7.1.2 Geometric Corrections

It is the process of rectification of geometric errors introduced in the image during the process of acquisition. The aim is to transform the remotely sensed image to have the scale and projection properties of a map. The geometric distortions in the raw digital images arise from earth's rotation; panoramic distortion, further affected by earth curvature; scan skew; variations of platform's height, velocity, attitude (pitch, roll, and yaw); and aspect ratio distortion. The main source of geometric error in satellite data is satellite path orientation (non-polar). The distortions may be systematic distortions—the effects that are constant, can be predicted in advance; or non-systematic—caused due to variations in spacecraft variables, and atmospheric scatter. The systematic distortions (errors) are corrected by using ephemeris of the platform and the precisely known sensor distortion characteristics. The non-systematic distortions are corrected by matching the image coordinates of the physical features recorded in the image with the geographic coordinates of the same feature from a map or using GPS. The geometric correction process consists in first considering the systematic distortions and then the non-systematic ones.

Systematic Distortions The various types of systematic distortions are as follows.

1. *Scan skew:* It is caused by the forward motion of platform during the time required for each mirror sweep. The ground swath is not normal to the ground track but is slightly skewed, producing cross-scan geometric distortion (Fig. 7.6). The scanned lines do not remain exactly perpendicular to the ground track.

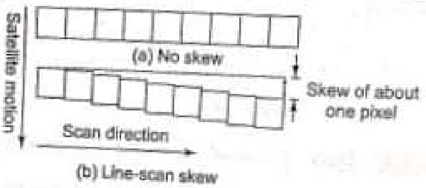


Fig. 7.6 *Scan skew*

2. *Scanner mirror velocity variance:* The mirror scanning rate is usually not constant across a given scan, producing along-scan geometric distortion. An oscillating mirror must stop at the end of each scan and reverse direction.

3. *Panoramic/scanner distortion:* The ground area imaged is proportional to the scan angle rather than to the angle itself (Fig. 7.7). Because data are sampled at regular intervals, this produces along-scan distortions.

4. *Spacecraft/platform velocity:* If the speed of the platform changes, the ground track covered by the successive mirror scan (IFOV) changes, producing along-track distortions in the form of oversampling—when forward platform velocity decreases (higher orbit), or undersampling—when forward platform velocity increases (lower orbit).

Table 7.1 *Geometric errors and their effects*

Error type	*Source*	*Effects*	*Direction*
Non-systematic			
Altitude	Platform	Deviation from nominal altitude of satellite	Along/across scan
Attitude	Platform	Deviation of sensor axis from normal to earth ellipsoid surface	Along/across scan
Systematic			
Scan skew	Platform	Scanned lines are not exactly perpendicular to ground track	Across scan
Space craft velocity	Platform	Change in along track IFOV (Instantaneous Field of View)	Across scan
Earth rotation	Scene	Westward shift of different scan lines of a scene	Along scan
Map projection	Scene	Geometric error in projecting image on 2D map plane	Along/across scan
Terrain relief	Scene	Relative planimetric error between objects imaged at different heights	Along/across scan
Earth curvature	Scene	Change in image pixel size than actual one	Along/across scan
Optical	Sensor	Barrel and pincushion distortions in image pixels	Along/across scan
Aspect ratio	Sensor	Image pixel size different in horizontal and vertical directions	Along/across scan
Mirror velocity	Sensor	Compression or stretching of image pixels at various points along scan line	Along scan
Detector geometry and scanning sequence	Sensor	Misalignment of different band scan lines of multispectral sensors	Along/across scan
Perspective projection	Scene and sensor	Enlargement and compression of image scene close and far off to nadir point respectively	Along scan
Panoramic	Scene and sensor	Introduces along scan distortions	Along scan

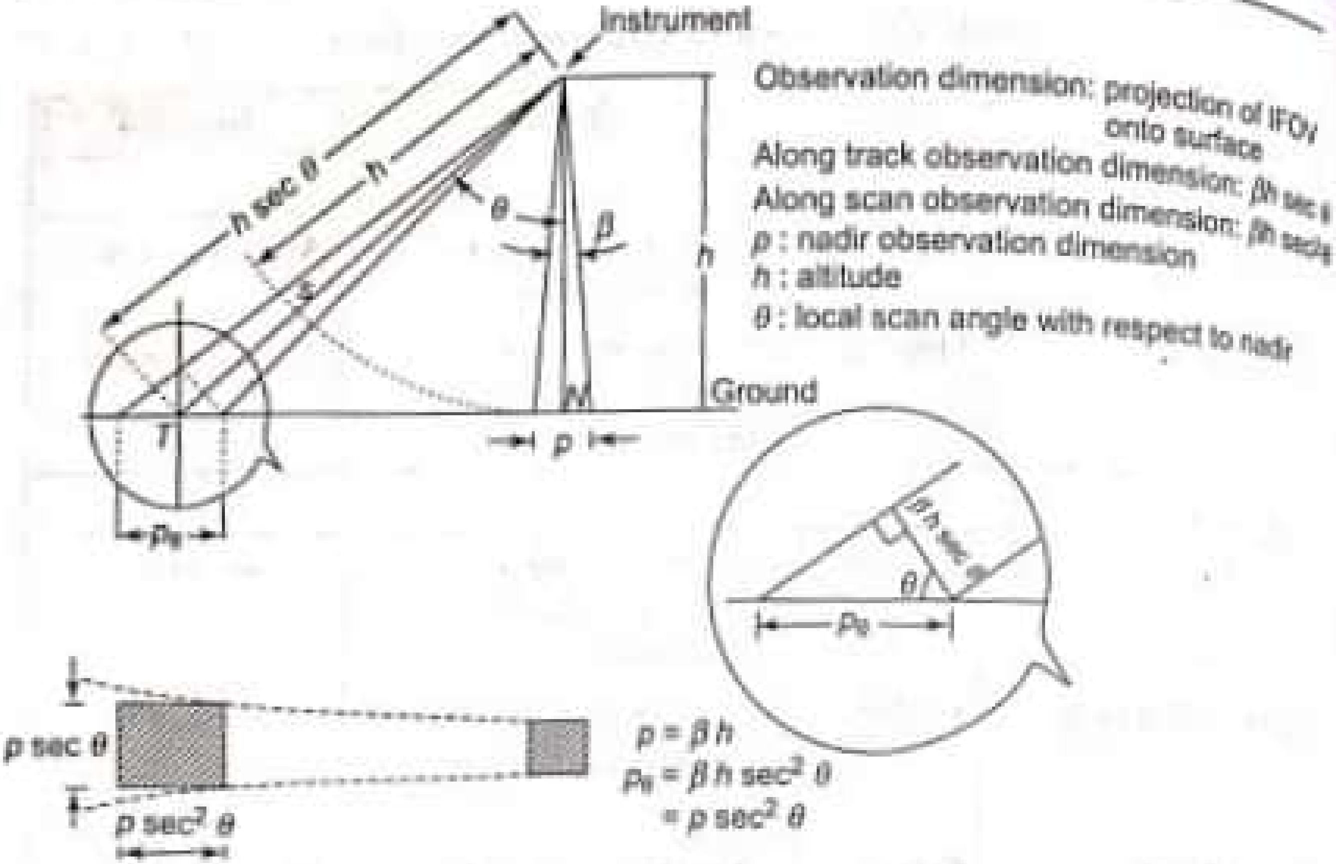
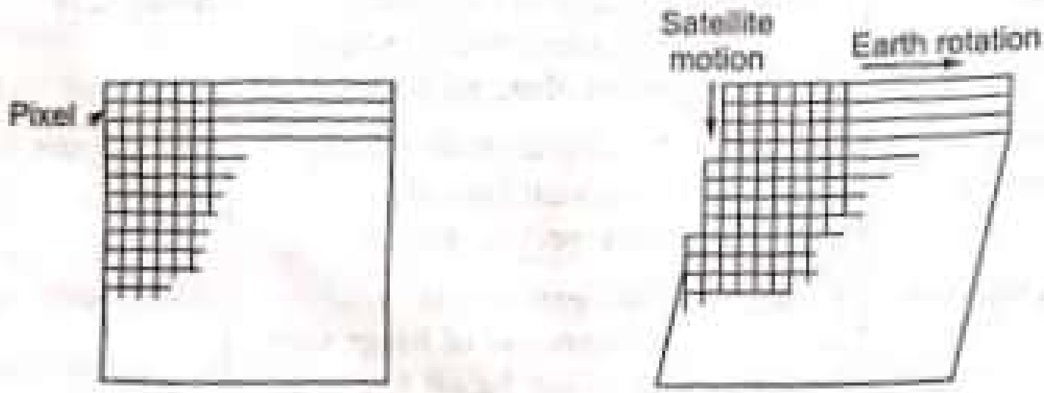


Fig. 7.7 *Panoramic distortion*

5. *Earth's rotation:* The earth rotates as the sensor scans the terrain. This results in a shift of the ground swath being scanned, causing along-scan distortion. Since between the time of first scan and the time of last scan, the earth rotates eastwards significantly relative to the resolution element, each optical sweep of the scanner covers an area slightly to the west of previous sweep. The amount of earth rotation during this period results in image distortion known as *skew distortion*. This distortion can be corrected by scanning successive groups of lines offset towards the west, in proportion to the amount of movement of the ground during image acquisition. This results in the parallelogram outline of the restored image (Fig. 7.8(b)).

The systematic distortions are well understood and can be easily corrected by applying formulae derived by mathematically modelling the sources of distortions.



(a) Image: line arranged on a square grid

(b) Offset of successive lines to the west to correct for the rotation of Earth's surface during the frame acquisition time

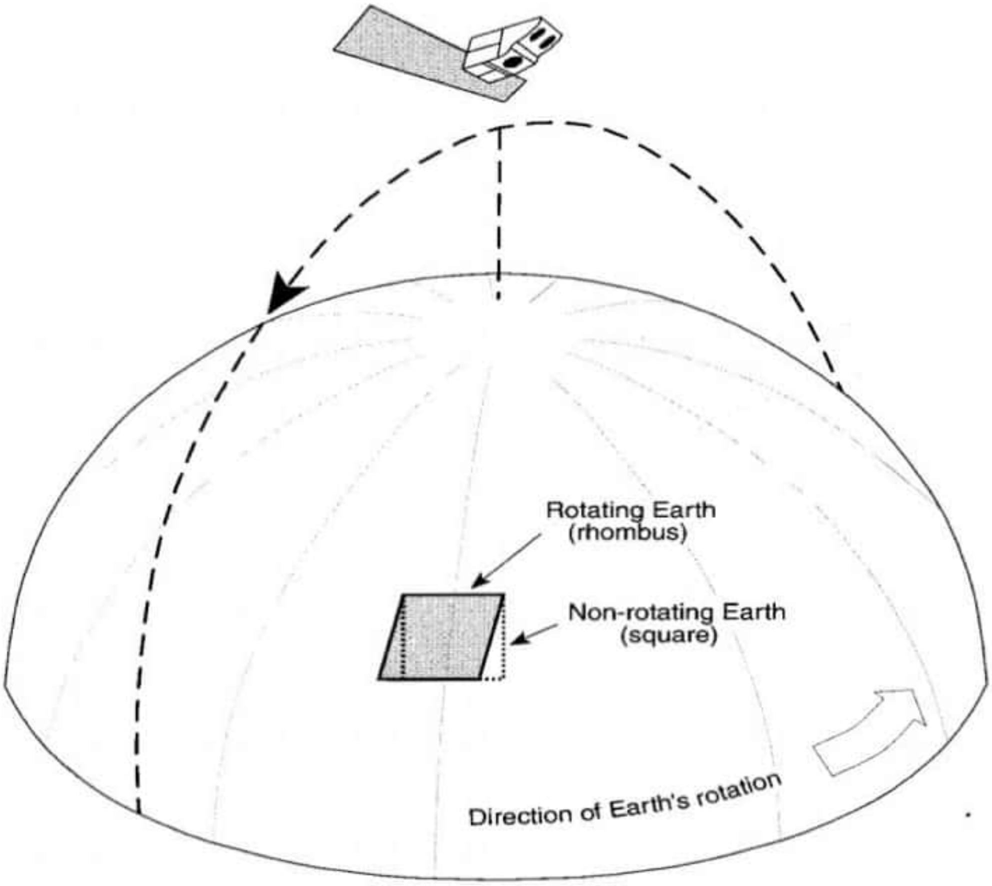


Figure 1: Figure showing distortion due to earth's rotation

Non-symmetric Distortions The non-systematic geometric distortions occur because of followings. Platform motion affects the images with changes in altitude and attitude.

1. *Altitude variance:* If the sensor platform departs from the normal altitude or terrain increases in elevation, change in scale or pixel size occurs. With a change in altitude, the platform motion results in variations in scale (Fig. 7.9).

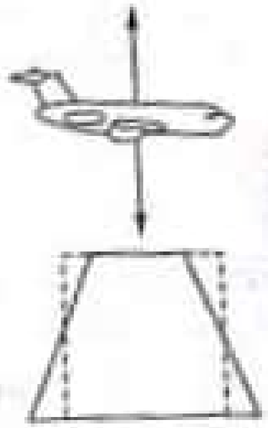


Fig. 7.9 *Distortions due to altitude variance*

2. *Platform attitude:* One sensor system axis is usually maintained normal to earth ellipsoid surface and other parallel to the spacecraft direction of travel. If the sensor departs from this attitude, the result is geometric distortion. Attitude change implies the change in platform orientation that is significant over the time required to scale a full scene. This is termed as *skew motion*—motion of aircraft/satellite perpendicular to the intended direction of motion. It may be yaw, pitch, or roll as shown in Fig. 7.10. The effect of attitude variations are shown in Fig. 7.11. *Pitch* is the vertical rotation of a sensor platform, in the direction of motion (noise-up plane), resulting in changes in the spacing of scan lines. *Roll* is the rotation of sensor platform around the velocity vector, and scale changes in the line direction resulting in lateral shift in scan line positions. *Yaw* is the rotation of a senor platform in the horizontal plane, or about its vertical axis, hence in a nose-right direction. It causes rotation and skew distortion. Changes in yaw result in scan lines that are not parallel.

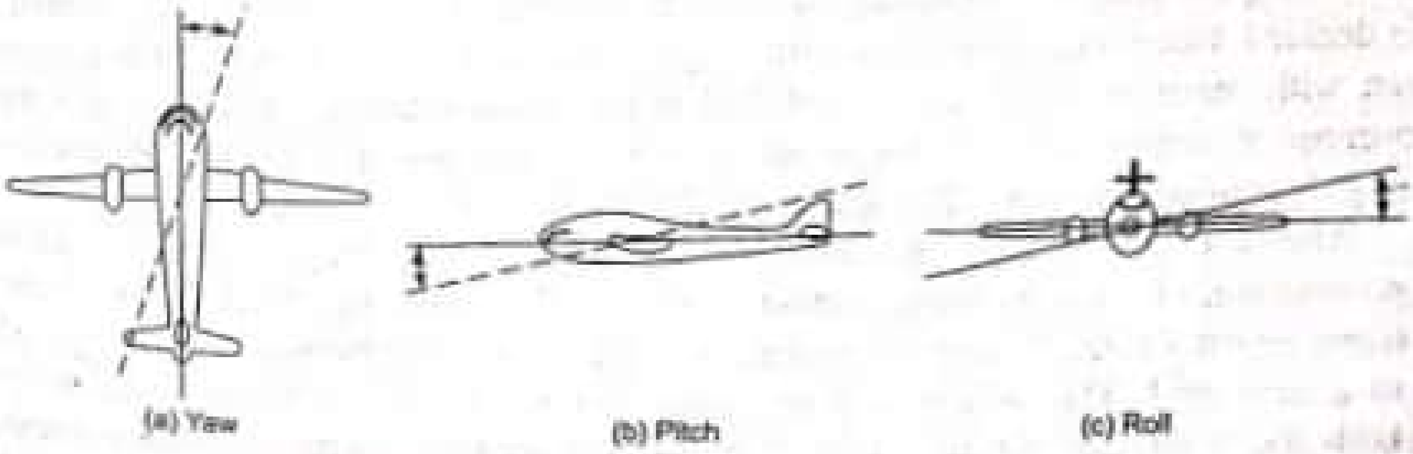


Fig. 7.10 *Platform attitude change (skew motion)*

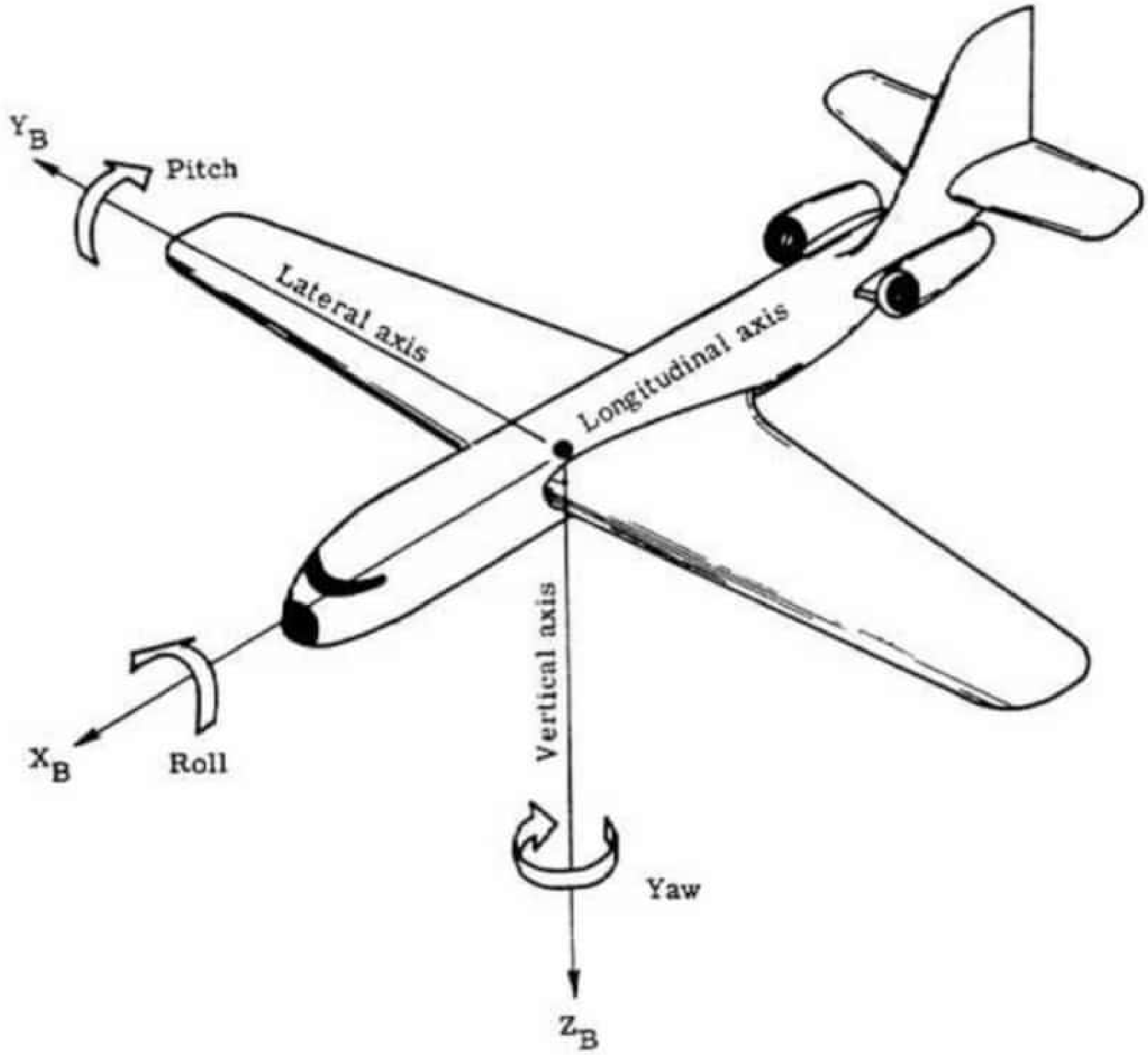


Figure 3: Attitude Distortions of an aircraft

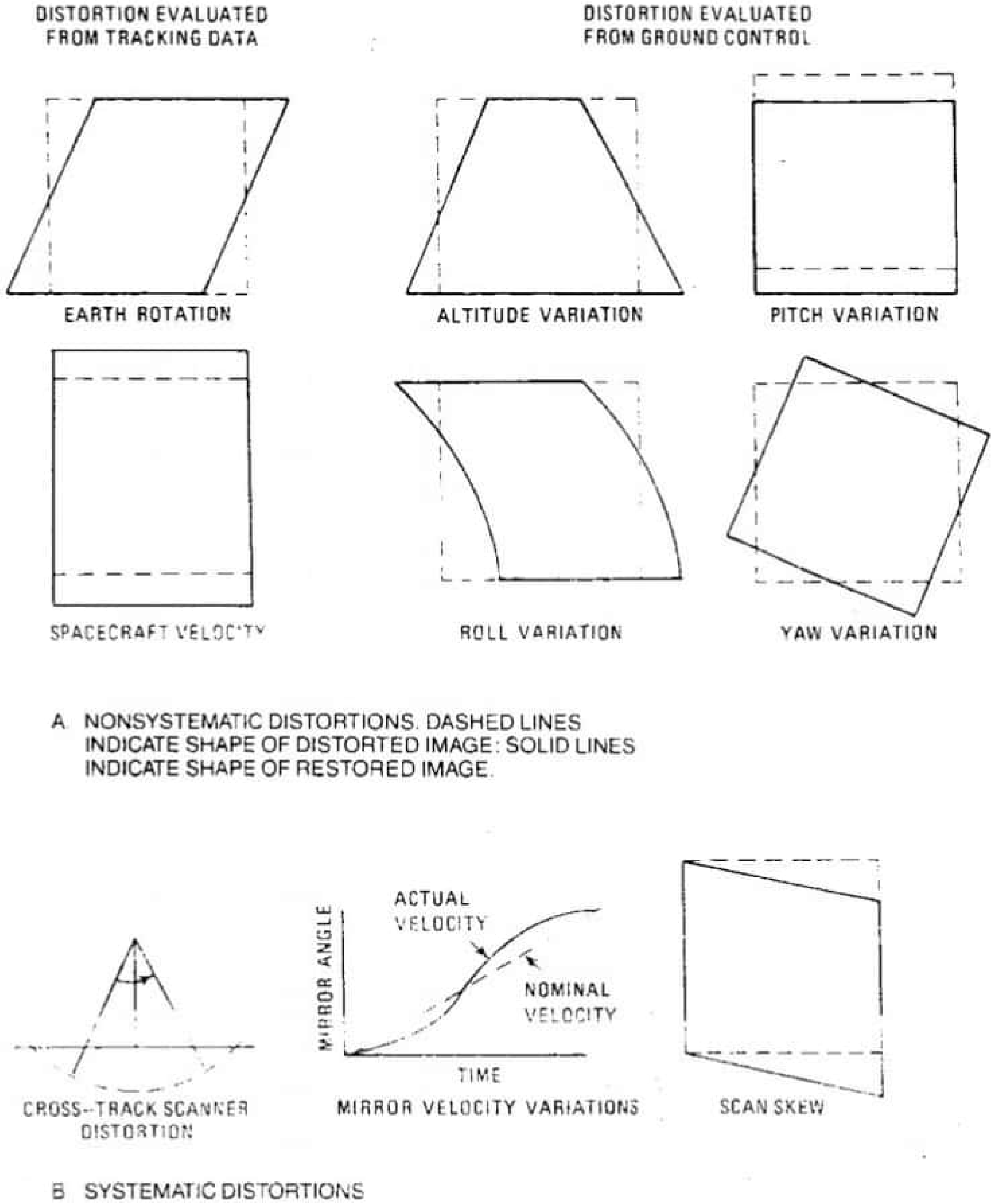


Figure 2: Schematic representation of the systematic and non systematic distortions

Correction The non-systematic variations can be evaluated from tracking data, or from ground control. Also known as *random distortions*, these can be corrected by analysing well-distributed ground control points (GCPs) occurring in an image. Following are the two methods for correcting non-systematic distortions evaluated from ground control. The basic concept underlying is the transformation of satellite images into a standard map projection so that image features can be accurately located on earth's surface. Furthermore, the corrected image can be compared directly with other sources of geographic information, such as maps, etc.

Georeferencing The geographical features on the digital image, called *ground control points* (GCPs), whose positions are known, are identified. These points of known ground locations can be accurately located on digital image. Examples of GCPs are the intersection of streams, highways, runways, airports, etc. The latitudes and longitudes of GCPs are determined from base maps, if available; else GPS may be used for this purpose. It may be noted that the accuracy of fixation of GCPs has a direct bearing over the extent of rectification affected. GCPs should be reliably matched between source and reference, and should be widely dispersed throughout the source image.

The location of the output pixels are derived from the GCPs. Then these are used to establish the geometry of the output image and its relationship to the input image. The difference between the actual GCPs locations and their respective positions in the image are the required geometric transformations to restore the image.

Coordinate Transformation In this method the input pixels are rearranged on a new grid. The image correction is carried out using polynomial equations converting the source coordinates to rectified coordinates; the order of polynomials is decided depending upon the extent of geometric distortion. Usually, it is carried out with the help of 1st order and 2nd order transformations. For accuracy the number of control points must be more than the number of unknown parameters in polynomial equations. The accuracy should be within ±1 pixel.

After carrying out the coordinate transformation of the image, a process called *resampling*, or *intensity interpolation* is used to determine the pixel values of the transformed image. Image resampling involves the reformation of an image on to a new grid. This is achieved by using features (GCPs) that are common to both the image and the new grid. Suppose that an image with pixel coordinates (x, y) undergoes geometric distortion. The process consists in first defining a geometrically correct geographical grid in terms of latitude and longitude. With computer the latitude and longitude values of each cell of the grid is transformed into x and y coordinates, which becomes the new address of an image pixel. The computer program scans this new address in the image and transfers the appropriate DN based on nearby DN values in original image to this address. The process is repeated until the geographical grid is full at which point the image has been geometrically corrected (Fig. 7.12).

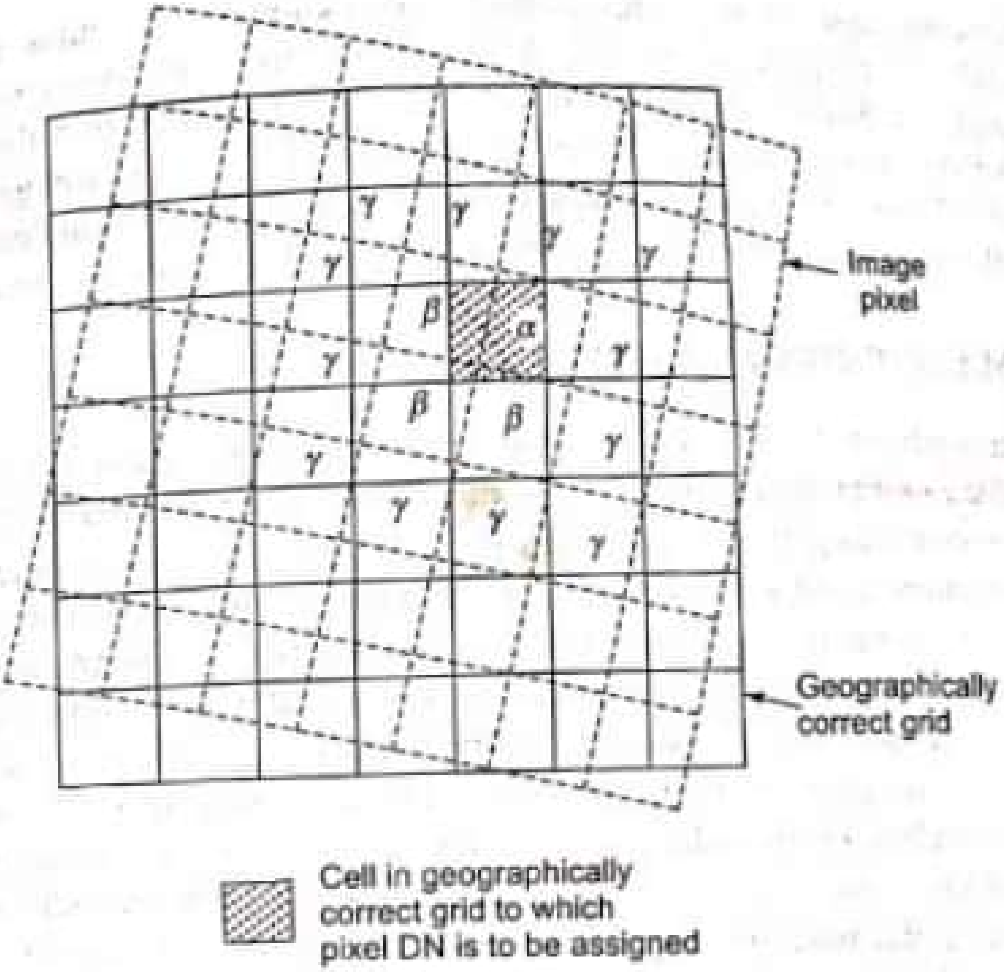


Fig. 7.12 *Resampling procedure*

There are generally three types of resampling methods, viz., the nearest neighbour method, the bilinear interpolation method and the cubic convolution method, to assign the appropriate digital number to an output cell or pixel. These methods are described as follows.

1. *Nearest neighbour method:* The method is also known as zero-order interpolation method. It consists in assigning each corrected pixel, the value of the nearest uncorrected pixel. The method is simple in application and has the advantage of preserving the original values in the altered scene. However it may introduce noticeable errors, especially in linear features, where the realignment of pixels is obvious. Some of the other disadvantages of the method are blocky picture appearance and spatial shifts. The effects although are negligible for most visual applications, but may be important for subsequent numerical analysis.

2. *Bilinear interpolation method:* In this method, the calculation of each output pixel value is based on a weighted average of values within a neighbourhood of (2 × 2) four adjacent input pixels. This process is simply the two dimensional equivalent to linear (first-order) interpolation. Since each output value is based on several input values, the output image is much smoother than nearest neighbour method. However, some changes such as loss of brightness values in the input image, a reduction in the spatial resolution of the image, and blurring of sharp boundaries in the picture do occur when bilinear interpolation creates a new pixel value.

3. *Cubic convolution method:* This method is also known as bi-cubic convolution or second-order interpolation method. It is supposed to be the most sophisticated and complex method of resampling. It uses a weighted average of values within a neighbourhood of (4 × 4) 16 adjacent input pixels. Though, the images produced are noticeably sharper than the previous two methods, but get drastically altered. This method, however, introduces some loss of high frequency information.