Modern Surveying Techniques

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Lecture - 12

Rectification & Restoration

In my previous session, I had discussed regarding the first process in the digital image processing. That was statistical examination of the remote sensing data. Having performed this, the next step in digital image processing is rectification and restoration.

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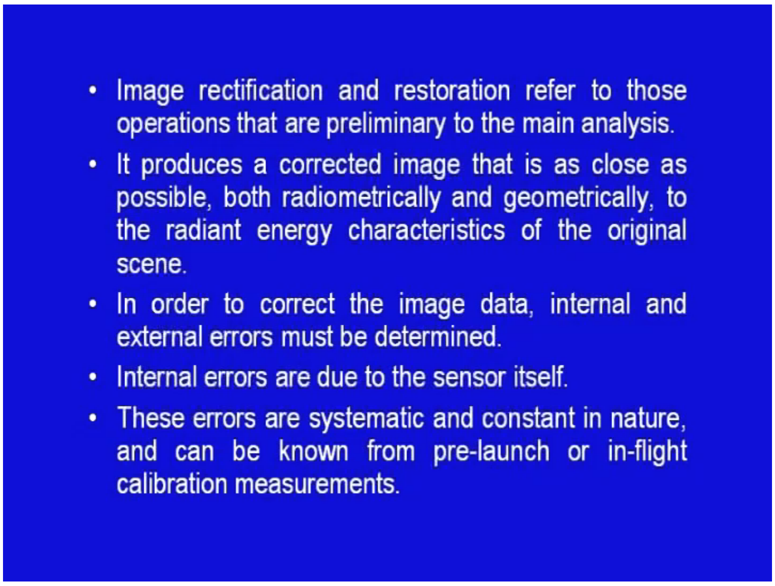

Image rectification and restoration refers to those operations which are preliminary to the main analysis. It produces a corrected image that is as close as possible; both radiometrically and geometrically to the radiant energy characteristics of the original scene. In order to correct the image data, internal and external errors must be determined. The internal errors are due to the sensor itself. These errors are systematic in nature and constant in nature and thus can be known from pre-launch or in-flight calibration measurements.

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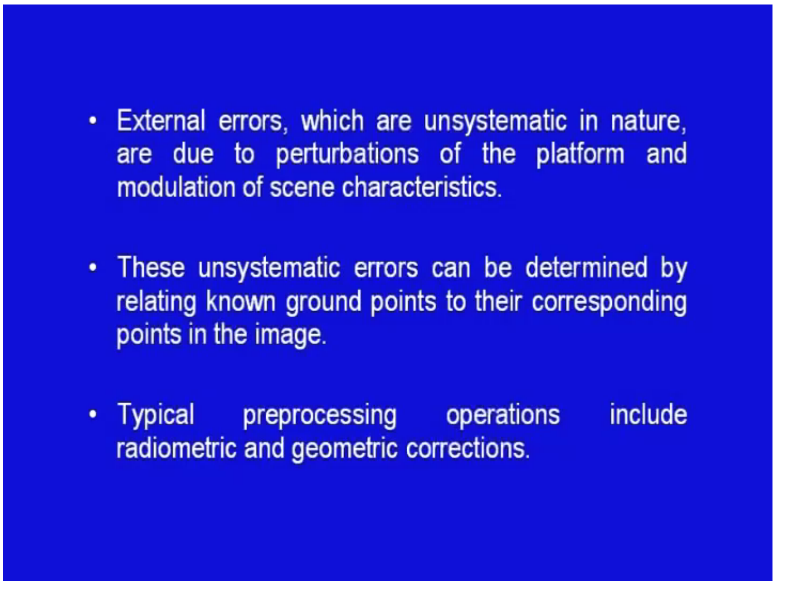

External errors which are unsystematic in nature are due to perturbations of the platform and modulation of scene characteristics. These unsystematic errors can be determined by relating known ground points to their corresponding points in the image. Typical preprocessing operations include radiometric and geometric corrections.

First of all, let us to look at some of the radiometric correction which have to be done. First is atmospheric correction.

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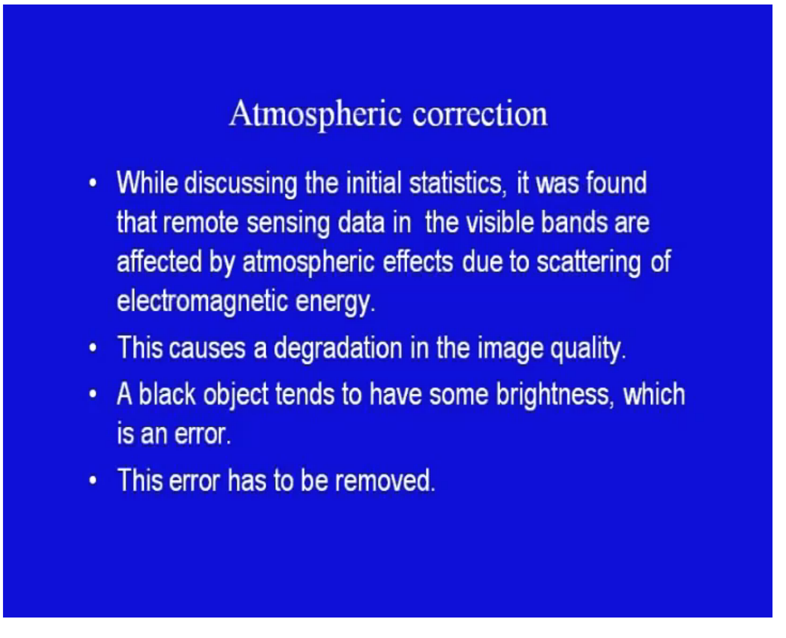

While discussing the initial statistics, it was found that remote sensing data in the visible bands are affected by atmospheric effects due to scattering of the electromagnetic energy. This causes degradation in the image quality. A black object tends to have some brightness which is an error. Now, this error has to be removed. So, let us look at how this can be performed.

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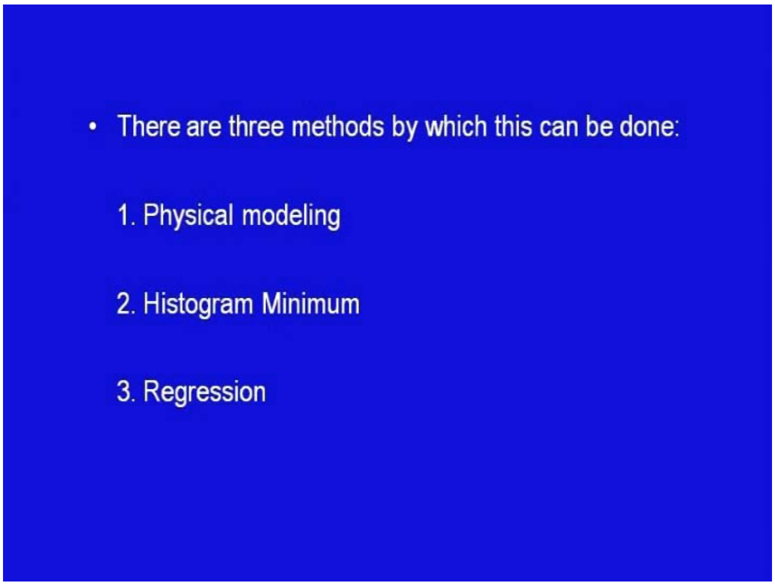

Basically, there are 3 methods by which this can be done. First is physical modelling, second is histogram minimum and third is regression.

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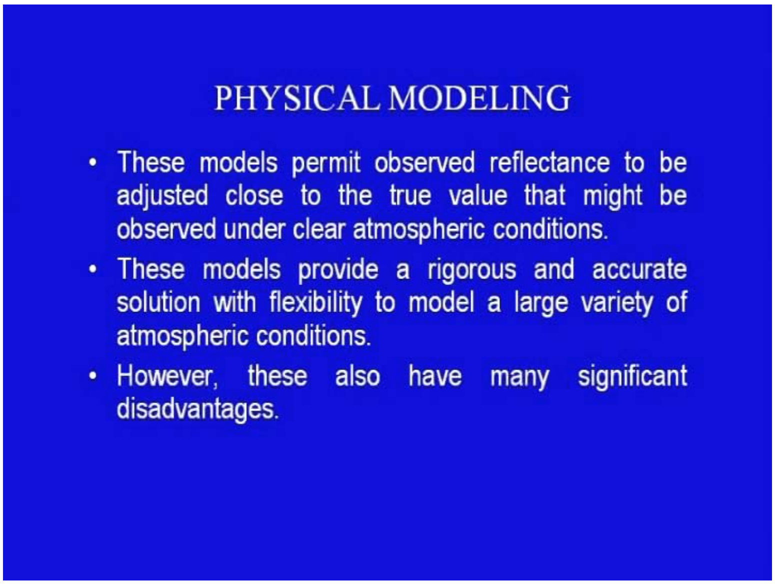

So, let us check physical modelling. Well, these models permit reflectance to be adjusted close to the true value that might be observed under clear atmospheric conditions. These models provide a rigorous and accurate solution with flexibility to model a large variety of atmospheric conditions.

However, there are many significant disadvantages. One of them is the quantum of data which is required in order to run these physical models which means that many of the parameters have to be acquired and stored as the sensor acquires the image data.

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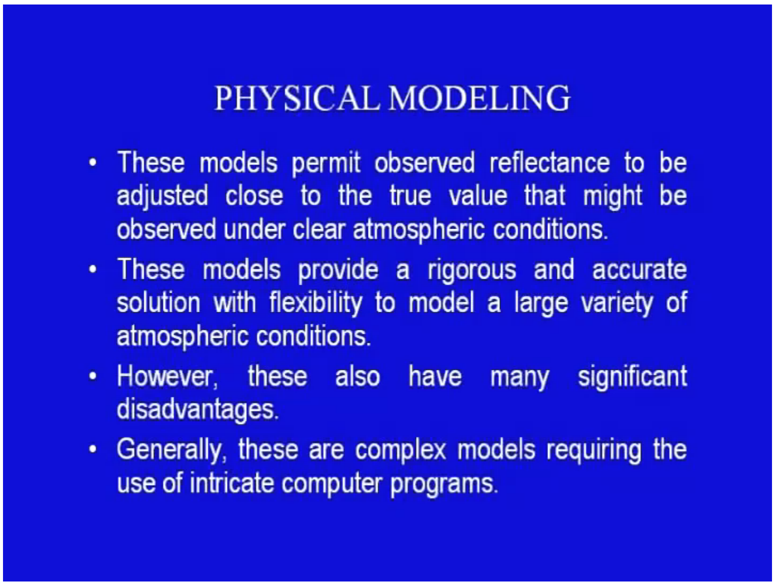

Further, these this physical modelling requires complex models requiring the use of integrate computer programs. By and large, this activity or approach is adopted by those who are interested in studying these bases of the atmospheric conditions and their relation to the reflectance characteristic.

However, a general user may not be interested in this particular method. The next method is histogram minimum method, in short known as HMM.

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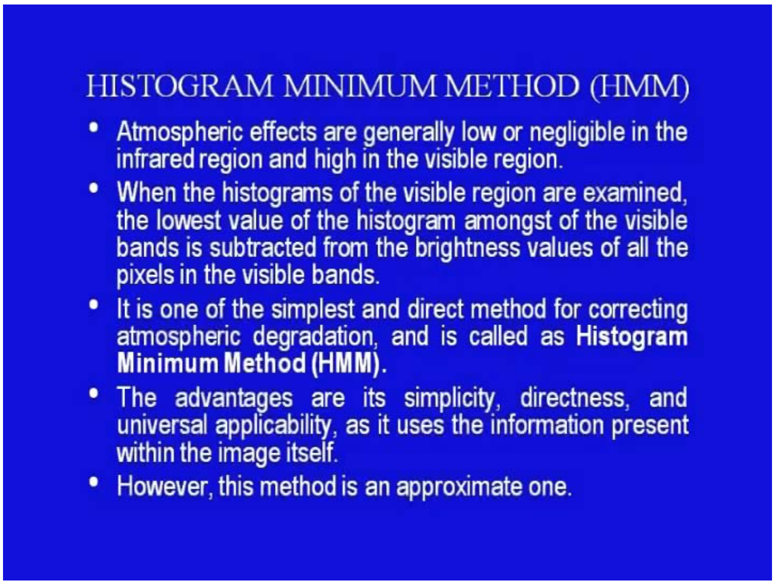

As we have already seen; atmospheric effects are generally low or negligible in the infrared region and high in the visible region. When the histograms of the visible region are examined, the lowest value of the histogram amongst the visible bands is subtracted from the brightness values of all the pixels in the visible bands.

It is one of the simplest and direct methods for correcting atmospheric degradation. The advantage of this method is its simplicity, directness and universal applicability as it uses the information present within the image itself. However, this method is an approximate one.

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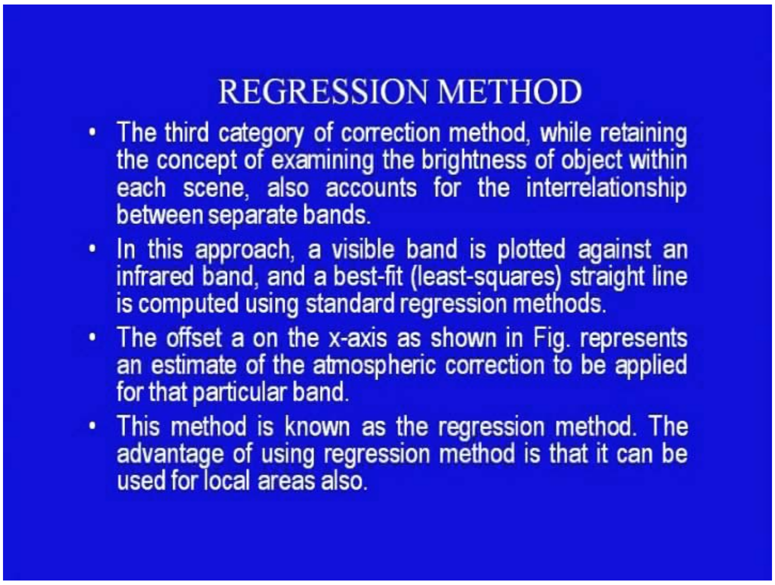

The third method which is regression method of correcting the atmospheric effects, tries to retain the concept of examining the brightness of each object within each scene and also accounts for the interrelationship between the bands. In this approach, a visible band is plotted against an infrared band and a best-fit that is least-square straight line is computed using standard regression methods.

The offset a on the x-axis as shown in the figure, represents an estimate of the atmospheric correction to be applied for that particular band. The advantage of using regression method is that it can be used for local areas also.

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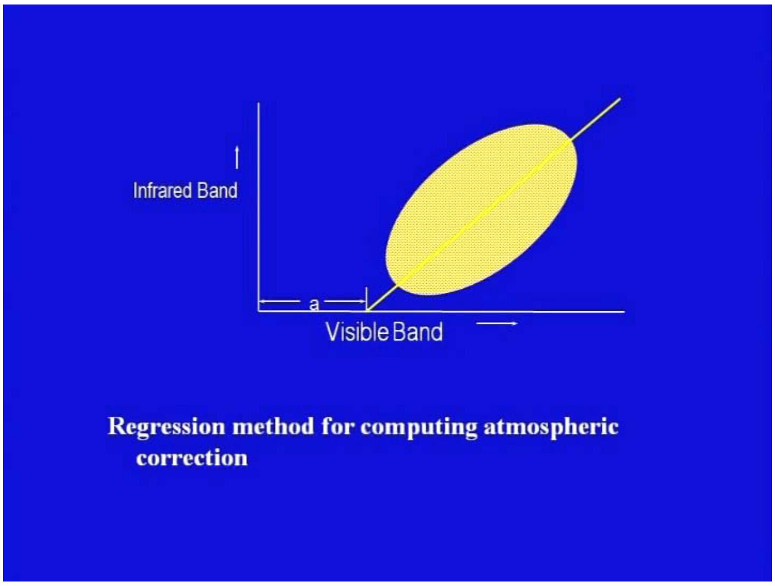

This particular slide shows the physical and the logical concept behind the regressions method.

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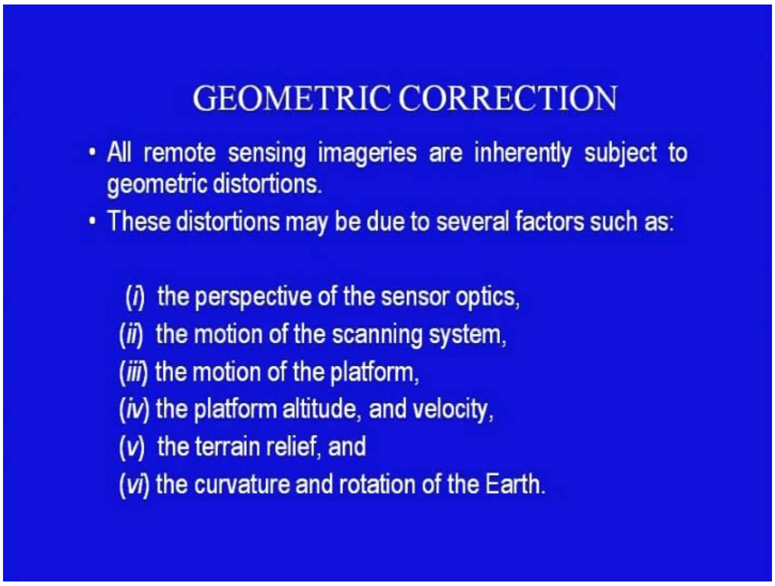

Having done the radiometry correction, now the geometric corrections have to be performed. It has been observed that all remote sensing imageries are inherently subjected to geometric distortions. Such distortions may be due to several factors such as the perspective of the sensor optics, the motion of the scanning system, the motion of the platform, the platform altitude and velocity, the terrain relief and the curvature and rotation of the earth.

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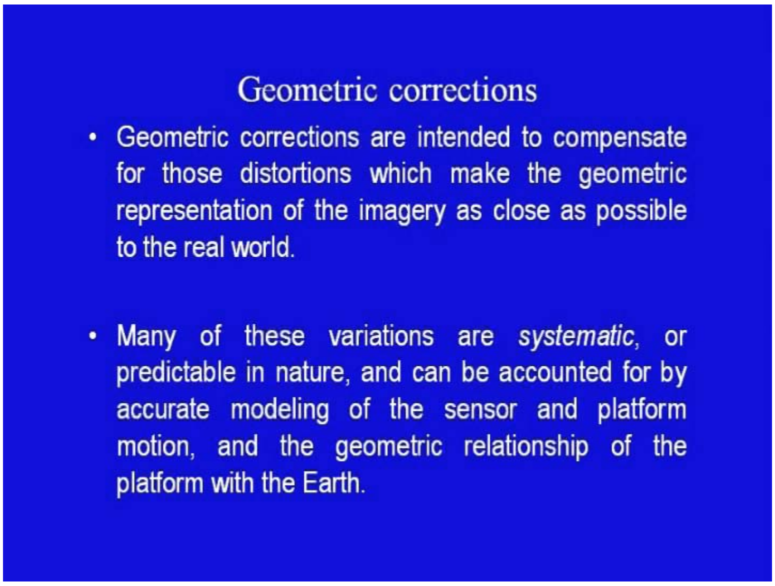

Geometric corrections are intended to compensate for those distortions which make the geometric representation of the imagery as close as possible to the real world. Many of these variations are systematic or predictable in nature and can be accounted by accurate modelling of the sensor and platform motion and the geometric relationship of the platform with the earth.

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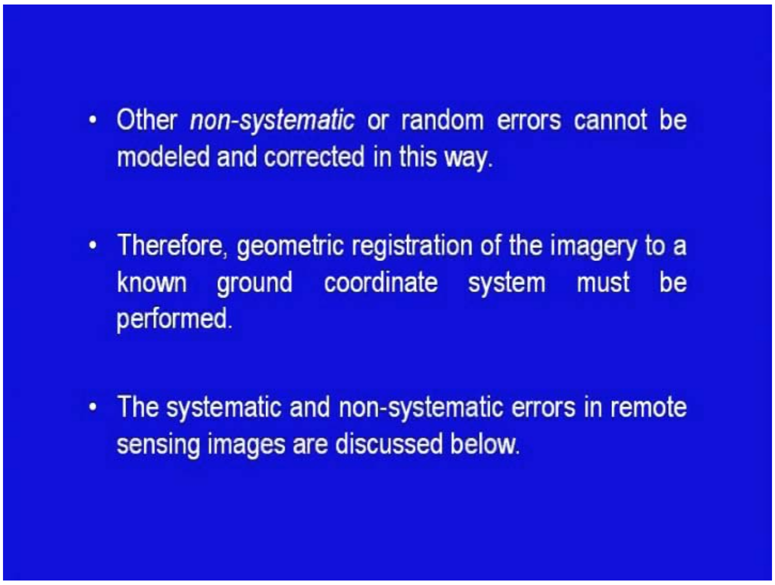

Other non-systematic or random errors cannot be modelled and corrected in this manner. Therefore, geometric registration of the image to a known ground coordinate system must be performed. Now, let us look at these systematic and non-systematic errors in the remote sensing images and these are discussed.

First is the systematic error.

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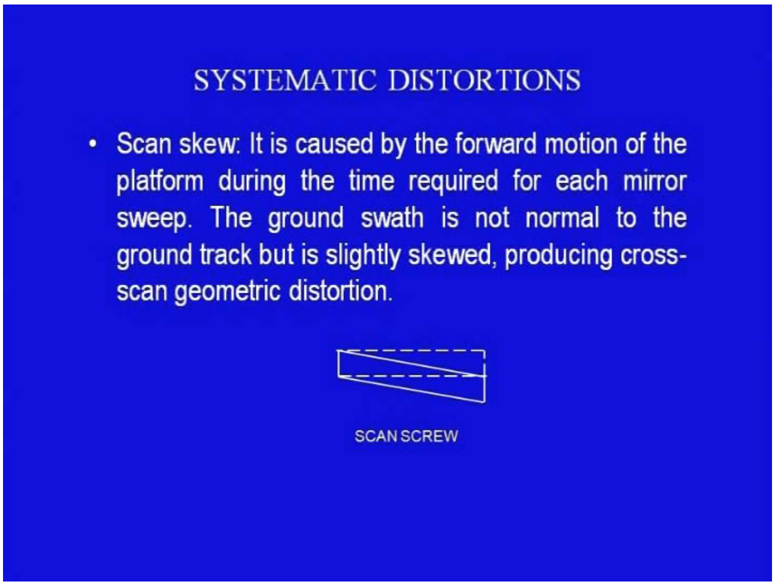

In systematic errors; first, let us look at scan skew. It is caused by the forward motion of the platform during the time required for each mirror sweep. The ground swath is not normal to the ground track but is slightly skewed producing cross scan geometric distortion. The figure below conceptualises the scan skew distortion.

Next is mirror scan velocity.

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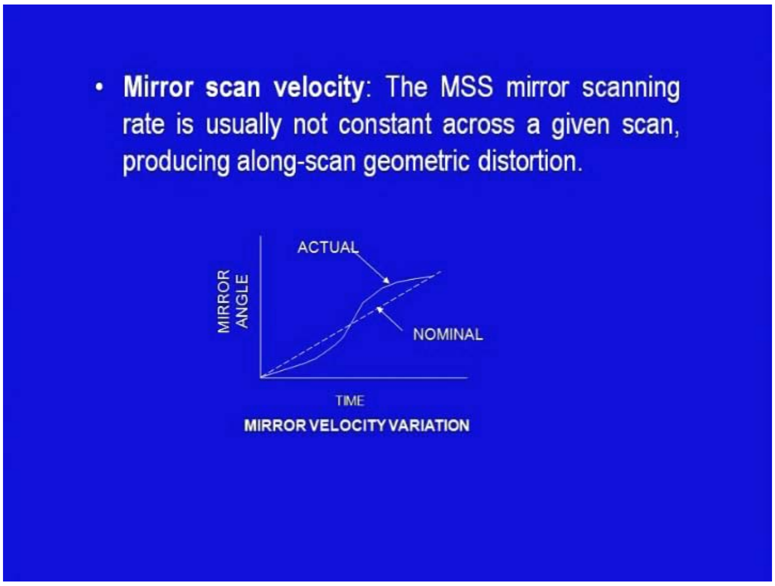

The mirror scanning rate is usually not constant across given scan and produces along-scan geometric distortion. The figure below shows the actual path of the mirror with mirror angle against the calibrated motion path. It may be noted that this type of error probably is no more applicable in the current sensor technology which is being used which is charge couple devices. The earlier mss sensors which carried a mirror type of scanning procedure, this type of error were had to be accounted for.

Next is panoramic distortion.

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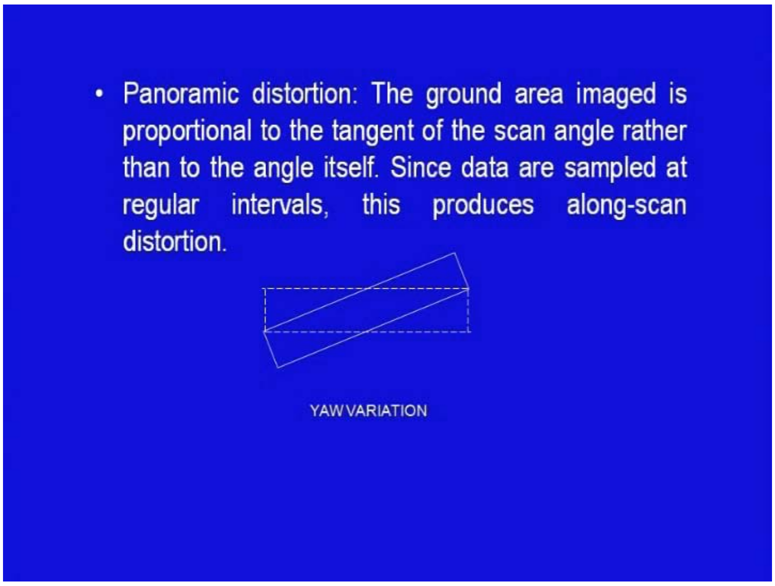

The ground area that is being imaged is proportional to the tangent of the scan angle rather than the angle itself. Since, the data are sampled at regular intervals; this produces along-scan distortion. This is conceptualized in the figure shown below and the solid line shows the actual manner in which data has been collected; whereas, the doted one shows the theoretical shape of the image that should have been there.

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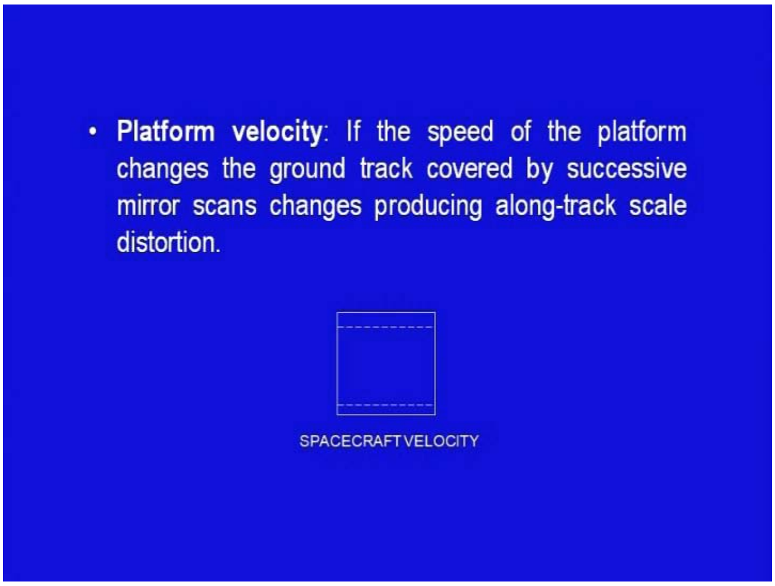

Next is platform velocity. If the speed of the platform changes, the ground tracks coverage by successive mirror scan changes producing a long track scale distortion.

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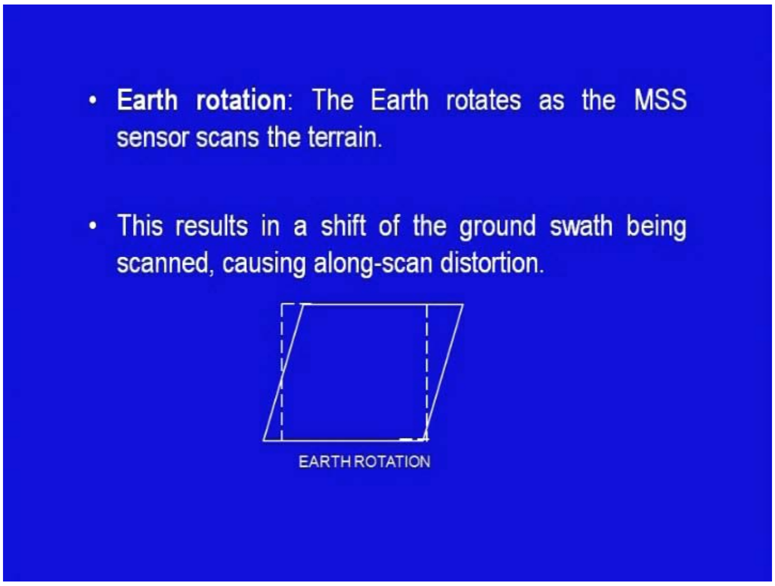

Next is earth rotation. The earth rotates as the sensor scans the ground. This results in a shift of the ground swath being scanned causing along-scan distortion.

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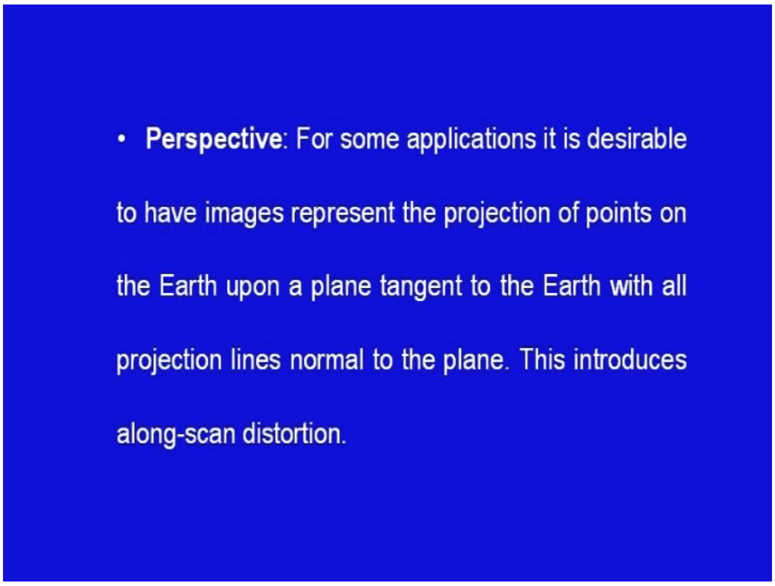

Perspective: for some applications, it is desirable to have images represent the projection of points on the earth upon a plane tangent to the earth with all projection lines normal to the plane. This introduces along-scan distortion.

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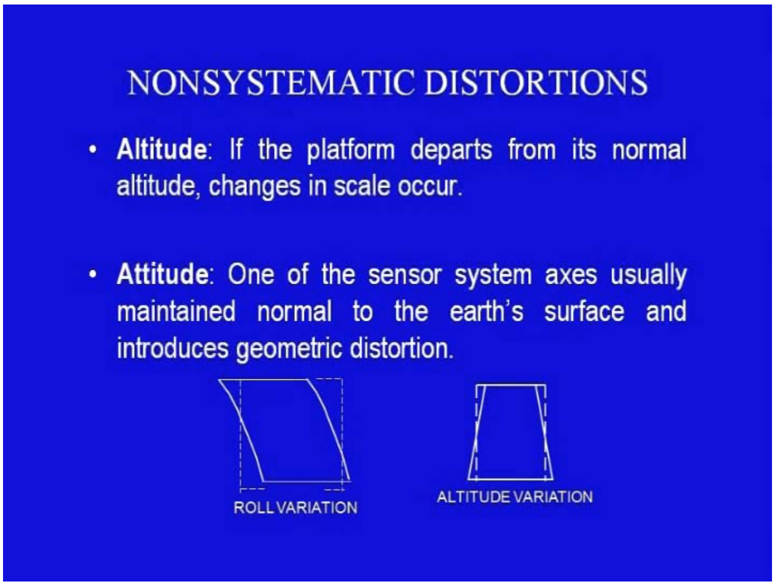

Now, we come to the non systematic distortions which are there. First is altitude. If the platform departs from its normal altitude; it changes, a changes in scale occurs. Next is attitude. One of the sensor systems is usually maintained normally to the earth's surface and introduces geometric distortion.

Having had a look at the systematic and non systematic errors which could into play due to various factors as discussed earlier; now, let us look at procedure by which these can be removed from the digital images or remote sensing datasets. This is what we this process is what we call it as geometric rectification.

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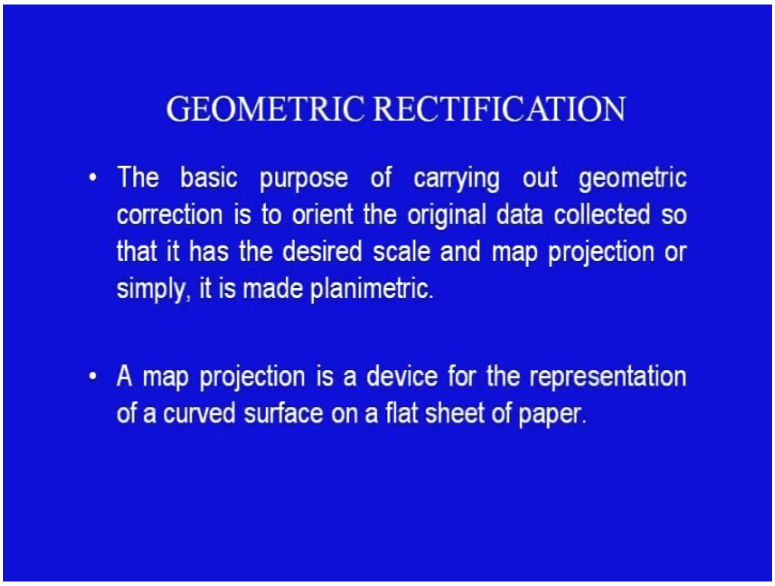

The basic purpose of carrying out geometric correction is to orient the original data collected so that it has the desired scale and map projection or simply we can say; it is made planimetric. A map projection is a device for the representation of a curved surface on a flat sheet of paper.

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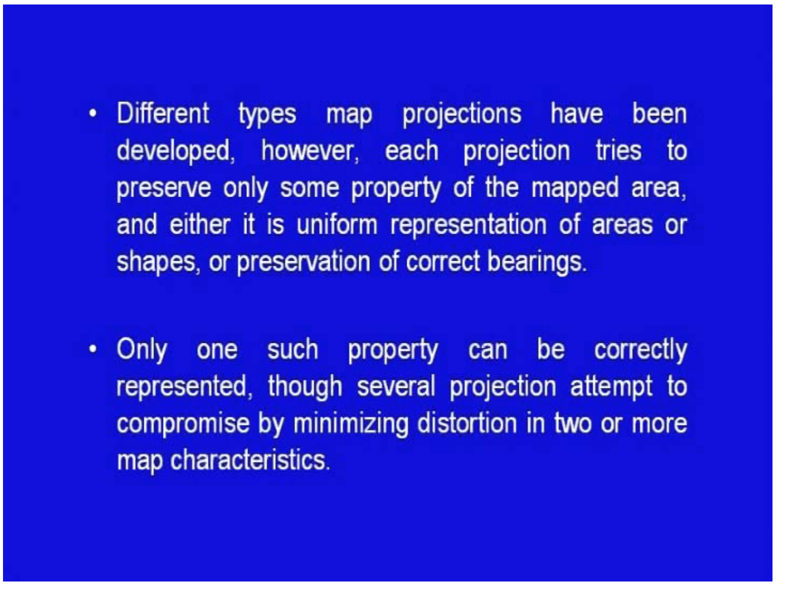

Different types of map projections have been developed. However, each projection tries to preserve only some property of the mapped area and either it is uniform representation of area or shape or preservation of correct bearings. Only one such property can be correctly represented though several projection attempt to compromise by minimizing distortion in 2 or more map characteristics.

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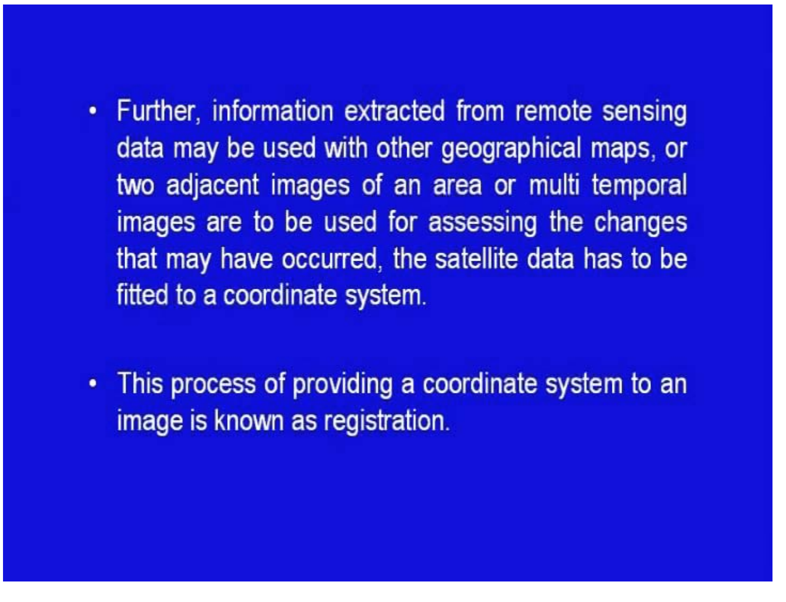

Further, information extracted from remote sensing data may be used with other geographical maps or 2 adjacent images of an area or multi temporal images are to be used for assessing the changes that may have occurred. The satellite data has to be fitted to a coordinate system. This process of providing a coordinate system to an image is known as registration.

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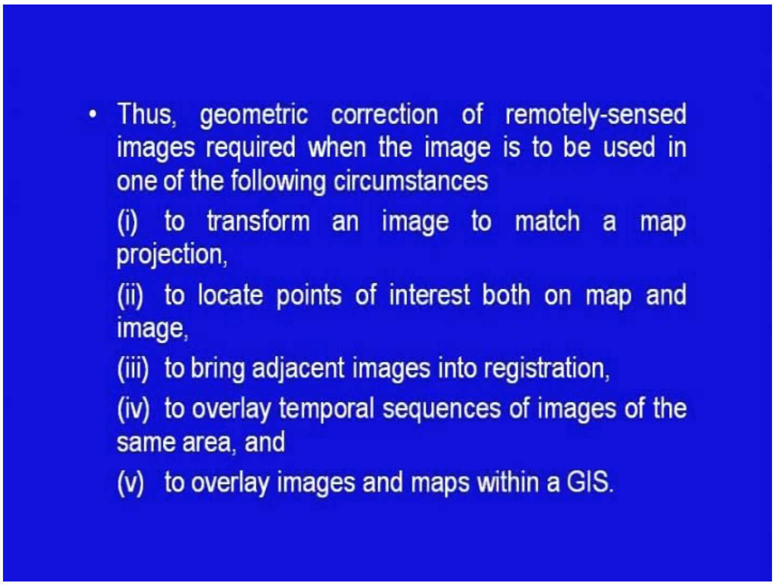

Thus, geometric correction of remotely-sensed images is required when the image is to be used in one of the following circumstances: to transform an image to map a map projection, to locate points of interest both on the map and on the image, to bring adjacent images into registration, to overlay temporal sequences of images of the same area and to overlay images and maps within a GIS.

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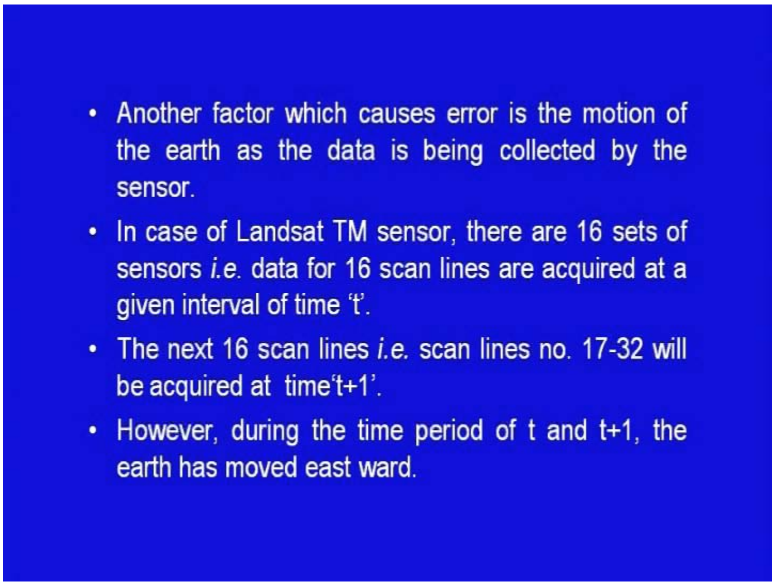

Another factor which causes error is the motion of the earth as the data is being collected by the sensors. In case of LANDSAT TM sensor, there are 16 sensors. That is data for 16 scan lines are acquired at a given interval of time t. The next 16 scan lines, that is scan lines number – 17 - 32 will be acquired at time t plus 1. However, during the time period, t and t plus 1; the earth has moved east wards.

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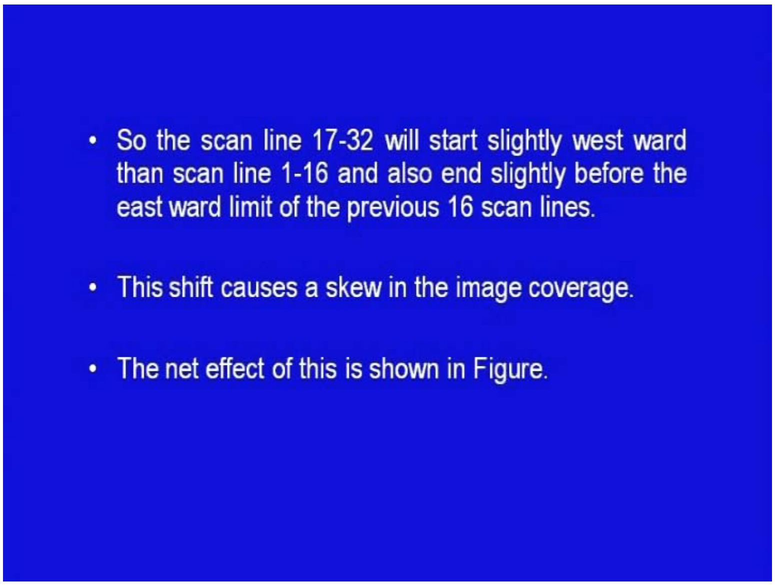

So, the scan line 17 - 32 will start slightly westward than the scan line 1-16 and also ends slightly before the eastward limit of the previous 16 scan lines. This causes a skew in the image coverage. The net effect of this is shown in this particular figure.

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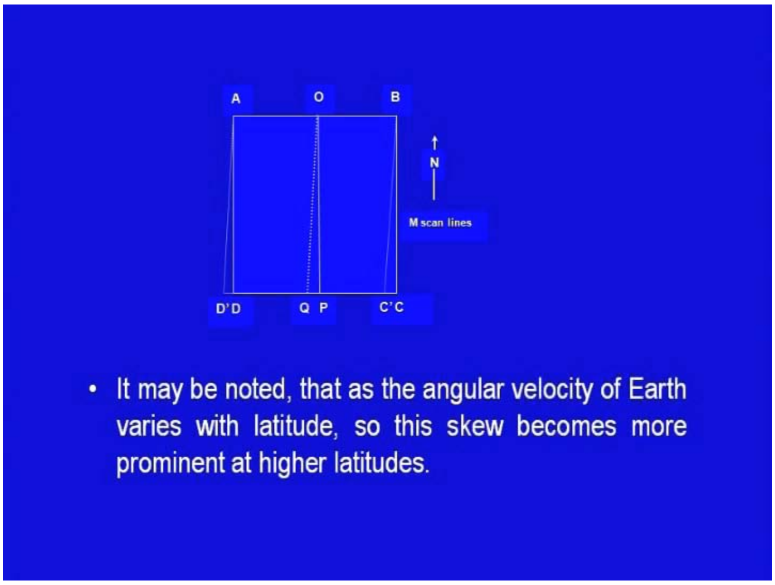

It may be noted that as the angular velocity of earth varies with latitude, so this skew becomes more prominent at higher altitudes.

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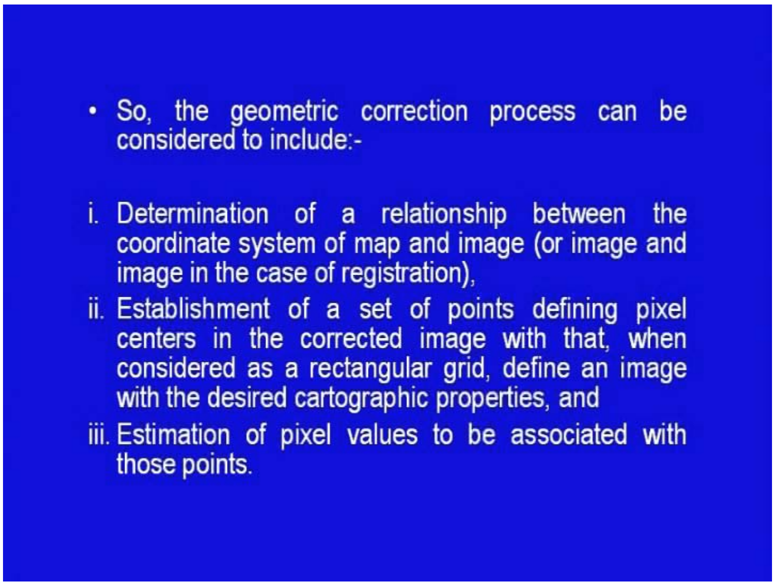

So, the geometric corrections process can be considered to include; 1. Determination of a relationship between the coordinate system of a map and image or image and image in the case of registration, establishment of a set of points defining pixel centers in the corrected image with that when considered as a rectangular grid and define an image with the desired cartographic properties and estimation of pixel values to be associated with those points.

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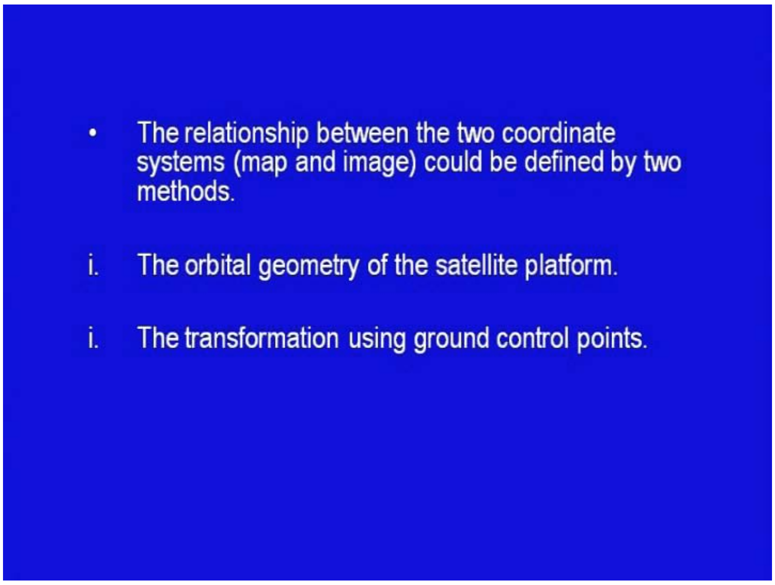

The relationship between the 2 coordinate systems - map and image, could be defined by 2 methods. First, the orbital geometry of the satellite platform and the second is the transformation using ground control points or in short known as GCPs.

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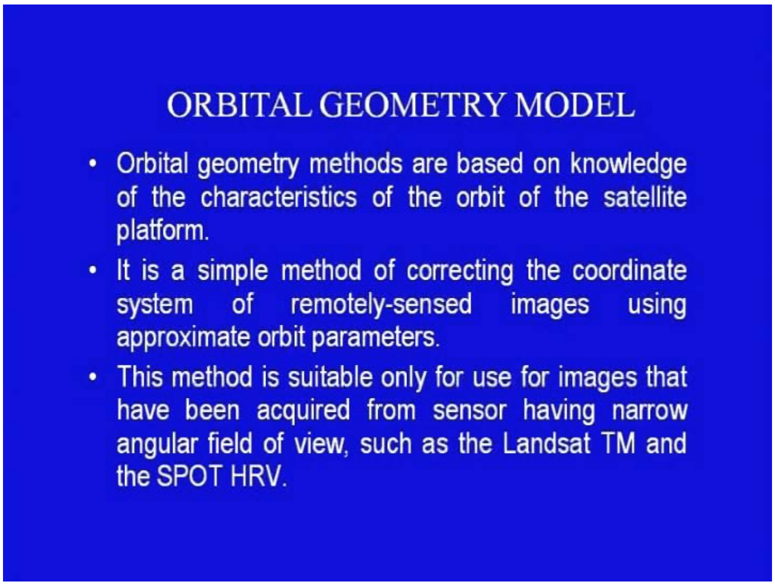

So now, let us look at the orbital geometry model. Orbital geometry methods are based on knowledge of the characteristics of the orbit of the satellite platform. It is a simple method of correcting the coordinate system of the remotely-sensed images using approximate orbit parameters. This method is suitable only for use for images that have been acquired from sensor having narrow angular field of view such as the LANDSAT TM and the SPOT HRV.

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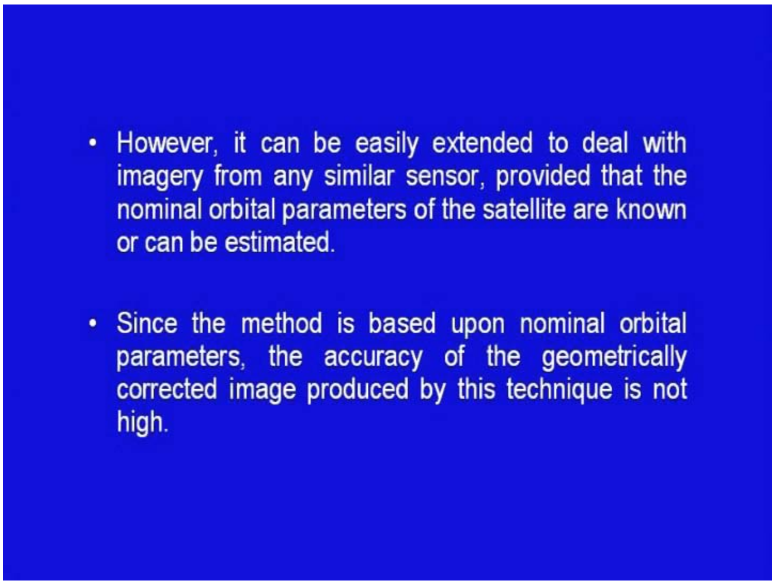

However, it can be easily extended to deal with imageries with similar sensor provided that the nominal orbital parameters of the satellite are known or can be estimated. Since, the method is based on the nominal orbital parameters, the accuracy of the geometrically corrected image produced by this technique is not high.

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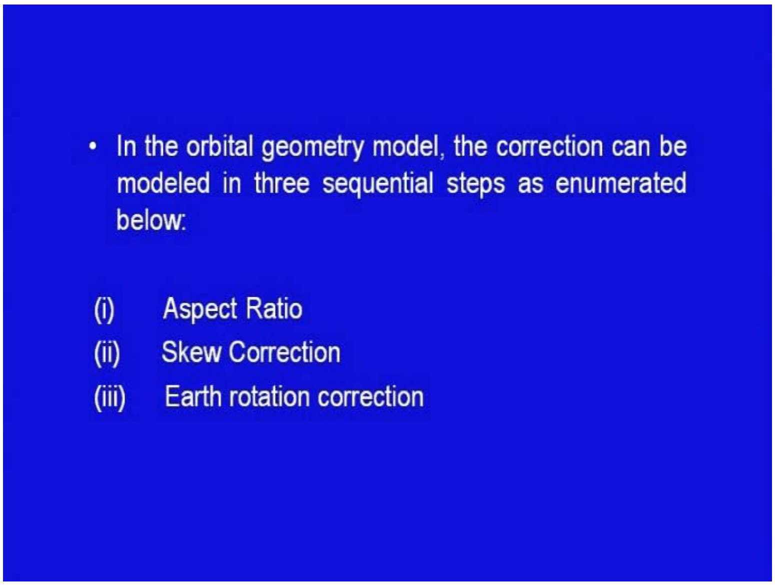

In orbital geometry model, the correction can be modelled in 3 sequential steps as enumerated below. First is aspect ratio, second is skew correction and third is earth rotation correction.

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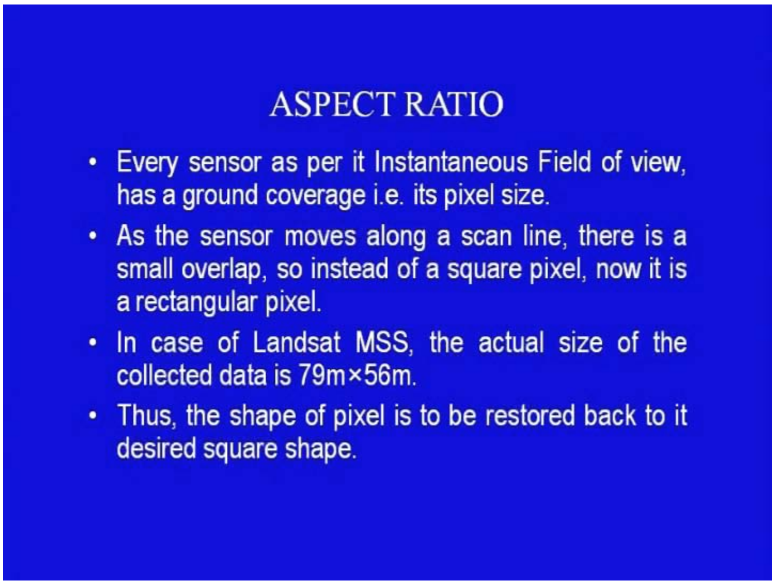

Aspect ratio: Each sensor as per its instantaneous field of view has a ground coverage which is known its pixel size. As the sensor moves along its scan line, there is a small overlap. So, instead of a square pixel, it is now a rectangular pixel. In case of LANDSAT MSS, the actual size of the collected data is 79 metres by 56 metres against the design value of 79 metres by 79 metres. Thus, the shape of the pixel is to be restored back to its desired square shape.

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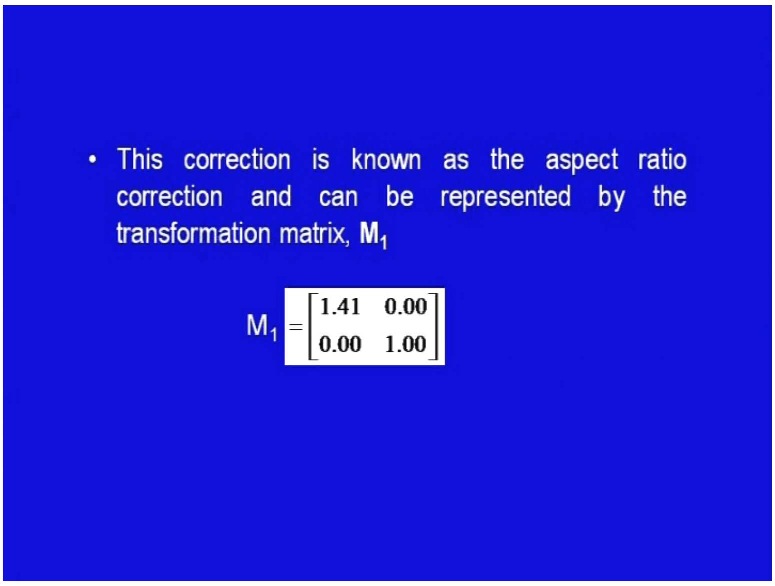

This correction is known as the aspect ratio correction and can be represented by the transformation matrix M_1 where M_1 can be defined to have 2 rows by 2 columns and the elements are as shown in the equation.

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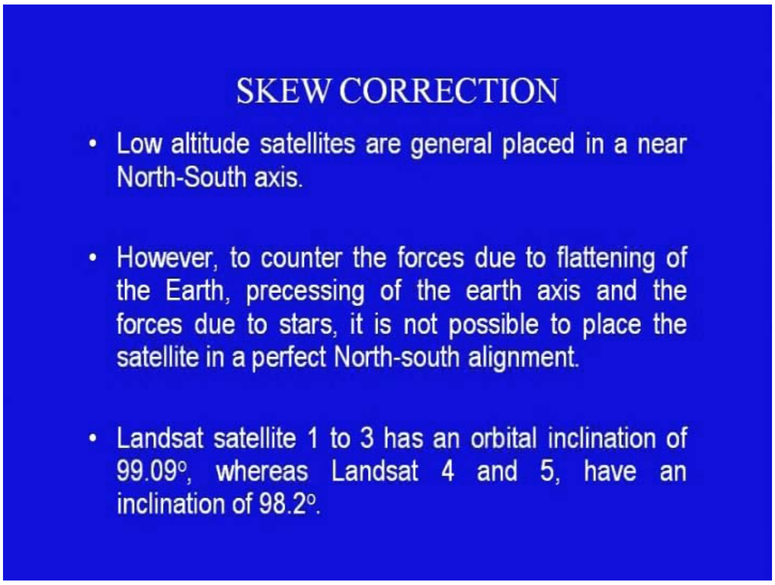

Next, we come to skew correction. Low altitude satellites are generally placed in a north-south axis. However, to counter the forces due to flattening of the earth, precessing of the earth axis and the forces due to the stars, it is not possible to place the satellite in a perfect north south alignment. LANDSAT 1 to 3 has an orbital inclination of 99.09 degrees; whereas, LANDSAT 4 and 5 have an inclination of 98.2 degrees.

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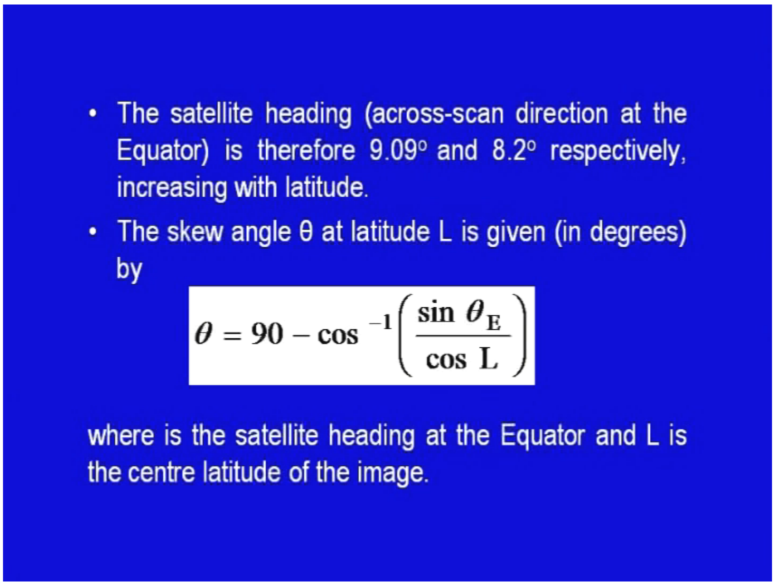

The satellite heading that is across-scan direction at the equator is therefore 9.09 degree and 8.2 degrees respectively, increasing with latitude. The skew angle theta at latitude L can be expressed as theta is equal to 90 minus cos inverse of the ratio of sin theta E over cos L, where L is e is the satellite heading at the equator and L is the centre latitude of the image.

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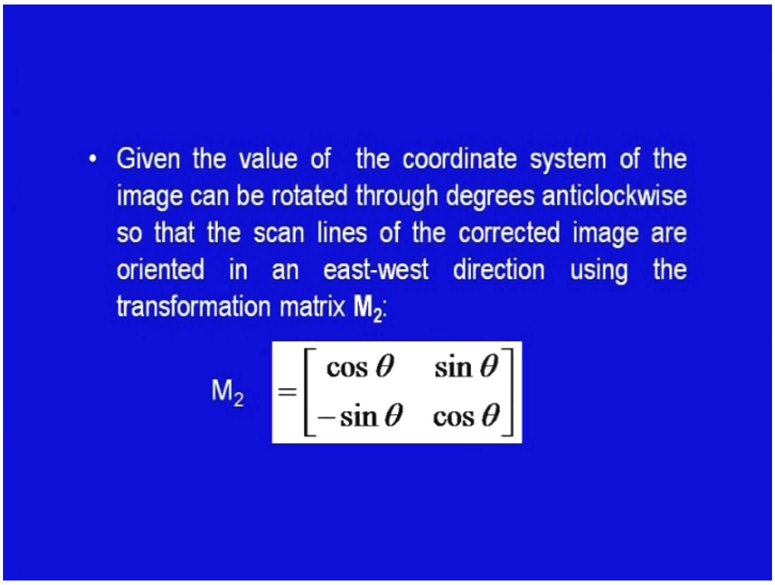

Given the value of the coordinate system of the image can be rotated through degrees anticlockwise so that the scan lines of the corrected images are oriented in an east-west direction using the transformation matrix M_2, where M_2 can be represented as the matrix as seen here.

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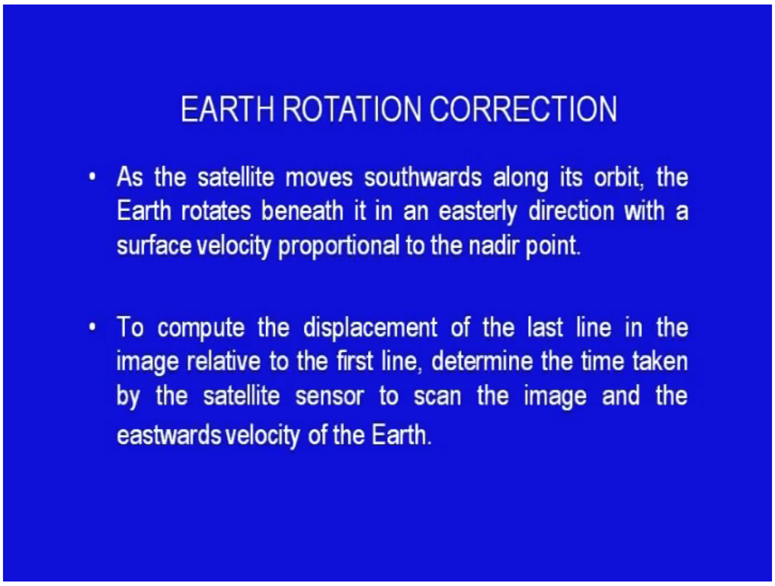

Next, we come to the earth's rotation correction. As satellite moves southwards along its orbit, the earth rotates beneath an easterly direction with a surface velocity proportional to the nadir point. To compute the displacement of the last line in the image relative to the first line, we have to determine the time taken by the satellite sensor to scan the image and the eastward velocity of the earth.

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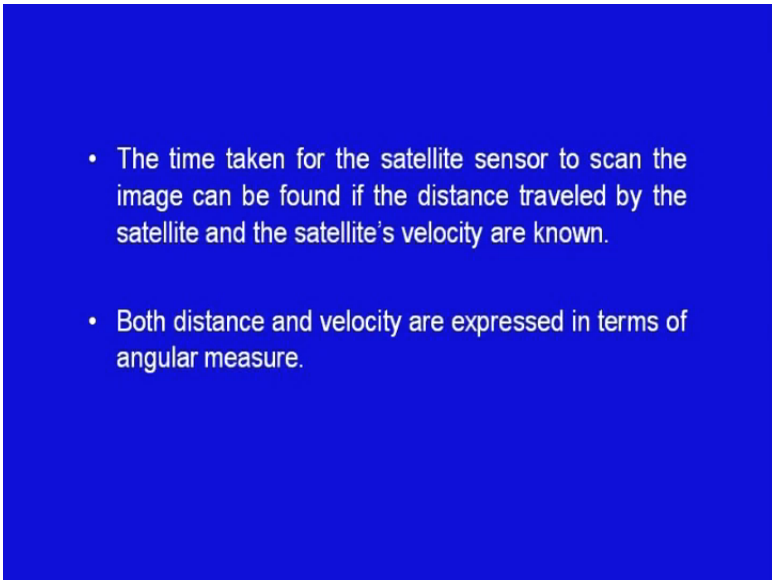

The time taken by the satellite sensor to scan the image can be found out if the distance travelled by the satellite and the satellite velocity are known. Here, both distance and velocity are expressed in terms of angular measurements.

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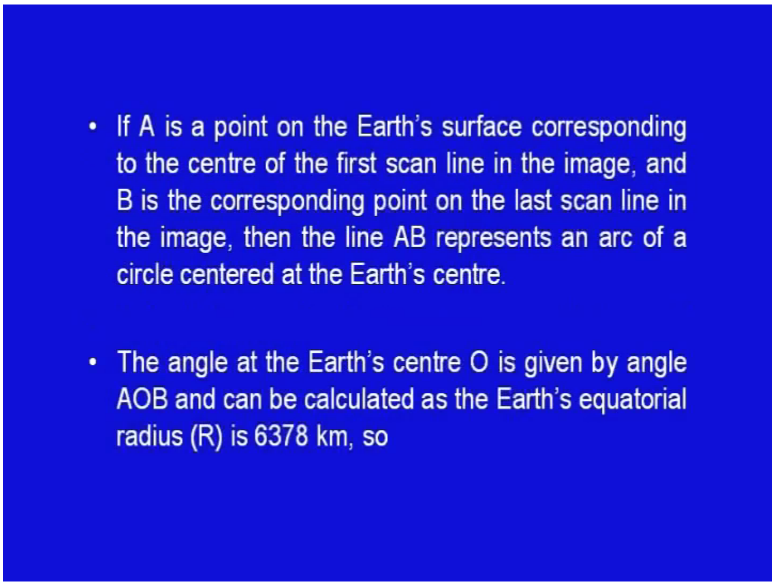

So, if A is a point on the earth surface corresponding to the centre of the first scan line in the image and B is the corresponding point in the last scan line in the image, then the line AB represents an arc of a circle centred at the earth's centre. The angle at the earth's centre O is given by angle AOB and can be calculated as the earth's equatorial radius is 6378 kilometres.

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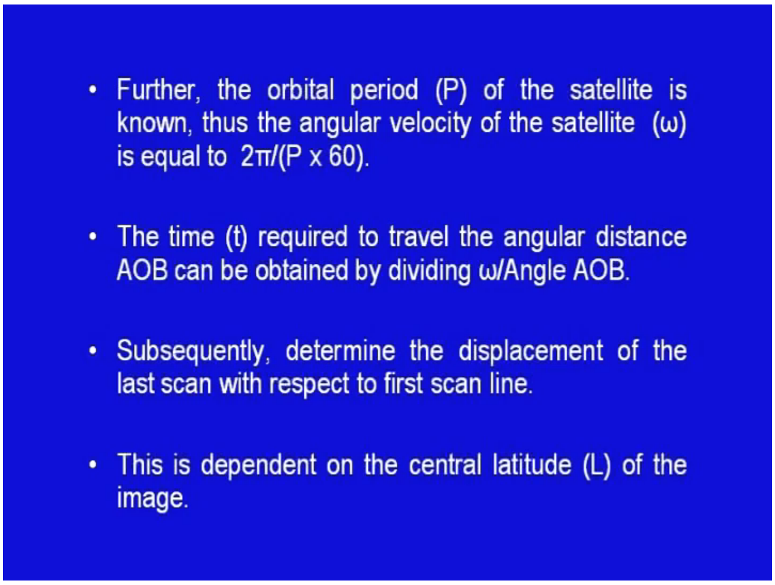

So, further the orbital period of the satellite is known. Thus, the angular velocity of the satellite omega which is equal to 2 pi divided by P multiplied by 60. The time t required to travel the angular distance AOB can be obtained by dividing omega by the angle AOB. Subsequently, we can determine the displacement of the last scan with respect to the first scan line. This is dependent on the central latitude L of the image.

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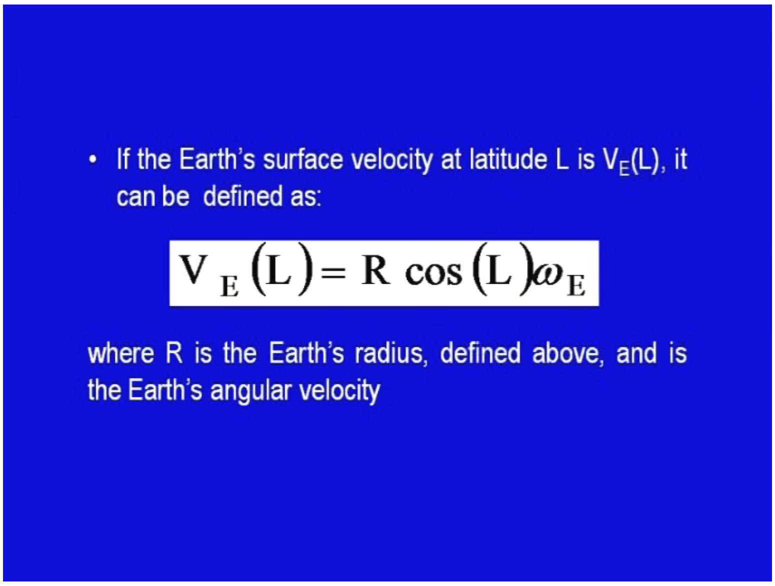

If the earth's velocity at the latitude L is given by V_E (L), it can be defined as V_E equal to R cos of L omega E, where r is the earth's radius defined above and omega is the earth's angular velocity.

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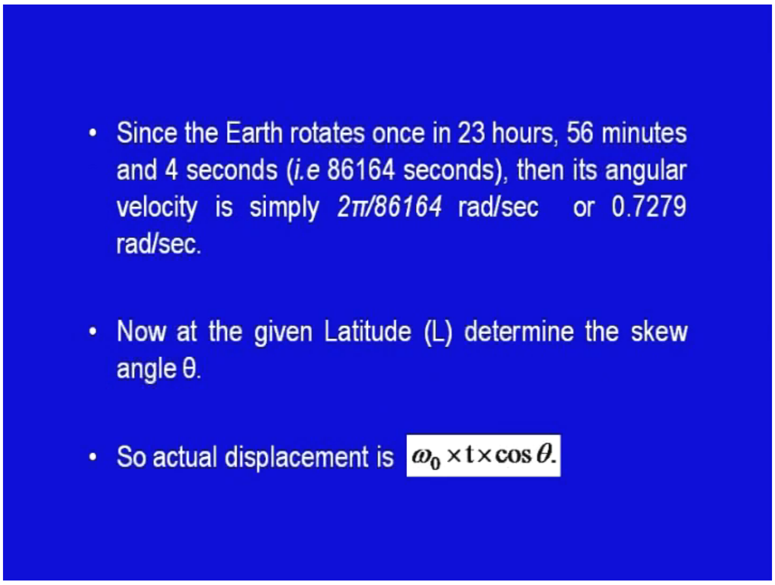

Since, the earth rotates once in 23 hours, 56 minutes and 4 seconds that is 86,164 seconds, then its angular velocity is simply 2 pi divided by 86,164 radians per second or this is equal to 0.7279 radians per seconds. Given the latitude L, now we can determine this skew angle theta. So, the actual displacement is omega zero multiplied by t into cost theta.

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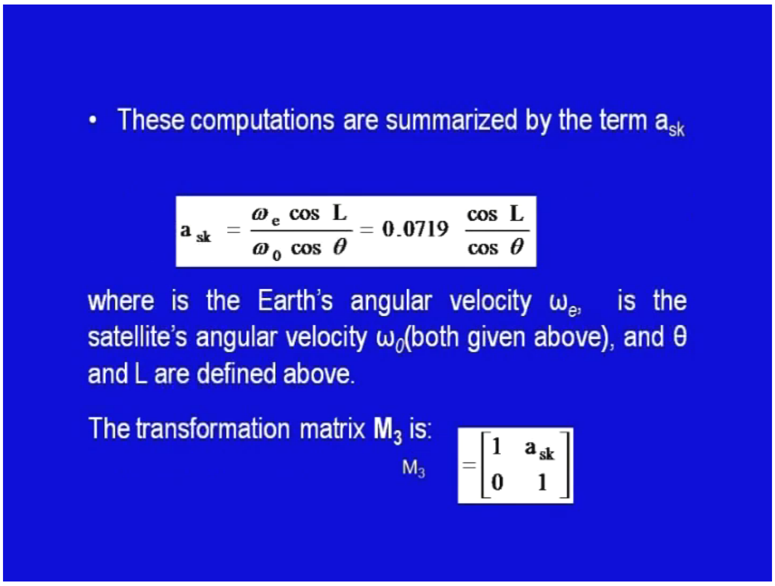

These computation are summarized by the term a_{sk} which is can be simplified and written as 0.0719 multiplied by the ratio of cos L of and cos theta, where the earth's angular velocity is omega e is the satellites angular velocity omega zero and theta and L are as defined above. So, the transformation matrix 3, can now be expressed as it is shown in at the bottom.

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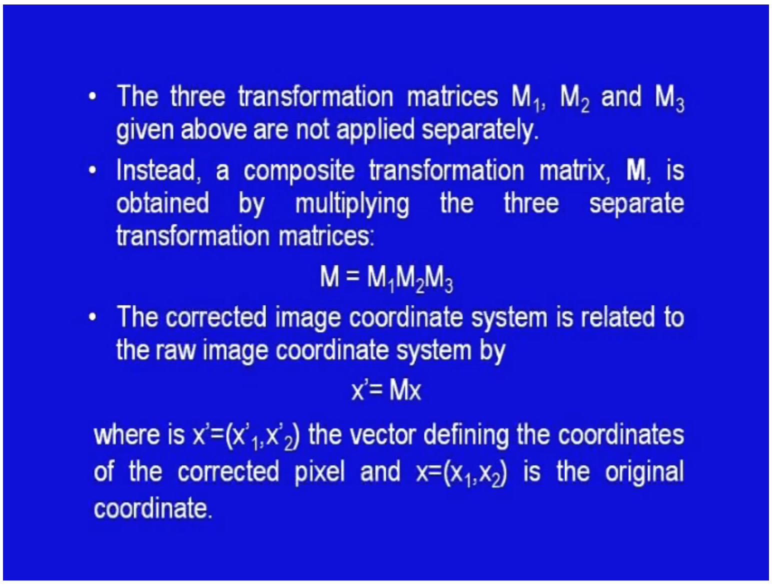

The 3 transformation matrices; M_1, M_2 and M_3 are not applied separately. Instead, a composite transformation matrix M is obtained by multiplying the 3 separate transformation matrices. The corrected image coordinate system is related to the raw image coordinate system by x dash is equal to Mx, where x dash is nothing but x_1, x_2, the vector defining the coordinates of the corrected pixel and x is equal to x_1 and x_2 is the original coordinate.

Now, we come to the next method and that is the geometric rectifications.

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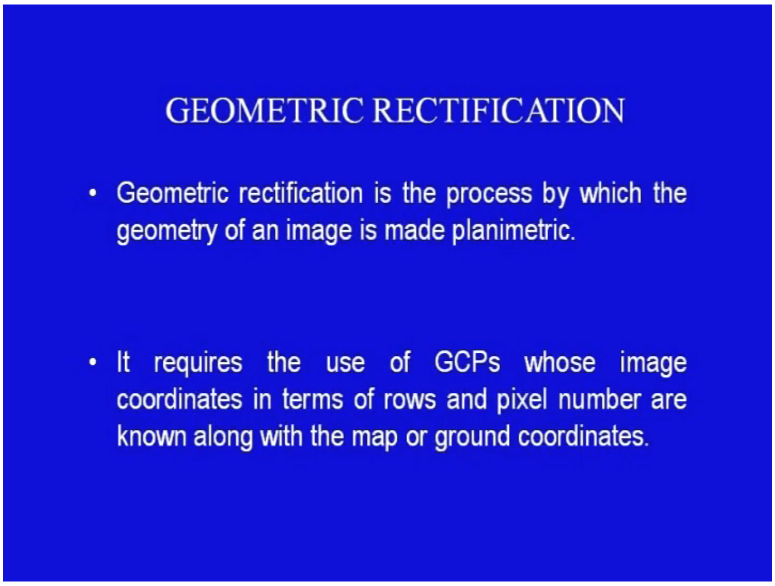

Geometric rectification is the process by which the geometry of an image is made planimetric. It requires the use of the GCPs whose image coordinate in terms of rows and pixel number are known along with the map or ground coordinates.

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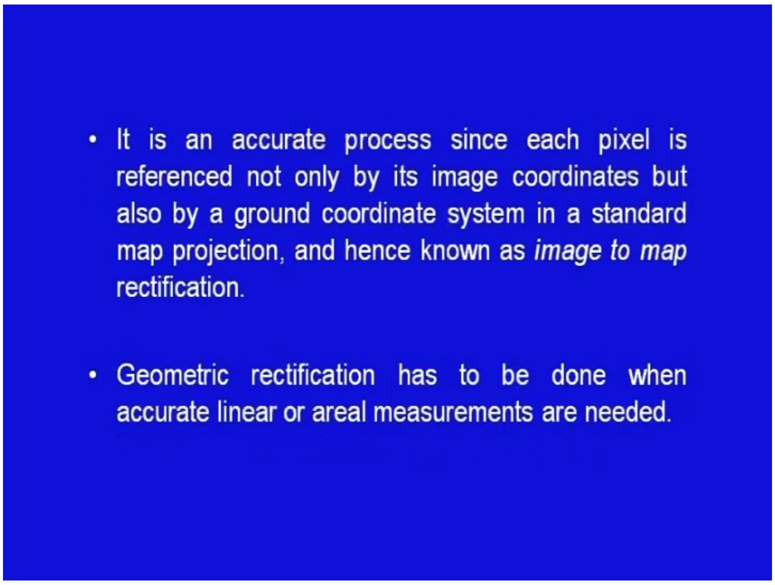

It is an accurate process, since each pixel is referenced not only by its image coordinate but also by its ground coordinate system in a standard map rejection and hence, it is known image to map rectification. Geometric rectification has to be done when linear accurate linear or areal measurements are needed.

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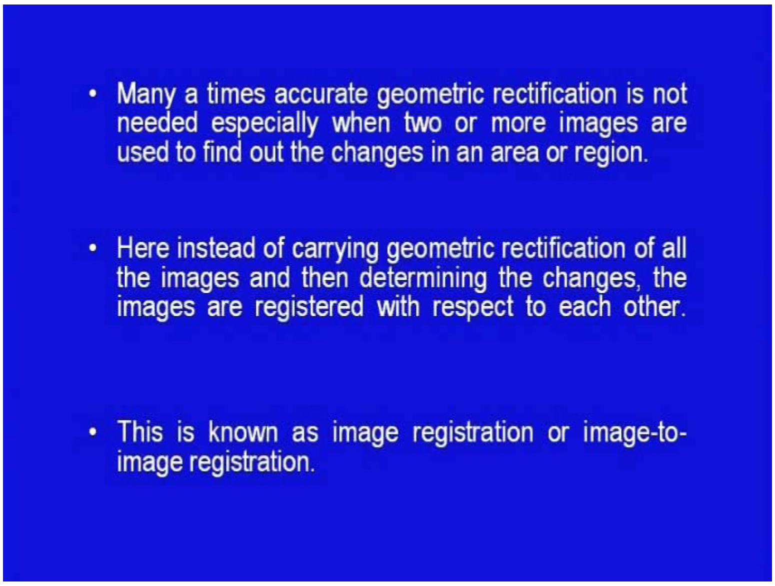

Many a times, accurate geometrical rectification is not needed; specifically, when two or more images are used to find out the changes in an area or region. Here, instead of carrying geometric rectification of all the images and then determining the changes, the images are registered with respect to each other. This is known as image registration or image-to-image registration.

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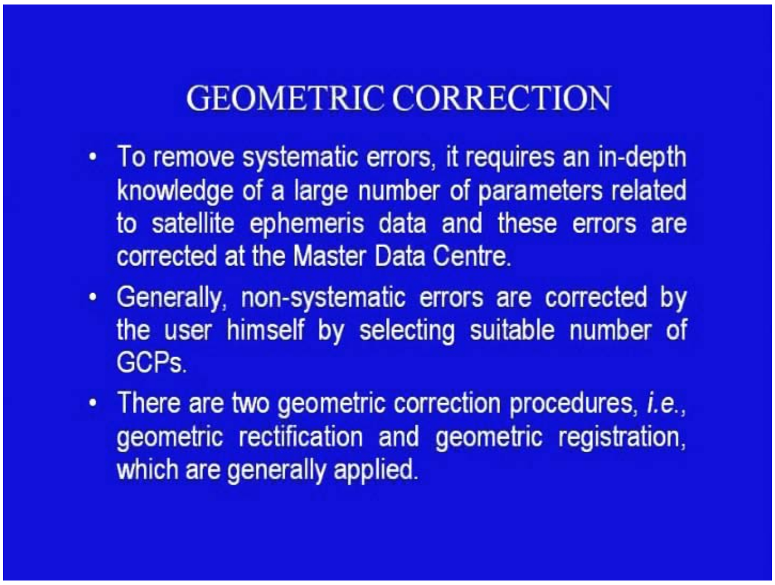

To remove systematic errors, it requires an in depth knowledge of a large number of parameters related to the satellite ephemeris data and these errors are corrected at the master data centre. Generally, non systematic errors are corrected by user himself by selecting suitable number of GCPs. There are two geometric correction procedures that is geometric rectification and geometric registration which are generally applied.

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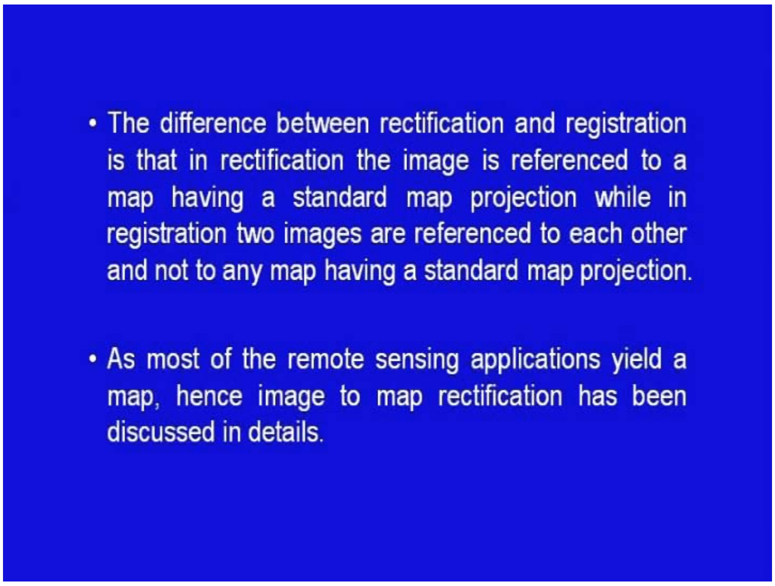

The difference between rectification and registration is that in rectification, the image is referenced to a map having a standard map projection; while in registration, 2 images are referenced to each other and do not have any map having a standard map projection. As most of the remote sensing applications yield a map, hence image to map rectification has been discussed in details.

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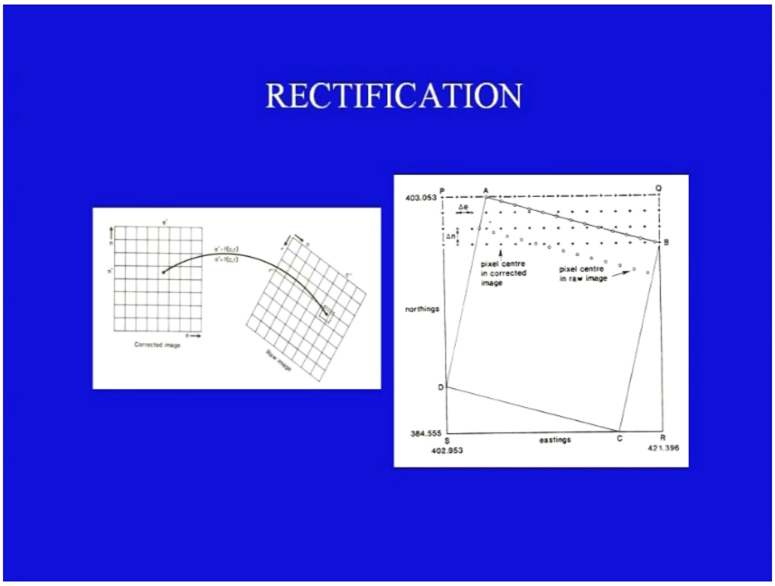

In this particular slide, it illustrates the procedure of rectification which actually has to be carried out. On the left hand side, we can see that there is one image which is tilted which is the raw data and the upright corrected image is shown on the right hand side and we have to map, we have to correct the tilted shape of the image onto the upright corrected shape as shown.

In order to do so, we have to now define a system by which the tilted or oriented image can be made in an upright format.

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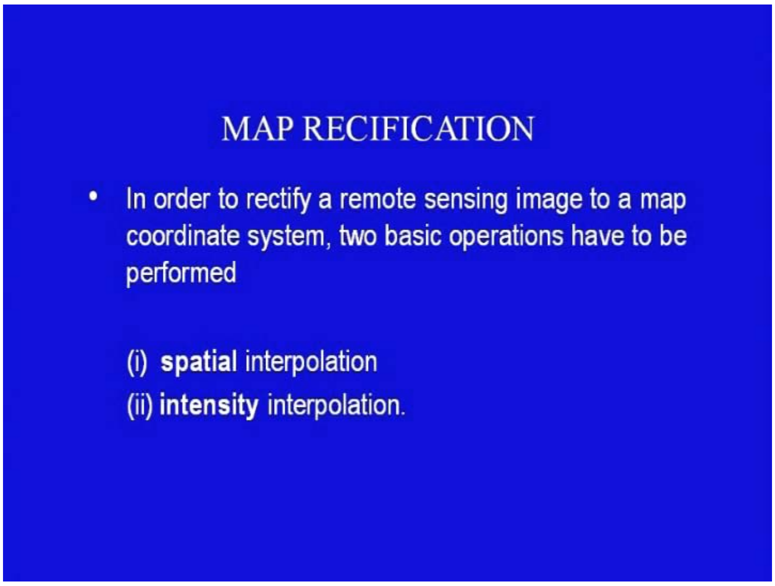

In order to rectify a remote sensing image to a map coordinate system, 2 basic operations have to be performed. First is spatial interpolation and second is intensity interpolation.

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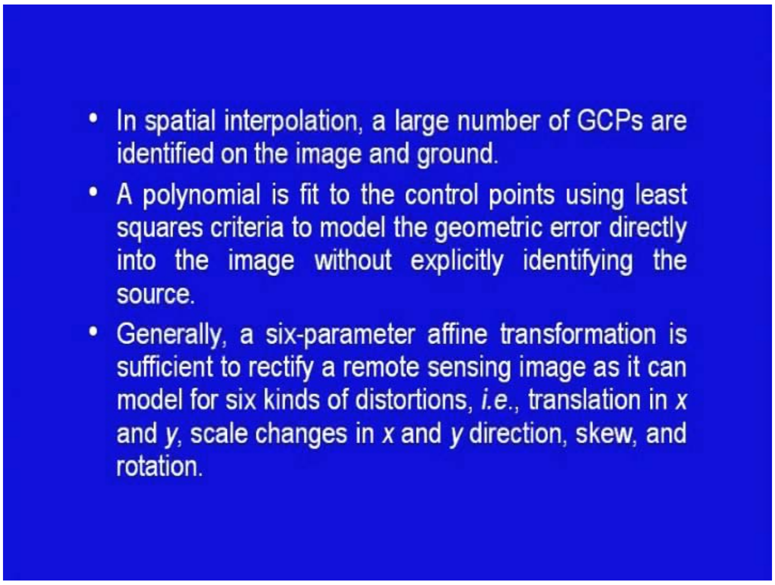

In spatial interpolation, a large of number of GCPs are defined on the image and on the ground. A polynomial is fitted to the control points using least squares criteria to model the geometric error directly into the image without explicitly defining or identifying their source.

Generally, a 6 parameter affine transformation is sufficient to rectify a remote sensing image as it can model for 6 kinds of distortions; that is translation in x and y, scale changes in x and y and direction and skew and rotation.

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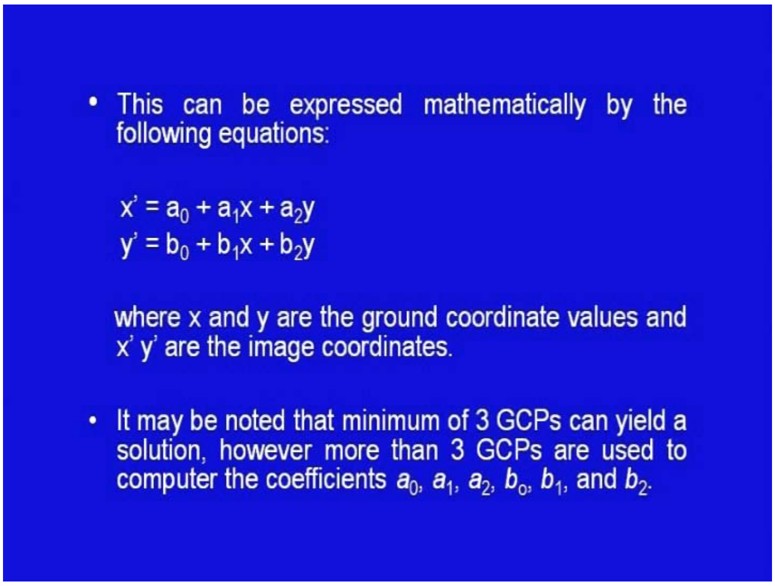

Thus, this can be expressed mathematically by following equations; x dash is equal to a_0 plus a_1x plus a_2y and y dash is equal to b_0 plus b_1x plus b_2y, where x and y are the ground coordinates values and the x dash and y dash are the image coordinate values. It may be noted that minimum of 3 GCPs can yield a solution. However, more than 3 GCPs are used to compute the coefficients; a_0, a_1, a_2, b_0, b_1 and b_2.

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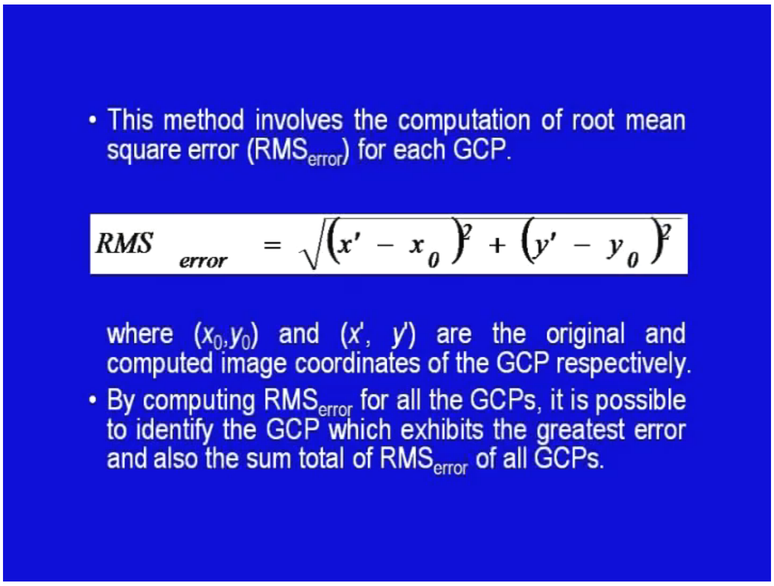

This method involves the computation of root means square error for each GCPs, where the root RMS_{error} can be expressed as under root of x dash minus x_0 whole square plus y dash minus y_0 whole square, where x_0 y_0 and x dash and y dash are the original and the computed image coordinates of the GCP respectively.

By computing the RMS of all the GCPs, it is possible to identify the GCP which exhibits the greatest error and also the sum total of RMS_{error} of all the GCPs.

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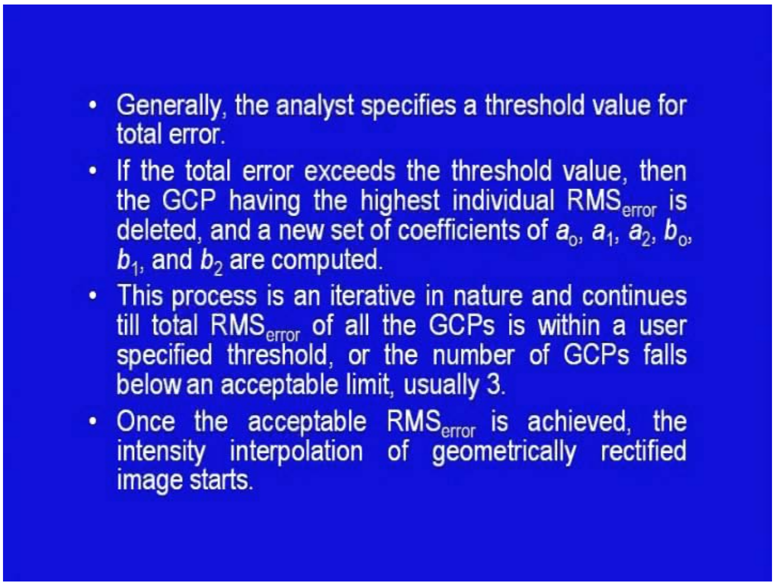

Generally, the analyst specifies a threshold value for total error. If the total error exceeds the threshold value, then the GCP having the largest individual RMS_{error} is deleted and a new set of coefficients of a_0, a_1, a_2, b_0, b_1 and b_2 are computed.

This process is an iterative in nature and continues till total RMS_{error} of all the GCPs is within a user specified threshold or that the number of GCPs falls below an unacceptable limit, usually 3. Once the acceptable RMS error is achieved, the intensity interpolation of geometrically rectified image starts.

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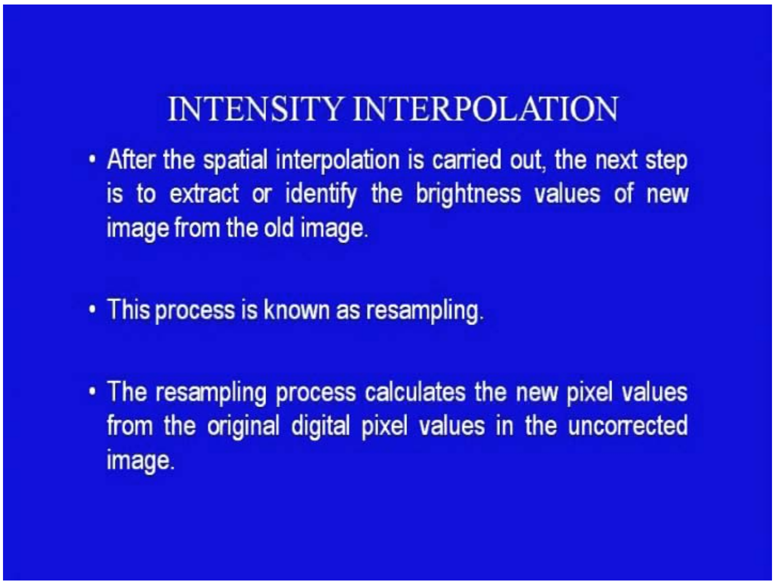

So, now let us look at the intensity interpolation. After the special is carried out, the next step to extract or identify the brightness value of the new image from the old image. This process is known as re-sampling. The re-sampling process calculates the new pixel values from the original digital pixel values in the uncorrected image.

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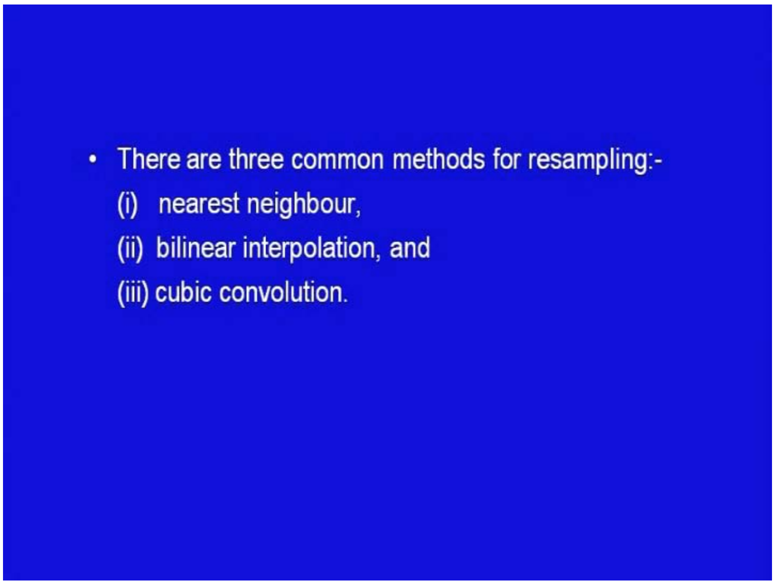

There are 3 common methods for re-sampling; nearest neighbourhood, bilinear interpolation and cubic convolution.

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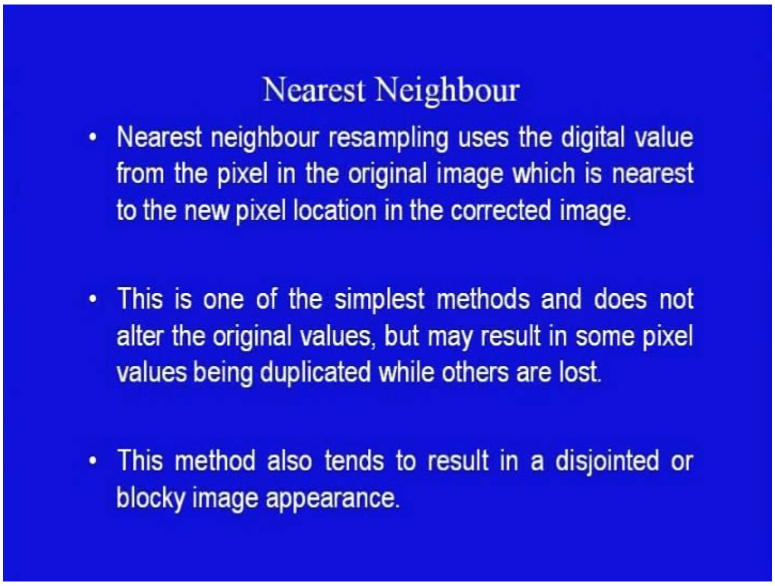

So, let us look at the first method that is nearest neighbourhood. Nearest neighbourhood re-sampling uses the digital value from the pixel in the original image which is nearest to the new pixel location in the corrected image. This is one of the simplest methods and does not alter the original values but may result in some pixel values being duplicated while others are lost. This method also tends to result in a disjointed or blocky image appearance.

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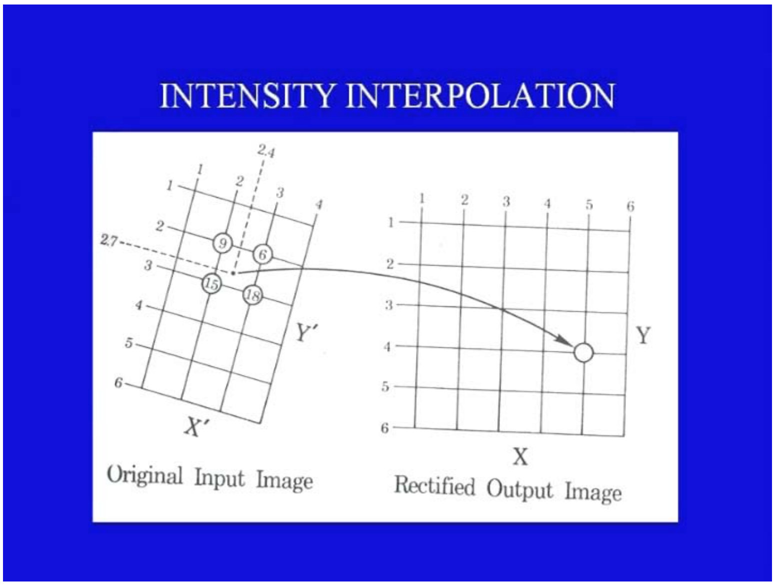

This particular figure shows the concept of nearest neighbourhood intensity interpolation, wherein, on the left hand side we have the original input image and on the right hand side we have the rectified output image.

We first find out what is the relationship between these two and on the basis of that we find out where is the centre of the pixel in the rectified image lies on the original input data. In this particular example, we can see that the centre of the rectified output image lies is not coincident with either of any of the points which specify the centre of the pixel. It lies somewhere in between. Now, it has to identify to which pixel it is closest to.

In order to do so, one will find out what is the equivalent distance between the pixel centre to the super impose position of the rectified output image pixel. Whichever distance is the minimum; to that particular pixel brightness value will be adopted for the new pixel in the rectified image.

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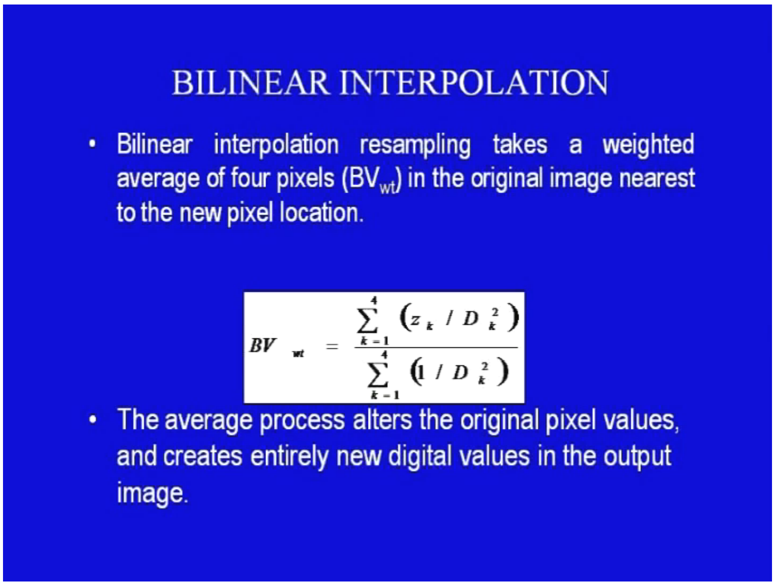

Then, we come to the bilinear interpolation. Bilinear interpolation re-sampling takes a weighted average of all the 4 pixel in the original image nearest to the pixel location. That is as seen in the previous slide, wherein, a graphical depiction of the location of the rectified pixel and the 4 nearest pixel lying in the close vicinity has been shown.

In bilinear interpolation, what is done is that all the 4 points; their weightages or their values are taken and they are and they are multiplied by inverse of the distance or one can say the inverse weight is provided to the brightness value or the 4 pixels which surround this particular pixel.

So, this can be expressed as BV mu which is equal to summation of all the 4 pixel brightness values divided by the inverse of square of the distances of these points. The average process altered the original pixel values and creates entirely a new digital value in the output data.

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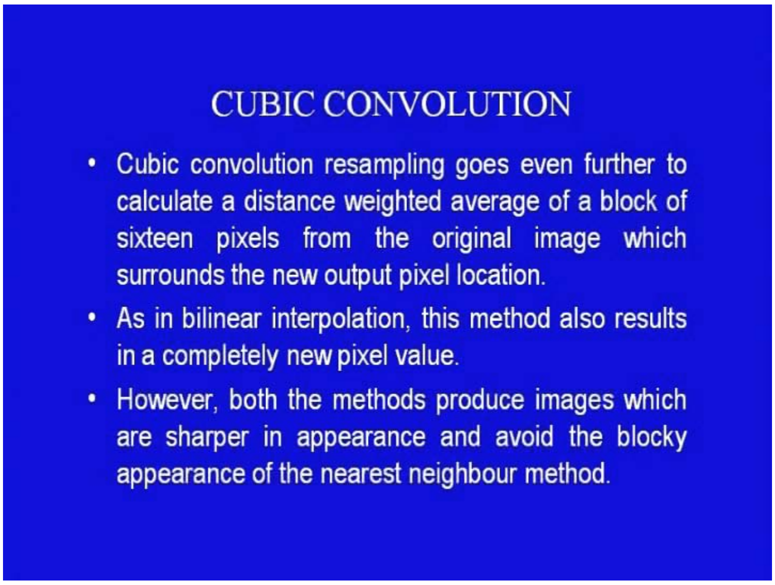

The next, the third method which is cubic convolution, it even goes one step further to calculate the distance weighted average of a block of 16 pixels from the original image which surrounds the new output pixel location. As in bilinear interpolation, this method also results in a completely new pixel value.

However, both the methods produce images which are sharper in appearance and avoid the blocky appearances of the nearest neighbourhood method. Having discussed these; now, let us look at a comparative evaluation of these 3 re-sampling technique methods.

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Method	Technique	Relative computin g	Advantages	Disadvantag es
Nearest neighbors	Transfers the brightness value of the nearest pixel.	1	Simple to compute array values unaltered	Image disjointed or blocky
Bilinear	Proximity weighted average method from nearest pixels	10	Smooth image, geometrically accurate	Grey values altered.
Cubic Convolutio n	Proximity weighted average method of sixteen nearest pixels.	20	Very smooth image	Complex to compute, gray value altered.

This particular table, as a matter of fact, provides the basis of the methods which are there that is the nearest neighbourhood. The technique basis is that it transfers the brightness value of the nearest pixel. A relative complexity in computing can be set to 1 in this particular case. The advantage of using nearest neighbourhood re-sampling technique is that it is simple to compute array values which are unaltered; disadvantage that this particular method has that the image appearance be disjointed or blocky in nature.

The next method that is bilinear, it is proximity base weighted average method from the nearest pixel. The complexity in term of computing relative to nearest neighbourhood is 10 times. Advantage is that the image is smooth and geometrically accurate.

However, in this particular process the brightness value or gray value of the original image may get altered. Cubic convolution, again a proximity weighted average method of 16 nearest pixels has a relative complexity in terms of computing with the respective nearest neighbourhood of 20. It produces a very smooth image, however it is complex to compute and the gray values get altered.

Having done this particular process of rectification and restoration; now, the original data has been actually made to be tied to the earth such that it bears a well defined relationship amongst the image and the ground points. This results in one unique aspect and that is all linear measurement or area measurement computed with the help such rectified data do not have any errors.

In my next session, I would be then proceeding onto the next part of the image analysis process which is image enhancement.

Thank you.