INTRODUCTION TO DIGITAL IMAGE PROCESSING

Pictures are the most common and convenient means of conveying or transmitting information. A picture is worth a thousand words. Pictures concisely convey information about positions, sizes and inter-relationships between objects. They portray spatial information that we can recognize as objects. Human beings are good at deriving information from such images, because of our inate visual and mental abilities. About 75% of the information received by Human is in pictorial form.

In the present context, the analysis of pictures that employ an overhead perspective, including the radiation not visible to human eye are considered. Thus our discussion will be focussing on analysis of remotely sensed images. These images are represented in digital form. When represented as numbers, brightness can be added, subtracted, multiplied, divided and, in general, subjected to statistical manipulations that are not possible if an image is presented only as a photograph.

Although digital analysis of remotely sensed data dates from the early days of remote sensing, the launch of the first Landsat earth observation satellite in 1972 began an era of increasing interest in machine processing. Previously, digital remote sensing data could be analyzed only at specialized remote sensing laboratories. Specialized equipment and trained personnel necessary to conduct routine machine analysis of data were not widely available, in part because of limited availability of digital remote sensing data and a lack of appreciation of their qualities.

After Landsat 1 began to generate a stream of digital data, analysts realized that the usual visual examination of Landsat images would not permit full exploitation of the information they conveyed. In time, routine availability of digital data increased interest among business and institutions, computers and peripheral equipment became less expensive, more personnel acquired training and experience, software became more widely available, and managers developed knowledge of the capabilities of digital analysis for remote sensing applications. Today, digital analysis has a significance that probably exceeds that of purely visual interpretation of remotely sensed data.

Digital Image

A digital remotely sensed image is typically composed of picture elements (pixels) located at the intersection of each row i and column j in each K bands of imagery. Associated with each pixels a number known as Digital Number (DN) or Brightness value (BV), that depicts the average radiance of a relatively small area within a scene (refer fig.1). A smaller number indicates low average radiance from the area and the high number is an indicator of high radiant properties of the area.

The size of this area effects the reproduction of details within the scene. As pixel size is reduced more scene detail is presented in digital representation.

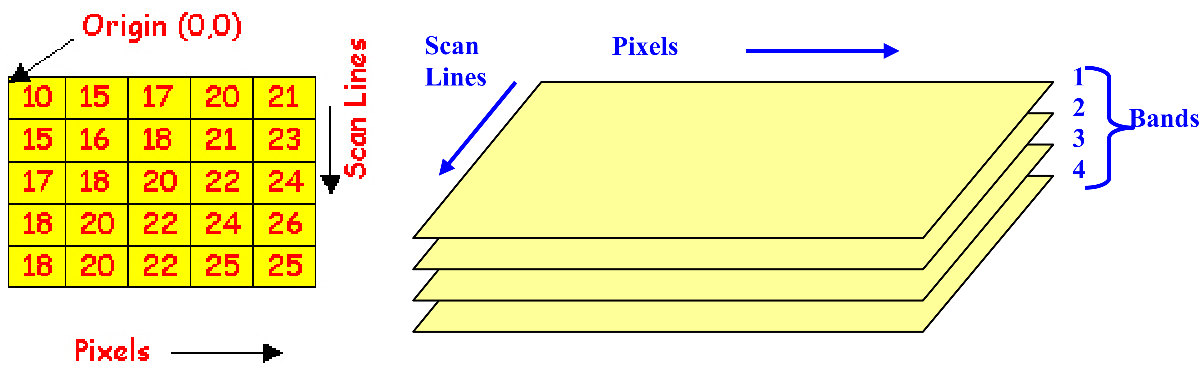


Figure 1 : Structure of a Digital Image and Multispectral Image

DIGITAL IMAGE DATA FORMATS

The image data acquired from Remote Sensing Systems are stored in different types of formats viz. (1) band sequential (BSQ), (2) band interleaved by line (BIL), (3) band interleaved by pixel (BIP). It should be noted, however, that each of these formats is usually preceded on the digital tape by "header" and/or "trailer" information, which consists of ancillary data about the date, altitude of the sensor, attitude, sun angle, and so on. Such information is useful when geometrically or radiometrically correcting the data. The data are normally recorded on nine-track CCTs with data density on the tape of 800, 1600, or 6250 bits per inch (bpi).

Band Sequential Format

The band sequential format requires that all data for a single band covering the entire scene be written as one file. Thus if one wanted the area in the center of a scene in four bands, it would be necessary to read into this location in four separate files to extract the desired information. Many researchers like this format because it is not necessary to read "serially" past unwanted information if certain bands are of no value. The number of tapes may be dependent on the number of bands provided for the scene.

Band Interleaved by Line Format

In this format, the data for the bands are written line by line onto the same tape (i.e. line 1 band 1, line 1 band 2, line 1 band 3, line 1 band 4, etc.). It is a useful format if all the bands are to be used in the analysis. If some bands are not of interest, the format is inefficient since it is necessary to read serially past all the unwanted data.

Band Interleaved by Pixel Format

In this format, the data for the pixel in all bands are written together. Taking the example of LANDSAT - MSS (Four Bands of Image Data every element in the matrix has four pixel values (one from each spectral band) placed one after the other [i.e., pixel (1,1) of band 1, pixel (1,1) of band 2, pixel (1,1) of band 3, pixel (1,1) of band 4, and then pixel (1,2) of band 1, pixel (1,2) of band 2 and so on]. Again, this is a practical data format if all bands are to be used, otherwise it would be inefficient. This format is not much popular now, but was used extensively by EROS Data Centre for Landsat scene at initial stage.

Image Processing Systems

Digital Image process is a collection of techniques for manipulation of digital images by computers. A digital image processing system consists of computer hardware and image processing software necessary to analyze digital image data.

(A) Hardware components

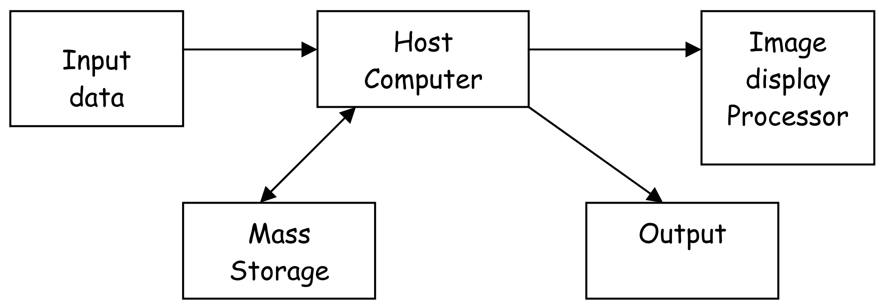


Figure 2 Digital Image Processing hardware components

Host computer

Although there was a time when some computers were specifically designed to analyze and display remotely sensed data. These computers were found to be too expensive and inflexible for widespread use. Today vast majority of remote sensing analysis uses general purposes computers using specialized remote sensing software.

Image analysts perform digital image analysis on mainframe computers, workstation or personal computers. The major difference is in the speed at which computer process millions of instruction per second (MIPS). Main frames are generally more efficient than workstation, which perform better than personal computers.

The heart of any digital computer is its central processing unit (CPU). Digital Image Processing of remote sensor data requires a large number of central processing unit (CPU) operation.

The CPU is burdened with two major tasks: numerical calculations and input-output to peripheral mass storage devices, color monitors, printers, and the like. Therefore, it is necessary to have a CPU that can manage data efficiently. In the past, micrometer CPUs were designed with 8-bit registers. The 8-bit CPUs were satisfactory for most input-output functions (since data are usually transferred 8 bits at a time), but were inefficient when performing numerical calculations. Personal computers now have CPUs with 16-to 32-

bit registers that compute integer arithmetic expressions at a greater speed than their 8-bit processors. Most reduced instruction set computer (RISC) workstations, use 32-bit RISC CPUs that address substantially more memory.

The 32-bit CPUs may also be configured to operate in parallel (concurrently Refer Figure 3), which can dramatically improve the speed of processing remotely sensed data when appropriate software is available. Parallel processing using multiple CPUs will have a significant impact on how digital image processing is performed in the future. Major vendors of computer hardware now provide workstation computers with multiple CPUs. Unfortunately, much of the digital image processing software of today does not take advantage of the parallel computing environment.

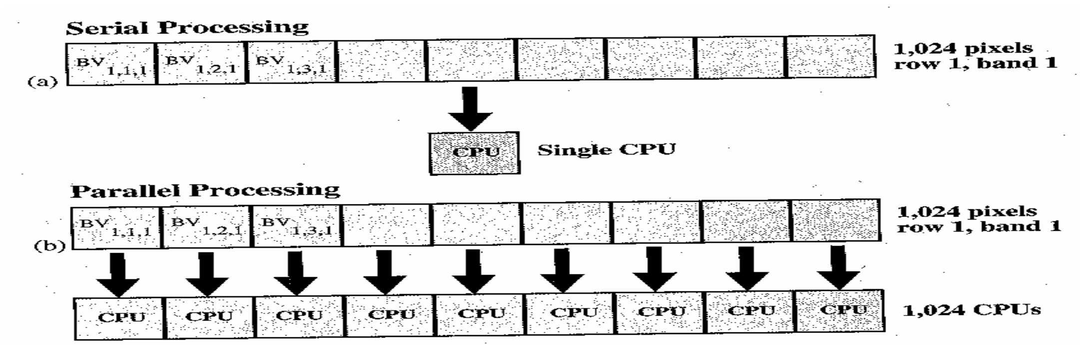


Figure 3: (a) Serial Vs. (b) Parallel Processing

An arithmetic (or floating point) coprocessor is often used to enhance the speed of the numerical calculations. The coprocessor works in conjunction with the CPU to perform real-number calculations very rapidly. Ideally, an array processor is available that can perform rapid arithmetic operations on an entire array (matrix) of numbers. This is especially useful for image enhancement and image analysis operations.

Mass Storage

Because remotely sensed data typically require large storage capacities, image processing systems use substantial amounts of disk storage. Disks can be manufactured from either rigid or flexible materials that are coated with a magnetized substance sensitized to record the bits that represent each digital value. The computer's disk drives rapidly spin the disk, allowing the computer to read data from both sides. Rigid (hard) disks provide rapid access to large amounts of storage required for image processing. The flexible (floppy) disks have smaller storage capacities, and provide slower access to the data; they are used primarily for smaller computers, whose demands for storage and access are not as critical. Also available are a variety of removable disk drives that can store from 20 to 230 MB of data in a compact, transportable form.

Computer tapes are strips of coated plastic film that have been sensitized to record digital data when the write heads of tape drives encode them with magnetic marks that record bits and bytes. Compute tapes are now available in a range of sizes and capacities, some as small as the audio cassettes familiar to most readers.

Older computer systems once used long tapes stored on large (10-in. diameter) reels. Each tape recorded data in nine tracks that ran parallel to each other for the entire length of the tape. Each track recorded one bit, so an eight-bit word could be written across the width of the tape. (The ninth track recorded the parity bit, used to detect errors in reading and writing data to and from tape). The amount of data recorded on a tape was determined in part by the density of data as written to the tape; usually data were written at either 1,600 bits per inch (BPI) or 6,250 BPI (although even older tapes may be written at 800 BPI). Today, use of these tapes has declined rapidly as they have been replaced by other mass storage media. Nonetheless, reel tapes still hold older data in archives, so they will be used in some institutions until the data can be transferred to more compact media.

Data cartridges and cartridge tape units are more compact versions of the tapes just described, usually using high-density tapes stored in small cassettes. Exact sizes, capacities, and data formats vary with manufacturers; cassettes vary in size from about 4 in. x 6 in. to about 2.5 in./ x 3.5 in. Some of these smaller high-density tapes, although as small as a common audiocassette, can store more data than can be older reel tapes. Because the drives for these smaller tapes are also compact and inexpensive, they greatly expand the capabilities of desktop computer systems and the ability of individuals and organizations to store and use remote sensing data.

CD-ROM (Compact Disk, Read-Only Memory) storage is familiar to most readers as the prevailing means of recording audio information for mass distribution. CD-ROMs are the oldest and most reliable form of optical storage: Each CD-ROM is a plastic disk, encoded by irregularities in very fine, textured grooves that can be read by a laser within a CD-ROM drive. Because each disk can hold 680 MB, they form a compact, durable means of storing remote sensing data.

Once encoded, CD-ROMs cannot be erased or rewritten, so they are suitable primarily, in the context of remote sensing, as a means of transmitting raw image data that will be read many times. Although the cost of preparing CD-ROMs was once so expensive that they were used only for data that were needed in many copies, costs are now low enough that they can be efficient for many fewer copies, and image data are now often distributed on CD-ROMs. CD-ROMs must be read using special drives available as peripheral units but now also increasingly offered as standard equipment on personal computers.

WORM (Write Once, Read Many) disks are another form of optical storage that permits the user, rather than the manufacturer, to write data to the disk. Once written, however, the information can be read but not altered. WORM disks vary in size from about 5.25 in. in diameter to 14 in. with larger disks holding as much as 3 GB on each side. Although WORM disks offer important advantages for some users, manufacturers have yet to agree on common standards for data formats, so they are not yet practical for users that require many transfers between different systems. Erasable optical disks are yet another form of optical storage, with the ability to store large amounts of data cheaply. Rewritable optical disk cartridges are 5.5 in. in diameter; they offer improved flexibility over WORM and CD-ROMs, although current drives are also compared to magnetic disks.

Operating System and Compiler

The operating system and compiler must be easy to use yet powerful enough so that analysts may program their own relatively sophisticated algorithms and experiment with them on the system. It is not wise to configure an image processing system around an unusual operating system because it becomes difficult to communicate with certain devices and to share applications with other scientists. Most workstations use the UNIX operating system, while most personal computers use DOS, Windows, or Windows NT, UNIX has exceptional networking capabilities and allows easy access to a variety of peripherals, including printers, plotters, the Internet, and color display .

The compilers most often used in the development of digital image processing software are BASIC, Assembler, C, and FORTRAN. Many digital image processing systems provide a tool-kit that more sophisticated analysts can use to compile their own digital image processing algorithms. The toolkit usually consists of primitive subroutines, such as reading a line of image data into core, displaying a line of data to the CRT screen, or writing the modified line of data to the hard disk.

Image Display

For remote sensing computing, the image display is especially important because the analyst must be able to examine images and inspect results of analysis, which often are themselves images. At the simplest level, an image display can be thought of as a high-quality television screen, although those tailored specifically for image processing have image display processors, which are special computers designed to receive rapidly digital data from the main computer and display them as brightness on the screen. The capabilities of an image display are determined by several factors. First is the size of the image it can display, usually specified by the number of rows and columns it can show at any one time. A large display might show 1,024 rows and 1,280 columns. A smaller display with respectable capabilities could show a 1,024 x 708 image; others of much more limited capabilities could show only smaller sizes, perhaps 640 x 480 (typical of display for the IBM PC).

Second, a display has a given radiometric resolution. That is, for each pixel, it has a capability to show a range of brightness. One-bit resolution would give the capability to show either black or white-certainly not enough detail to be useful for most purposes. In practice, six bits (64 brightness levels) are probably necessary for images to appear 'natural', and high-quality displays typically display eight bits (256 brightness levels) or more.

A third factor controls the rendition of color in the displayed images. The method of depicting color is closely related to the design of the image display and the display processor. Image display data are held in the frame buffer-a large segment of computer memory dedicated to handling data for display. The frame buffer provides one or more bits to record the brightness of each pixel to be shown on the screen (the bit plane); thus, the displayed images is generated, bit by bit, in the frame buffer. The more bits that have been designed in the frame buffer for each pixel, the greater the range of brightnesses that can be shown for that pixel, as explained above. For actual display on the screen, the digital value for each pixel is converted into an electrical signal that controls the brightness of the pixel on the screen. This requires a digital-to-analog (D-to-A) converter that translates discrete digital values into continuous electrical signals (the opposite function of the A-to-D converter mentioned previously).

Digital remote sensor data are usually displayed using the RGB color coordinate system which is based on additive color theory and three primary colors of Red ,Green and Blue(Refer Figure 4) . Display of color images requires a more complex process. For the simplest and cheapest color displays (sometimes known as pseudo-color displays) the image is stored in a single memory plane (Figure 5). The color for each pixel is determined by matching each pixel to a set of colors (a "palette") stored in a segment of memory known as a look-up table control the intensities of the three A-to-D converters (one for each primary) that create colors on the display screen. Therefore, the number of bits in the look-up table forms one limit on the number of colors that can be shown by a given display. The look-up table stores the current selection of colors; the number of colors that can be shown at a given time is controlled by the number of bits assigned to each pixel in the screen's RAM. The values in the look-up table control the brightness on the screen in the screen in the manner illustrated by Table 1. In this simple example, the intensity of each additive primary is controlled by only one bit, so a maximum of only eight colors can be displayed at a given time. Each primary is either "on" (1) or "off" (0), resulting in the eight combinations shown in Table 1. If the look-up table has more bits, the primaries can be represented more subtly (rather than simply as on or off), so, for example, 4 bits give intensities from 0 to 15, 5 bits intensities from 0 to 31, and 7 bits intensities from 0 to 127. With more subtle variations of the brightness's if the intensities, the colors on the screen assume a wider range of variations, more nearly approaching those we observe in nature. For example, with 7 bits the display could show red = 127, green = 0, and blue = 0 to produce a pure red on the screen But it could also show a more subtle shade of color by setting red = 127, green =37, and blue = 65, a choice that would not be possible with the simpler system.

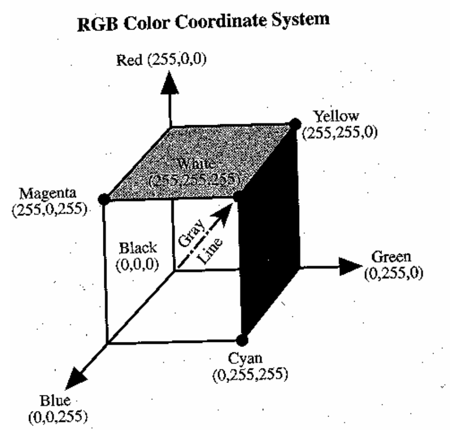


Figure 4 : RGB Color Cube.

Thus, the look-up table translates pixel values into intensities that can be displayed on the screen. Note that the look-up table may not have sufficient precision to accurately represent the varied detail within the data. The look-up table limits the number of colors that can be shown at a given time, but the analyst can reconfigure (or "reload") the look-up table to select another set of colors. The limitation of pseudo-color technology is both the restriction in the range of colors that can be shown at a given time and the time and inconvenience entailed in reloading and displaying colors.

Table 1 Example of Look-Up Table for Three-Bit Frame Buffer

Color on Screen	Value from bit plane		
	Red	Green	Blue
Black	0	0	0
Red	1	0	0
Green	0	1	0
Blue	0	0	1
Yellow	1	1	0
Cyan	0	1	1
Magenta	1	0	1
White	1	1	1

The alternative form of representing colors is known as true, full, or analog color display (Figure 6). A separate memory plane (8 Bit) is required for each primary color, each with its own look-up and D-to-A converter. Because each of the three primary colors resides in independent memory planes, manipulation of colors is much faster and easier than with pseudo-color systems. In addition, each primary color has its own look-up table, which permits a much wider range of intensities for each primary, and therefore a wide range of combinations on the screen, which in practice approximates the range of colors that might be observed in nature - hence, the term true color. Using three 8bit images we can conceivably display 2^{24} = 16,777,216 different color combinations. True color display shows much more realistic and attractive images than do pseudo-color displays but are also more expensive.

Table 2 Graphic Standards for PCs

Name and designation	Colors	Screen size
Color graphics adapter (CGA)	4	320 x 200
Extended graphics adapter *EGA)	16	640 x 350
Video graphics array (VGA)	16	640 x 450
Super VGA (S-VGA)	256	800 x 600
Extended graphics array (XGA)"	256	1,024 x 768
	16.7	1600 x 1200

Some PC displays, not now widely used, employ screen sizes of 1,280 x 1,024.

Table 2 lists characteristics of current graphics standards. Image display is important because remote sensing instruments typically record a much wider range of values than can be accurately displayed by film products or by any single representation on an image display device. As a result, displays that provide the analyst with the capability to conveniently change image scale, color assignments, viewing area, and so forth, provide a capability to explore visually the varied dimensions of an image. Such capabilities are not available with film images, which require considerable effort to study varied representations of a digital image.

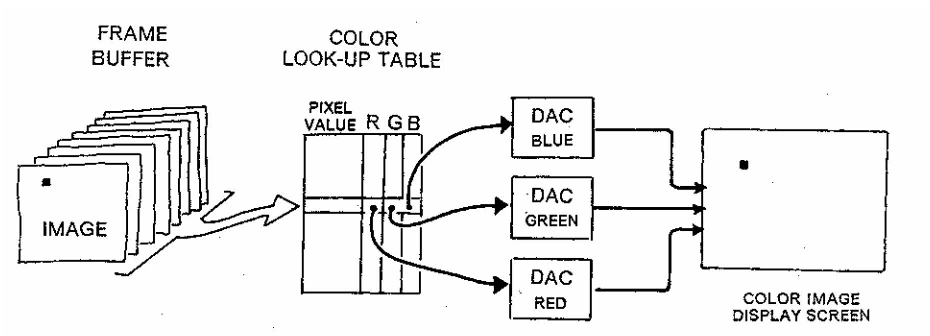


Figure5: Schematic diagram of a pseudo color display

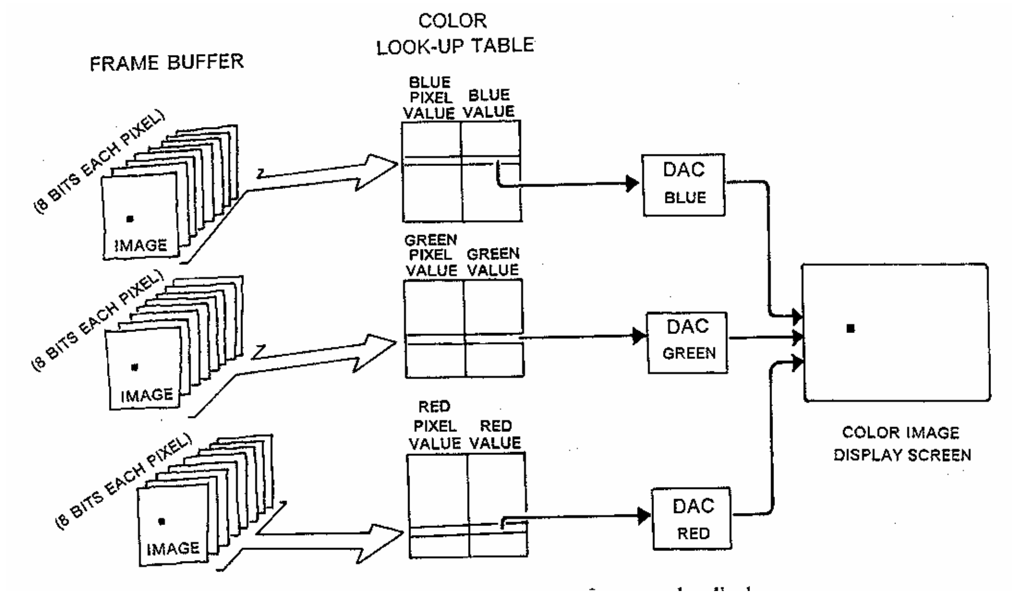


Figure 6 Schematic diagram of a true color display

SOFTWARE CONSIDERATIONS

Digital Image Processing is an extremely broad subject and involves procedures which are mathematically complex. The procedure for digital image processing may be categorized into the following types of computer assisted operations.

1. **Image Rectification** : These operations aim to correct distorted or degraded image data to create a faithful representation of the original scene. This typically involves the initial processing of raw image data to correct for geometric distortion, to calibrate the data radiometrically and to eliminate noise present in the data. Image rectification and restoration procedures are often termed preprocessing operations because they normally precede manipulation and analysis of image data.

2. **Image Enhancement** : These procedures are applied to image data in order to effectively display the data for subsequent visual interpretation. It involves techniques for increasing the visual distinction between features in a scene. The objective is to create new images from original data in order to increase the amount of information that can be visually interpreted from the data. It includes level slicing, contrast stretching, spatial filtering edge enhancement, spectral ratioing, principal components and intensity-hue-saturation color space transformations.

3. **Image Classification** : The objective of these operations is to replace visual analysis of the image data with quantitative techniques for automating the identification of features in a scene. This involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover identity

of each pixel in an image. The intent of classification process is to categorize all pixels in a digital image into one of several land cover classes or themes. This classified data may be used to produce thematic maps of the land cover present in an image.

COLOR COMPOSITIES

High spectral resolution is important when producing color components. For a true color composite an image data reused in red, green and blue spectral region must be assigned bits of red, green and blue image processor frame buffer memory. A color infrared composite or 'standard false color composite' is displayed by placing the infrared, red, green in the red, green and blue frame buffer memory. In this healthy vegetation shows up in shades of red because vegetation absorbs most of green and red energy but reflects approximately half of incidence Infrared energy. Urban areas reflect equal portions of NIR, R & G, and therefore they appear as steel grey.

Screen Colour Gun
Assignment

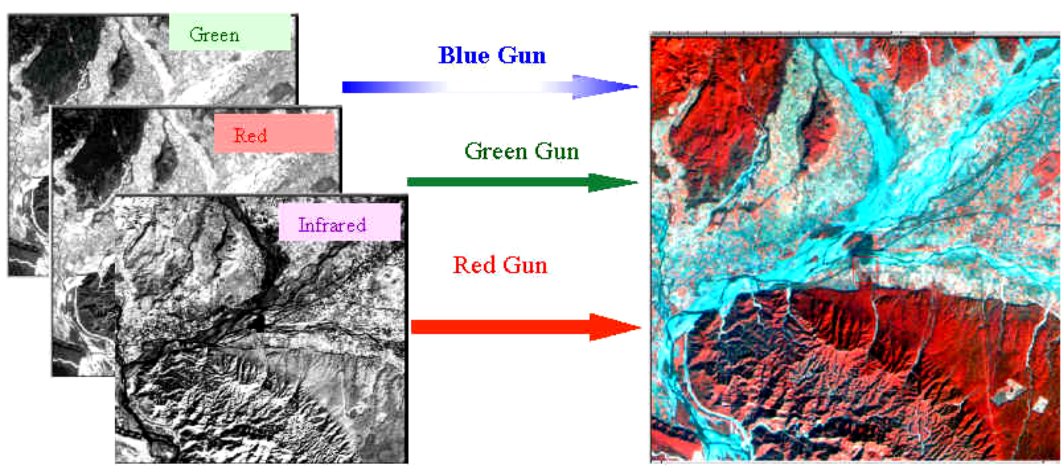


Figure 7: False Colour Composite (FCC) of LISS II Paonta Area

Best Band FCC Display

Optimum Index Factor (OIF) is applied to remotely sensed multispectral data in order to determine the three most suitable bands combination that has the maximum information with the least amount of duplication. The algorithm used to compute the OIF for any subject of three bands is

$$OIF_{1,2,3} = \frac{S_1 + S_2 + S_3}{|r_{12}| + |r_{23}| + |r_{13}|}$$

where $r_{mn} = (Cov)_{mxn} / \sigma_{mm} \sigma_{nn}$

Cov - Covariance between m & n
σ = standard deviation

Where S_k is the standard deviation for band K and r_j is the absolute value of correlation coefficient between any two of the three bands being evaluated. The three bands combination with largest OIF is considered the most suitable.

RADIOMETRIC AND GEOMETRIC CORRECTIONS

Introduction

In their raw form as received from imaging sensors mounted on satellite platforms, remotely sensed data may contain flaws or deficiencies. The correction of deficiencies and removal of flaws present in the data is termed as pre-processing.

Image pre-processing can be classified into three functional categories

i) Radiometric corrections
ii) Atmospheric corrections
iii) Geometric corrections

The intent of image correction is to correct image data for distortions or degradations that stem from the image acquisition process. Image Radiometry generally refers to the digital representation of the sensed data, while radiometric correction involves the re-arrangement of the digital numbers (DN) in an image so that all areas in the image have the same linear relationship between the DN and either radiance or backscatter. Digital Number (DN value) is also known as pixel value.

Image geometry refers to the projection, scale and orientation of the image, while geometric correction refers to the modification of the input geometry to achieve the desired geometry.

Radiometric Corrections

Radiometric errors are caused by detector imbalance and atmospheric deficiencies. Radiometric corrections are transformations on the data in order to remove errors, which are geometry independent. Radiometric corrections are also called as cosmetic corrections and are done to improve the visual appearance of the image.
Multiple detectors are used in the sensor system to simultaneously sense several image lines during each sweep of the mirror. This configuration requires an array of 24 detectors (6 lines x 4 bands) in case of MSS. As the detectors are not precisely equivalent in their output characteristics, their output changes gradually over time. Due to these variations there will be different output for the same ground radiance.

To accomplish this, the scanner views an electrically illuminated step wedge filter during each mirror sweep. Once per orbit, the scanner views the sun to provide a more absolute calibration. These calibration values are used to develop radiometric correction functions for each detector. The correction functions yield digital numbers that correspond linearly with radiance and are applied to all data prior to dissemination.
Some of the radiometric distortions are as follows
(1) correction for missing lines (2) correction for periodic line striping (3) random noise correction (4) atmospheric correction

Correction for Missing Scan Lines (Scan line drop out):

Although detectors onboard orbiting satellites are well tested and calibrated before launch, breakdown of any of the detectors may take place. Such defects are due to errors in the scanning or sampling equipment, in the transmission or recording of image data or in reproduction of CCT's. The missing scan lines are seen as horizontal black (pixel value 0) or white (pixel value 255) lines on the image. Techniques are available to locate these bad lines by selecting unusually large discrepancies in image values for sequential lines. The first step in the restoration process is to calculate the average DN value per scan line for entire scene. The average DN value for each scan line is then compared with scene average. Any scan line deviating from the average by more than a designated threshold value is identified as defective. Once detected, they may be cosmetically corrected in three ways

- Replacement by either the preceding or the succeeding line
- Averaging of the neighbouring pixel values
- Replacing the line with other highly correlated band.

i) Replacement by Preceding or Succeeding Line

This is the simplest method for estimating the pixel value along a dropped scan line, it involves replacement of the value of the missing scan line by the value of the corresponding pixel on immediately preceding or succeeding scan line.

$V_{i,j} = V_{i,j-1}$ or $V_{i,j} = V_{i,j+1}$

Where $V_{i,j}$ = missing pixel value of pixel i scan line j

$V_{i,j-1}$ = pixel value of pixel i and scan line j-1 (preceding), and
$V_{i,j+1}$ = pixel value of pixel i and scan line j+1 (succeeding)

ii) Averaging Method

The missing scan line is replaced by the average value of the corresponding pixel on immediately preceding and succeeding line.

$V_{i,j} = V_{i,j-1} + V_{i,j+1} / 2$

iii) Replacement with Correlated Band

This method relies on the fact that spectral bands in the same region of the spectrum are highly correlated. For e.g. Landsat-3 MSS band 4[green] and band 5[red] are highly correlated. The missing pixels in band k is estimated by considering contributions from the equivalent pixels in the same band in another highly correlated band and neighbouring pixels in the same band. If highly correlated band were denoted by subscript r then algorithm can be represented by

$$V_{i,j,k} = M \left[V_{i,j,r} - (V_{i,j+1,r} + V_{i,j-1,r}) /2 + (V_{i,j+1,k} - V_{i,j-1,k}) /2 \right]$$

Where $M = \sigma_k / \sigma_r$

Correction for line striping (De-stripping):

A sensor is called ideal when there is a linear relationship between input and the output. Although all the detectors are well calibrated prior to the launch, the response of some of the detectors may shift towards lower or higher end. The presence of a systematic horizontal banding pattern is frequently seen on images produced by electronic scanners such as MSS sixth line banding and on TM sixteenth line banding. Banding is a cosmetic defect and it interferes with the visual appreciation of the patterns and features on the image. Hence corrections for these bandings are to be applied to improve the visual appearance and interpretability of the image. Two methods of de-stripping are considered, both these methods are based upon the shape of the histograms of pixel values generated by the individual detectors in a particular band.

i) Linear Method

This method uses a linear expression to model the relationship between input and output values. It assumes that mean and standard deviation of data from each detector should be same. Detector imbalance is the only factor producing the differences in means and standard deviations. To get rid of this effect due to detector imbalance, the means and standard deviations of the six (MSS) histograms are equalised i.e. forced to equal the standard deviation of the whole image.

The overall standard deviation is given by

$$\sigma = \sqrt{\frac{\Sigma n_i (\bar{x}_i^2 + \nu_i)}{\Sigma n_i} - \bar{x}^2}$$

Where

$\bar{x}$ = overall mean ($\Sigma \bar{x}_i /6$)

$\bar{x}_i$ = mean of detector i

ν_i = variance of detector i

n_i = no. of pixels processed by detector i

ii) Histogram Matching (Non Linear)

In some images it appears that different gain and offsets are appropriate for different scene radiance images i.e. the sensor transfer curves are non linear. If the relationship between the input and output values is non-linear then histogram matching method should be applied. This method uses the shape of the cumulative frequency histogram of each detector to find an estimate of the non-linear transfer function. The cumulative frequency histogram of each detector and one target is computed. Then the shape of the individual cumulative histogram is matched to the target histogram as closely as possible. The first value in the target histogram to equal or exceed the values in detector histogram are taken as output reference and the corresponding input value is taken as output value.

Table 1: Example of histogram matching method

Input pixel value	Target histogram value	Detector histogram value	Output pixel value
0	.09	.08	0
1	.18	.11	1
2	.33	.18	2
3	.56	.57	4
4	.60	.66	4
5	.76	.78	6
6	.95	.95	6
7	1.00	1.00	7

Random Noise Correction

Random noise means pixels having offset values from the normal. It can be easily corrected by means of a smoothing filter on the data.

Atmospheric correction:

The value recorded at any pixel location on the remotely sensed image is not a record of the true ground-leaving radiance at that point, for the signal is attenuated due to absorption and its directional properties are altered by scattering. Figure 8 depicts the effects the atmosphere has on the measured brightness values of a single pixel for a passive remote sensing system.

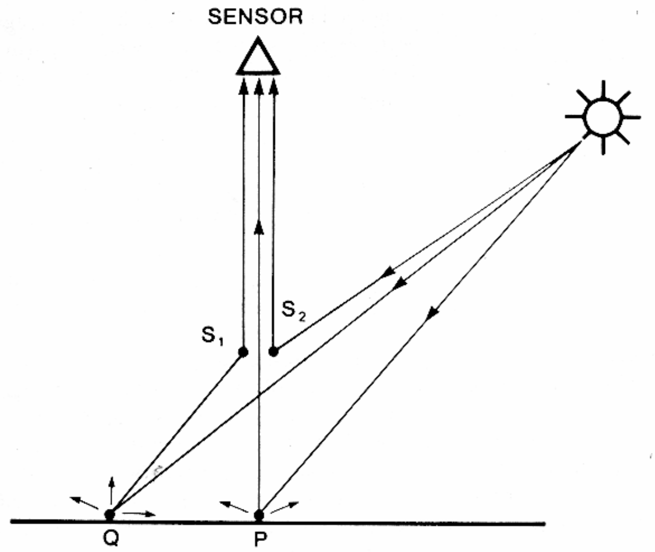


Fig 8. Components of the signal received by satellite mounted sensor.

Scattering at S_2 redirects some of the incident radiance within the atmosphere in the field of view of the sensor (the atmospheric path radiance) and some of the energy reflected from point Q is scattered at S_1 so that it is seen as coming from P. To add to these effects the radiance from P and Q is attenuated as it passes through the atmosphere. Other difficulties are caused by the variations in the illumination geometry (Sun's elevation and azimuth angles).

The relationship between radiance received at a sensor above the atmosphere and the radiance leaving the ground surface can be given as

$$L_s = H_{tot} \rho T + L_p$$

H_{tot} = total downwelling radiance in a specified spectral band
ρ = reflectance of the target
T = atmospheric transmittance
L_p = atmospheric path radiance

The path radiance L_p varies in magnitude inversely with wavelength for scattering increases as wavelength decreases. Atmospheric path radiance introduces haze in the imagery whereby decreasing the contrast of the data. In order to remove the haze component two simple techniques are discussed here

- Histogram minimum method
- Regression method

i) Histogram Minimum Method (Dark pixel subtraction technique)

In this method an assumption is made that there is a high probability that there are some areas in the image with low reflectance (clear water, deep shadow etc). These pixels will have values very close to zero in the short wave infrared band. Any value greater than zero is assumed to be a haze contribution. The histograms of all the bands in the image are computed for the full image. The lowest pixel values in the histograms of all the bands are taken as the first approximation of the atmospheric path radiance and these minimum values are subtracted from the respective images.

The atmospheric effects correction - algorithms is

$$I^{\circ}(i,j) = I(i,j) - \text{Bias}$$

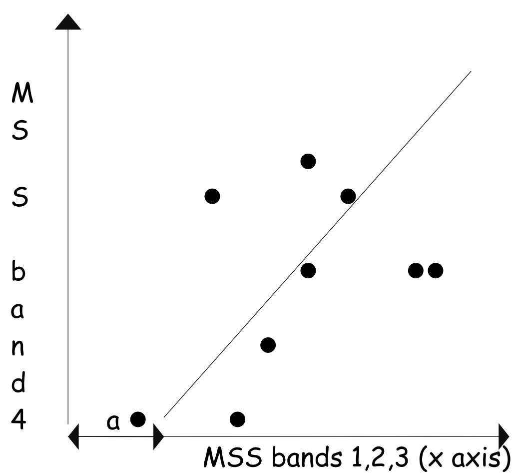
where, I (i,j) = input pixel value at line i and sample j

I° (i.j) = Enhanced pixel value at same location (i,j)

The bias is the amount of offset for each spectral band.

ii) Regression Method

In this method the pixel values corresponding to regions having low reflectance (water, deep shadow) in the short-wave infrared regions are plotted against the pixel values of the other spectral bands in turns and a best fit (least squares) straight line is computed using standard regression methods. The offset a on the x-axis in different bands is the atmospheric path radiance and hence has to be subtracted from the respective images



Geometric Errors and Corrections

Remotely sensed data usually contains both systematic and unsystematic geometric errors. Distortions whose effects are systematic in nature and are constant and can be predicted in advance are called systematic distortions. Systematic distortions are Scan skew, Mirror-scan velocity, Panoramic distortions and Non-systematic distortions include errors due to platform Altitude and Attitude, Platform velocity, Earth rotation, perspective projection(Fig 9). More over remotely sensed images are not maps. The transformation of a remotely sensed image so that it has a scale and projections of a map is called geometric correction. A related technique, called registration, is the fitting of the coordinate system of an image to that of second image of the same area.

These errors can be divided into two classes (a) those that can be corrected using data from platform ephemeris and knowledge of internal sensor distortion (b) those that cannot be corrected with acceptable accuracy without a sufficient number of ground control points (GCP).

Distortion evaluated from tracking data

1. **Earth Rotation**: As the scanning mirror completes successive scans, the earth rotates beneath the sensor. Thus there is a gradual westward shift of the ground swath being scanned. This causes along-scan distortion. To give the pixels their correct positions relative to the ground it is necessary to offset the bottom of the image to the west by the amount of movement of the ground during image acquisition. The amount by which the image has to be skewed to the west depends upon the relative velocities of the satellite and earth and the length of the image frame recorded.

2. **Spacecraft Velocity**: If the spacecraft velocity departs from nominal, the ground track covered by a fixed number of successive mirror sweep changes. This produces along-track scale distortion.

3. **Scan- Time Skew**: During the time required for the scanning mirror to complete an active scan, the spacecraft moves along the ground track. Thus, the ground swath scanned is not normal to the ground track but is slightly skewed, which produces cross-scan geometric distortion. The known velocity of the satellite is used to restore this geometric distortion. The magnitude of correction is 0.082 km for MSS.

4. **Sensor Mirror Sweep**: The mirror-scanning rate varies non-linearly across a scan because of imperfections in the electro mechanical driving mechanism. Since data samples are taken at regular intervals of time, the varying scan rate produces along-scan distortions. The magnitude of the correction is 0.37 km for MSS.

5. **Panoramic Distortions**: For scanners used on space borne and airborne remote sensing platforms the angular instantaneous field of view (IFOV) is constant. As a result the effective pixel size on the ground is larger at the extremities of the scan line than at the nadir. It produces along-scan distortion. If the instantaneous field of view (IFOV) is

β and the pixel dimension at nadir is p, then its dimension in the scan direction at a scan angle of θ is $p_\theta = \beta h \sec^2\theta = p \sec^2\theta$ where h is altitude.

6. **Perspective projection**: For some applications it is desired that Landsat images represent the projection of points on the earth upon a plane tangent to the earth, with all projection lines normal to the plane. The sensor data represent perspective projections, projections whose all lines meet at a point above the tangent plane. For the MSS, this produces only along-scan distortion.

Distortion evaluated from ground control

1. **Altitude:** Departures of the spacecraft altitude from nominal produces scale distortions in the sensor data. For MSS, the distortion is along-scan only and varies with time. The magnitude of correction is upto 1.5 km for MSS.

2. **Attitude**: Normally, this sensor axis system is maintained with one axis normal to the Earth's surface and another parallel to the spacecraft velocity vector. As the sensor departs from this attitude, geometric error results. Roll and pitch errors shift the image linearly. Yaw error rotates each image line about its center. Maximum shift occurs to the edge pixels under yaw. For LISS-II, a roll error of 0.1 degree will shift the image line by 1.57 km across the track. For pitch error of same magnitude, the line gets shifted along the track by 1.57 km.

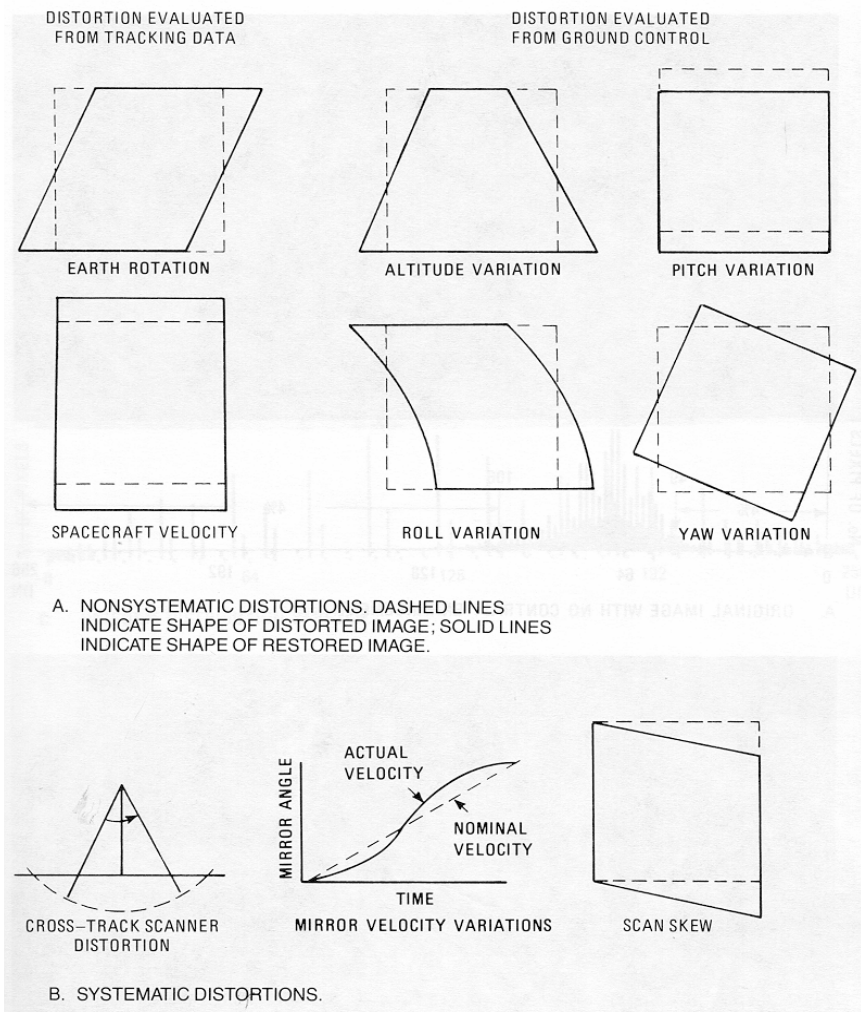


Fig 9. Geometric distortions

IMAGE RECTIFICATION AND REGISTRATION

These operations aim to correct distorted or degraded image data to create a more faithful representation of the original scene. This typically involves the initial processing of raw image data to correct for geometric distortions, to calibrate the data radiometrically, and to eliminate noise present in the data. Thus, the nature of any particular image restoration process is highly dependent upon the characteristics of the sensor used to acquire the image data. Image rectification and restoration procedures are often termed preprocessing operations because they normally precede further manipulation and analysis of the image data to extract specific information.

GEOMETRIC CORRECTION

Raw digital images usually contain geometric distortions so significant that they cannot be used as maps. The sources of these distortions range from variations in the altitude, and velocity of the sensor platform, to factors such as panoramic distortion, earth curvature, atmospheric refraction, relief displacement, and non-linearity's in the sweep of a sensor's IFOV. The intent of geometric correction is to compensate for the distortions introduced by these factors, so that the corrected image will have the geometric integrity of a map.

The geometric correction process is normally implemented as a two-step procedure. First, those distortions that are systematic, or predictable, are considered. Second, those distortions that are essentially random, or unpredictable, are considered.

Systematic distortions are well understood and easily corrected by applying formulas derived by modeling the sources of the distortions mathematically. For example, a highly systematic source of distortion involved in multi-spectral 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 to the west of the previous sweep. This is known as skew distortion. The process of deskewing the resulting imagery involves offsetting each successive scan line slightly to the west. The skewed-parallelogram appearance of satellite multi-spectral scanner data is a result of this correction.

Random distortions and residual unknown systematic distortions are corrected by analyzing 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 make good control points are highway intersections and distinct shoreline features. In the correction process 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 in terms of UTM coordinates or latitude and longitude). 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. 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,

$$x = f_1 (X,Y)$$
$$y = f_2 (X,Y) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where, (x,y) = distorted image coordinates (column, row)
(X,Y) = correct (map) coordinates
f_1, f_2 = transformation functions

Intuitively, it might seem as though the above 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. 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 Figure 11. This diagram shows the geometrically correct output matrix of cells (solid lines) superimposed over the original, distorted matrix of image pixels (dashed lines). After producing the transformation function, a process called re-sampling 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.

After the transformation the image will have the same geometry as the map. So, if we superimpose the image and the map , all corresponding points are at same position. The transformation will change the geometry of the image, which means that the pixels are moved to new positions in an input driven approach or a new image is formed by means of an output driven resampling. Resampling is the combination of changing pixel positions and assignments of the proper radiometric value to that new position

Input driven resampling is the movement of all pixels in the input to their new position in the output image. The disadvantage of input driven resampling is that some output pixels are multiple assigned and some output pixels are not assigned at all and gaps are created in the output image.

To overcome these disadvantages , output driven resampling technique is applied. In the output driven resampling approach the new image is created by filling it pixel after pixel and line by line. The pixel indices in the output image are transformed to find the position of the corresponding pixel in the input image. The radiometric value of that input pixel will be stored in the output image pixel. After transformation of the pixel position of the output image it will be found that the resulting line and column numbers are often not the whole numbers , but the fractional numbers, which mean that we cannot find the corresponding radiometric value at the computed position.

The next step is to select a suitable technique to find the reflectance values of the new pixels. This technique is known as resampling. As expected , grid centres from map registered pixel grid will not usually project to exact pixel centres . The technique to find the new value from the original image is known as interpolation. There are three interpolation techniques. Nearest neighbour interpolation simply chooses the actual pixel that has its centre nearest the point located in the image. Bilinear interpolation uses weighted average of four surrounding pixels to compute the value. Cubic convolution uses the surrounding sixteen pixels .The interpolations are depicted in figure 11.

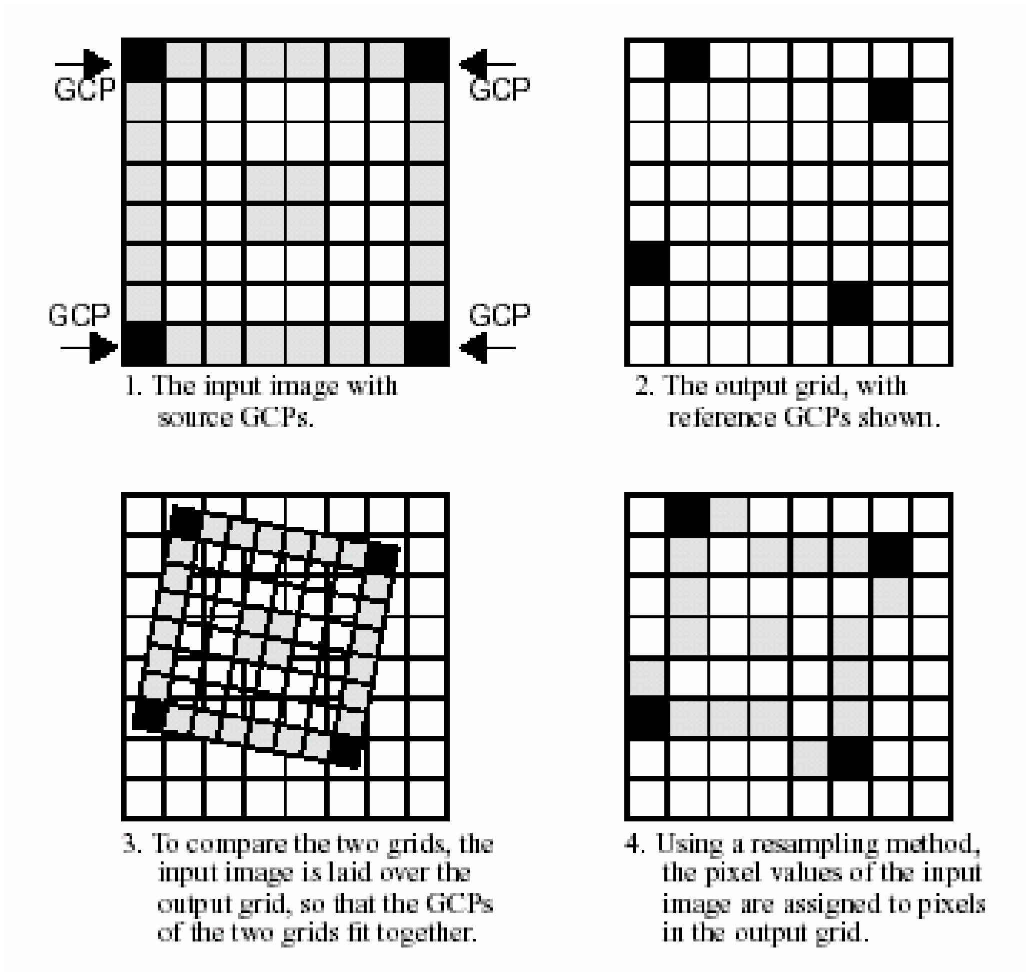
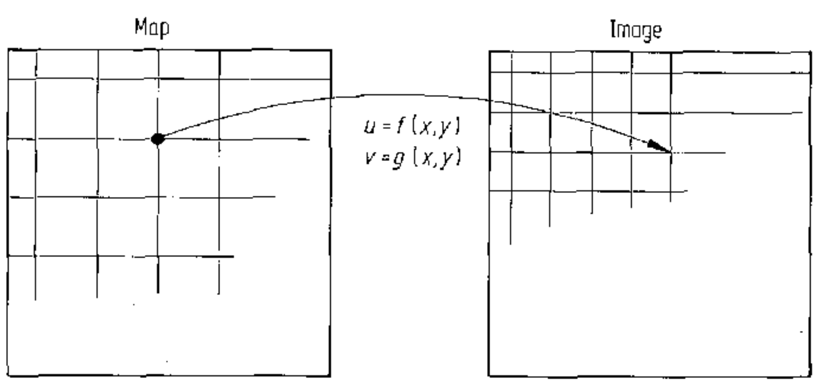


Fig.10 : Matrix of geometrically correct output pixels superimposed on matrix of



Original, distorted input pixels.

Figure 12 : Use of mapping polynomials to locate points in the image corresponding to map positions.

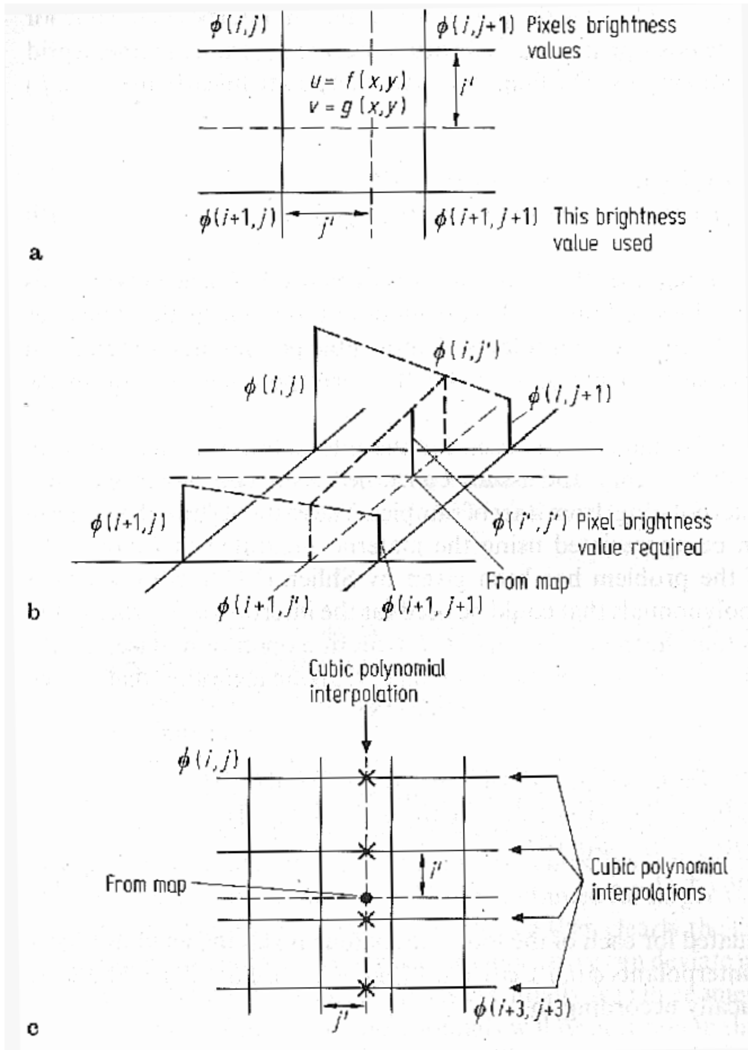


Figure 13 Determining new pixel values - Intensity interpolation a) nearest neighbour b) bilinear interpolation c) Cubic convolution.