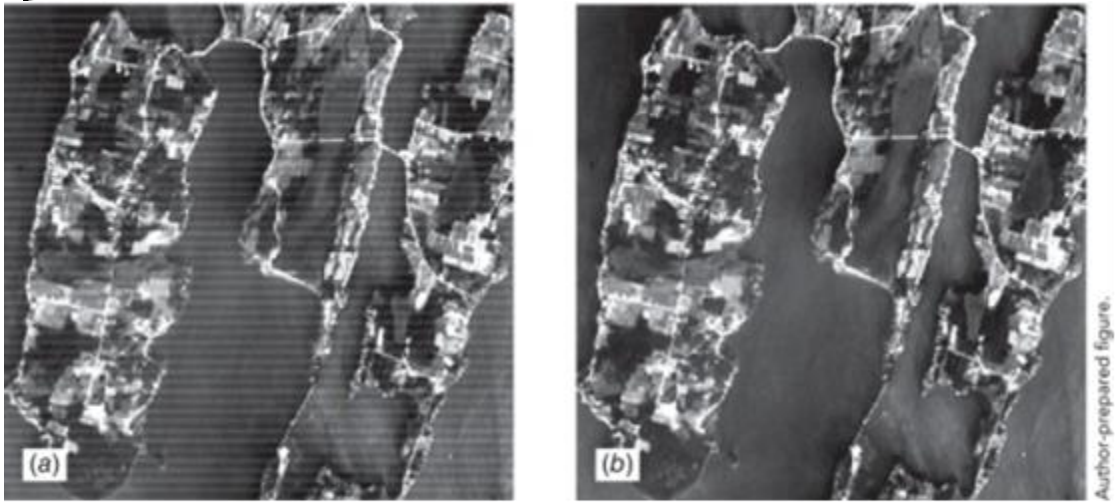
43	47	51	57
40	46	50	54
39	43	46	52
38	40	42	50

Or use other spectral band

Chapter 2: "Image Rectification & Restoration"

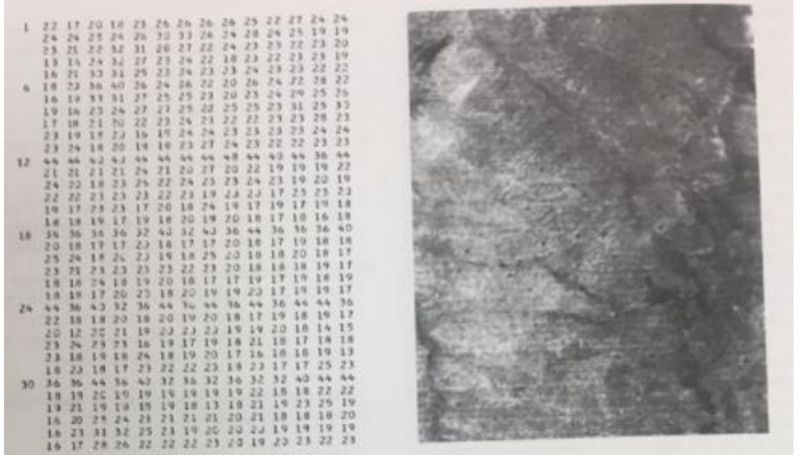
2. *Line Striping:*

- *Valid data are present in this kind of line oriented problem; however, the defected lines have to be corrected to match the overall scene.*
- *To fix this problem, we first plot histograms for the DNs recorded by each detector, then compare these histograms to each other.*
- *A gray-scale adjustment factor can then be determined to adjust the histogram for the problem lines.*
- *These correction is somewhat similar to the correction of the atmospheric scattering correction.*

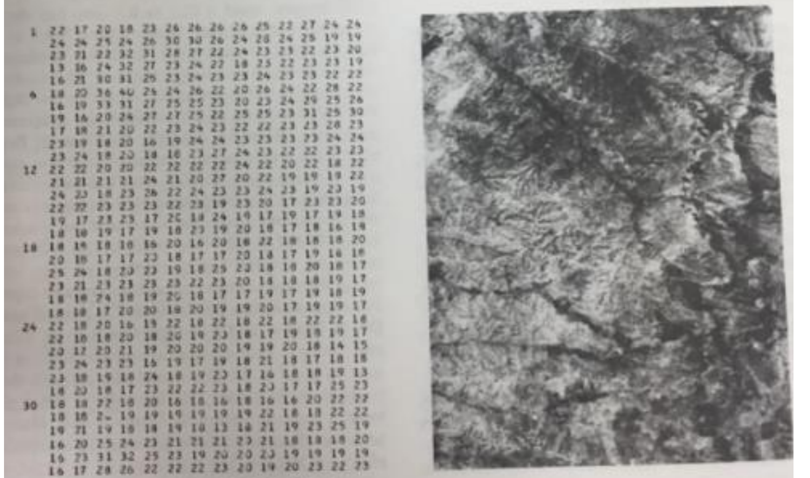


Chapter 2: "Image Rectification & Restoration"

2. *Line Striping: (continue)*



A. BEFORE DIGITAL RESTORATION.



B. AFTER DIGITAL RESTORATION.

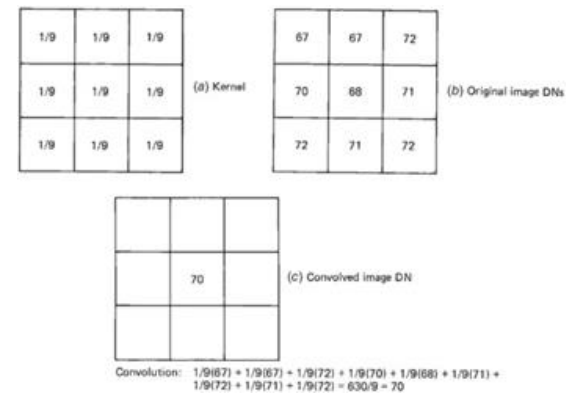
Chapter 2: "Image Rectification & Restoration"

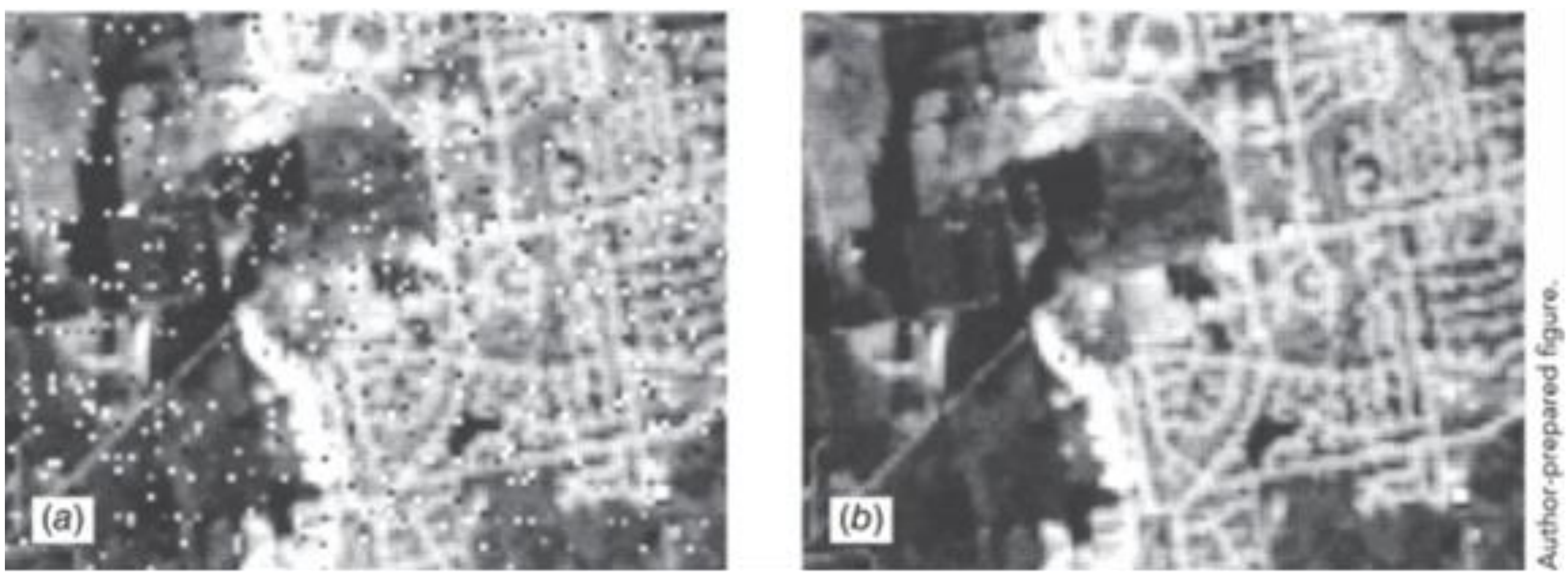
Random Noise Removal:

- *This type of noise is characterized by non-systematic variations in DNs from pixel to pixel called bit errors. Such errors are often referred to as being "spikey in character & it can cause a "salt & paper" appearance.*
- *Random noise can be handled by recognizing that noised values normally change much more abruptly than the rest of the image values.*
- *They can be fixed by applying 3x3 digital filters, such as: (1) a 3x3 average digital filter, or (2) a 3x3 average digital filter with double the weight in the center, (3) or simply we can take the median of a 3x3 digital filter, & so on.*

Chapter 2: "Image Rectification & Restoration"

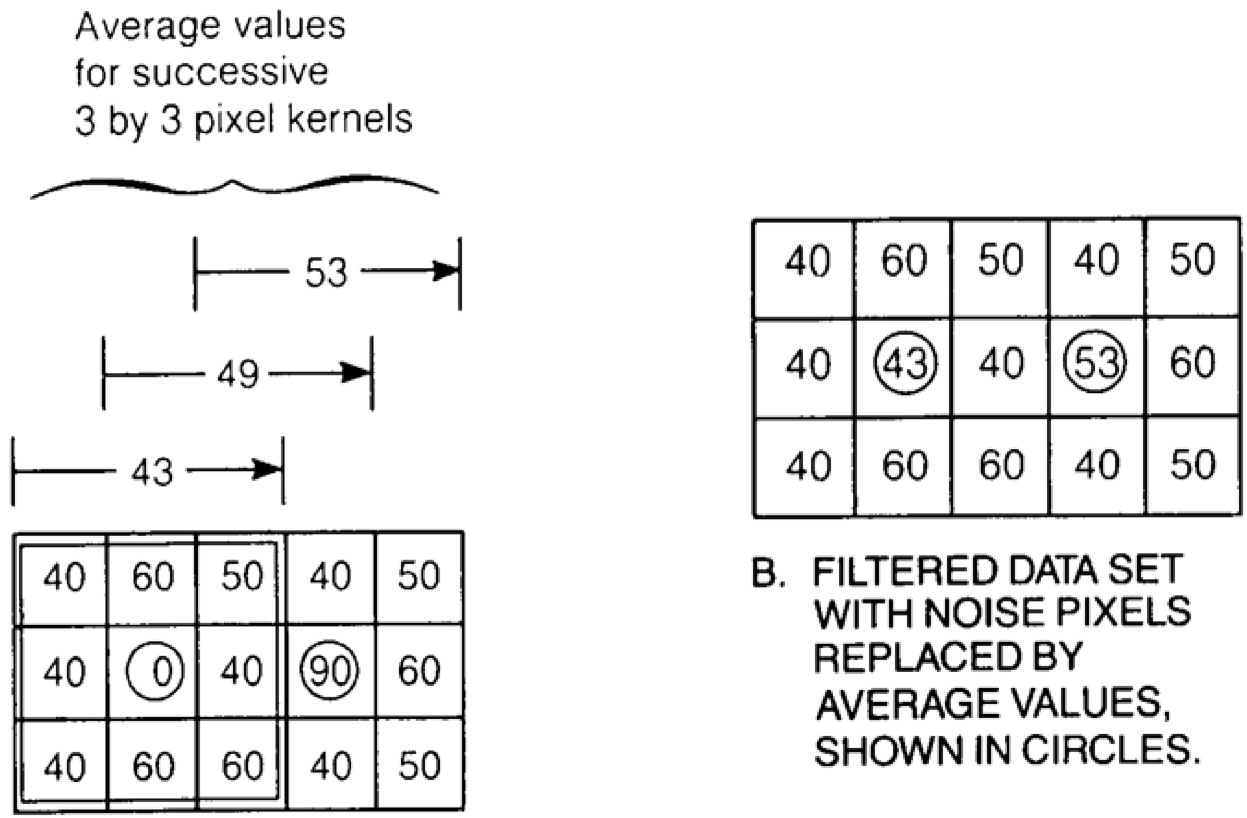
***Random Noise Removal**: (continue)*





Chapter 2: "Image Rectification & Restoration"

Random Noise Removal: (continue)



A. ORIGINAL DATA SET SHOWING OUTLINE OF FILTER KERNEL (3 BY 3 PIXELS).

B. FILTERED DATA SET WITH NOISE PIXELS REPLACED BY AVERAGE VALUES, SHOWN IN CIRCLES.