Remote Sensing essentials
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Lecture-22
Geo-referencing technique

Hello everyone and we are going to discuss in this lecture geo-referencing technique also called image registration. But in why it has started we have started calling a geo-referencing because now not only we are doing image registration. But we are also referencing some maps also and bringing them into geographic coordinate system that is why it is more appropriate word is geo-referencing technique.

This is a common technique between digital image processing and also in geographic information system that is in GIS. Nonetheless, this is very, very important technique to transform your data especially the satellite images or maps from geometric domain into geographic domain. And in order to achieve the task from transformation from geometric to geographic domain, we do this geo-referencing.

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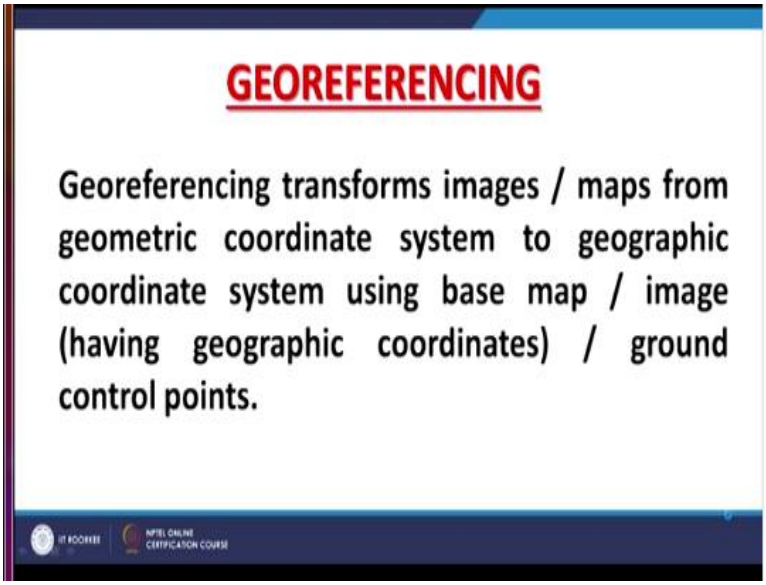

So what exactly the geo-referencing is that we transform images and maps from geometric coordinate system to geographic coordinate system. You know that in coordinate geometry our

concept were developed in geometric coordinate system. But GIS geographic information system or in images we would like to use along with certain maps, we want to overlay our images with certain maps and therefore, geo referencing is required.

So if we keep our data in geometric domain then it is becomes difficult to overlay with other datasets, other layers, other themes. And therefore it is necessary to transform from geometric coordinate system to geographic coordinate system. And this can be achieved either by using base maps having or images which are already geo reference having geographic coordinates. And also we can use ground control points maybe available through this GNSS that is Global Navigation Satellite Systems GPS or any other navigation systems.

And so if we are having some standard ground control points, those can also be use. And nowadays ground control points are also coming for referencing using Google earth. So by which we can again get the GCP's or ground control points. So, basically geo referencing is transforming from your data images from geometric coordinate system to geographic coordinate system using certain standard maps, base maps which are already in geography coordinate system or maybe ground control points.

So as you know that when image is acquired by the satellite the resulting image is having certain types of errors, some are systematic errors some are very temporary and non systematic geometric errors are there. Because of lot of movement of the satellite, because satellite moves at very high speed and in a space and may deviate from their axis or speed or other things.

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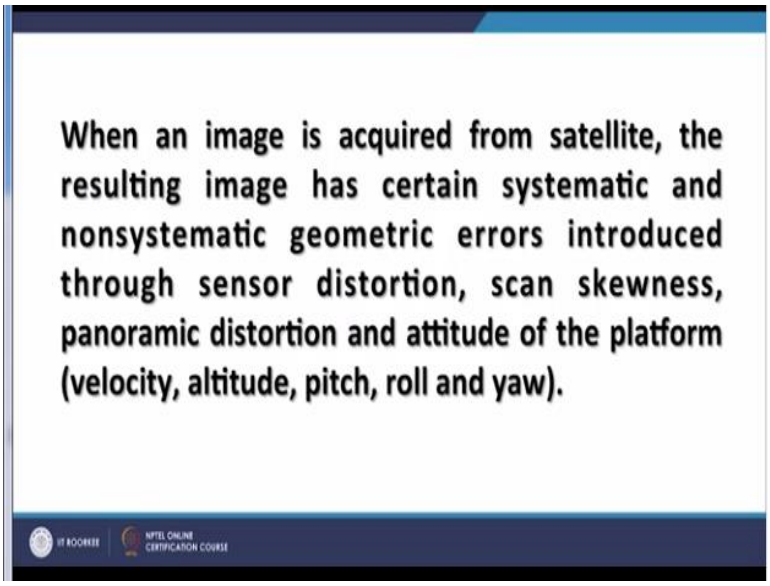

In early stages of satellite remote sensing these errors like scan skewness sensor distortions and other panoramic distortions were more. But nowadays these errors are becoming very less but nonetheless, they might be there. And they basically distort the image and we call as geometric errors in the image and when we want to transform from geometric domain to geographic domain, we need to correct these errors.

And systematic errors can be corrected very easily, whereas none systematic errors becomes very difficult to very challenging sometimes to remove them. So systematic errors can be removed quite easily, we will be seeing certain these errors through some schematics like a cross track scanner distortion.

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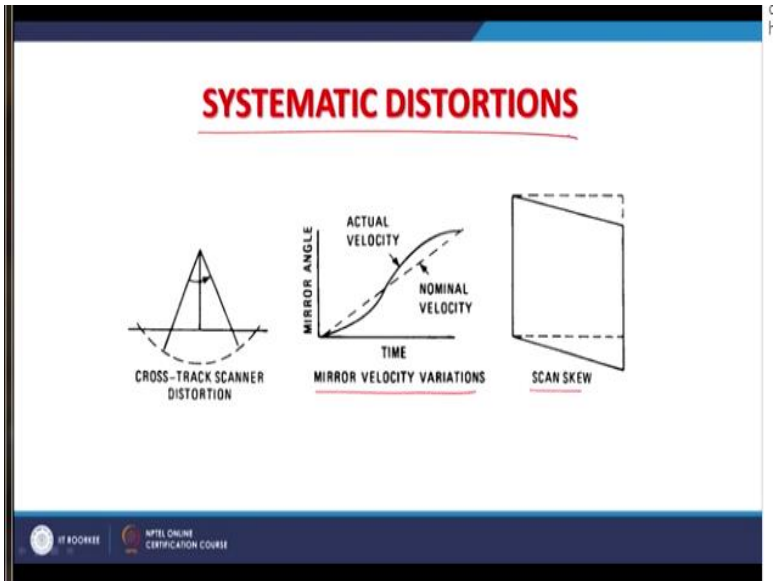

When we used to have these moving scanners Landsat and early stages of Landsat and IRS. And then we had these issues about the distortions being created by this cross track scanner. Mirror velocity variations if that mirror which is supposed to be helping focusing, the sensor may have changes in the velocity because of certain reasons within the spacecraft or within the sensor.

Then you may have a problem in your images the skewness issue will also come. Because as you know that these satellites polar orbiting satellites are not exactly from north to south pole. They are having certain angle about say 9 degree from pole and when the data is being acquired by a satellite, the earth is also rotating from west to east direction on it is own axis. And due to that a skewness in the images may also be seen and that can also be removed and these errors will fall in the systematic distortions or geometric distortions.

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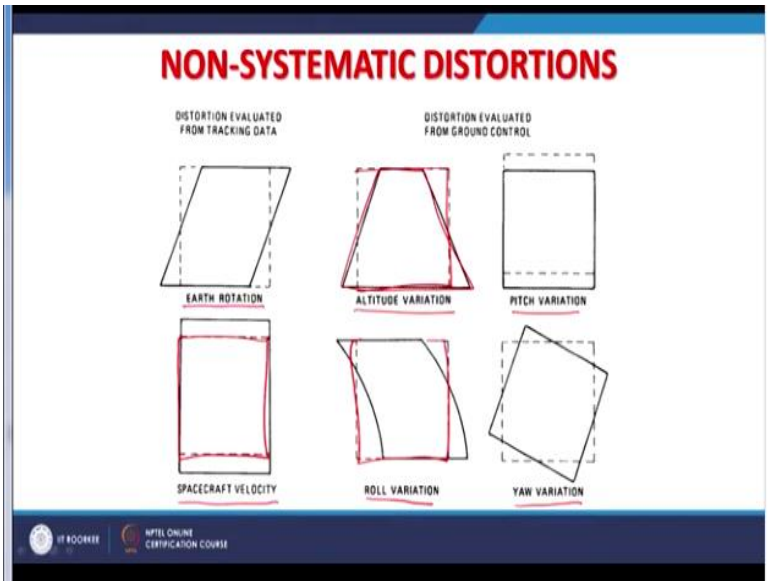

There are certain non systematic distortions like earth rotation that is because of some changes in the speed or satellite or some other thing. Then the earth rotation otherwise earth rotation can also be considered under the systematic distortions. Altitude variations suddenly there is a change in the satellite altitude. And if that is there, then it is supposed to be having image for this area but now it is having image of this area.

So that creates a this distortion due to altitude variation, there may be a pitch variations that certainly the satellite dips in either forward direction or backward direction and that may create pitch variations. Sometimes these errors are difficult to identify, so one has to be very careful while doing this geo-referencing process using the GCP's then you can get rid of most of these errors quite easily.

So that is why it is very important before utilizing these images, it is better to first geo-reference them and then use and create whatever the maps you want to create. If suddenly there is a change in the velocity of the spacecraft that too will substitute, so this area is supposed to be there in the image but it has covered a larger area because of high speed in this particular example now roll variations.

So if suppose a satellite is going like this it rolls on the sight scene like this. So if this movement is there then that will bring a data of like this, whereas supposed to be of this dashed mark area.

Your variation is like it is something like this moves in on own access the satellite and that may bring your variations. So pitch variations is there when it dips either forward or backward roll variations is something like this and your variation is like this.

So these can create problems in our images or can bring geometric distortions. You also know that when image is stored, it is basically having is a 2 dimensional matrix, so it is a row and column. And generally geometric coordinate systems when images in geometric coordinate system these are top left corner. The coordinates be address from top left corner, whereas in geo referenced images or data, we take coordinates from bottom left corner. So that thing has also be to considered while doing the geo -referencing.

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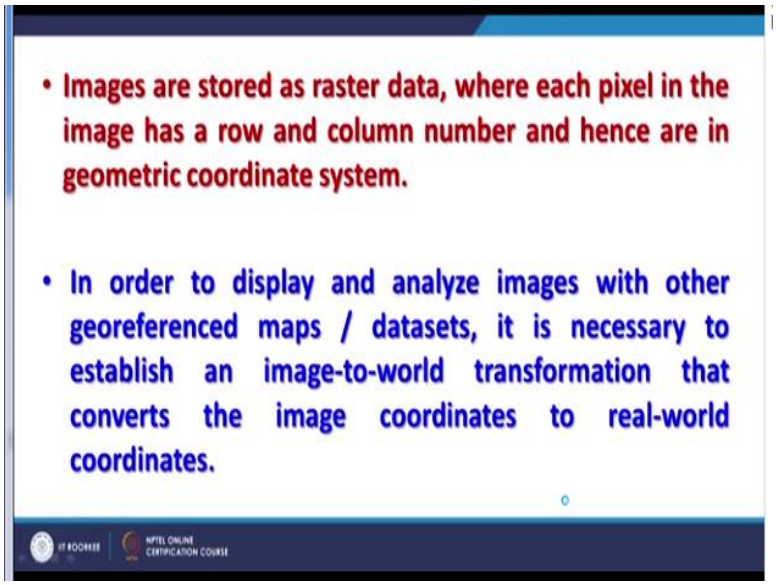

So in order to as I have mentioned in the beginning of this discussion, that in order to use this satellite image or products from the satellite images like land use map, forest cover map or lithology map or any other map lineament map. We would like to use those maps with other datasets which are already say geo reference. So for that purpose it is necessary to stabilized an image to word transformation and that will basically transform our image.

Image which is in geometric domain to the real world coordinates or geographic domain and this is how it is important. And there are the common method what is we are discussing is image geo-referencing.

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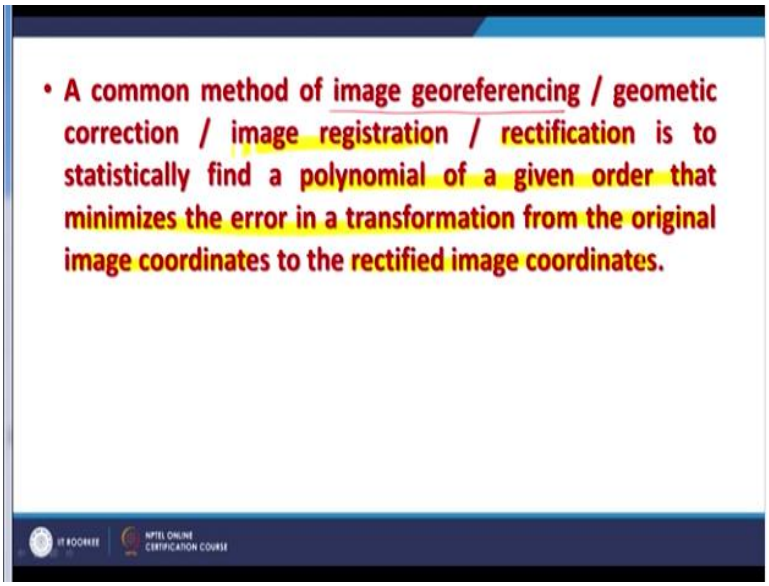

Sometime it is also called geometric corrections and also sometimes people call as image registration. Sometime also you may find in literature rectification the meaning is same. Basically transforming an image or a map from geometric domain to geographic domain. And basically finding out of a given order of polynomial which we will see through equation, which minimizes the error in transformation from the original image coordinates.

Those are in the rows and columns starting from top left to rectified image coordinates which are in terms of geographic coordinates and starting from bottom left. So by doing this we achieve the geo-referencing. Now there are basically 3 steps let me now bring in about these 3 steps here. There are 3 steps first is the registration using ground control points, these ground control points can come from already geo referenced image or map or collected from the field also using your GNSS devices.

And then first is registration tying up the ground control points, identifying the same feature on your geometrically in a geometric image or raw image and then registering it, that is first part. Second part is this polynomial choosing a appropriate polynomial order equation and because we need to know that where a pixel will go from which location to which location. And for that we need a transformation function and that can be achieved through a polynomial equation.

And third is what valued will carry pixel value and for which we do the re sampling. So, 3 steps the fastest step is the registration, second is step to find out the transformation through polynomial equation of a given order which we will discuss that which order I should choose and the third one is find out the pixel value that is through re sampling. So 3 steps are there, very distinct steps are there most of the softwares they have been prepared to do these task in a sequence.

So there is no confusion and geo referencing can be achieved if you use a RGIS software or LiDAR software no issue it is very easy.

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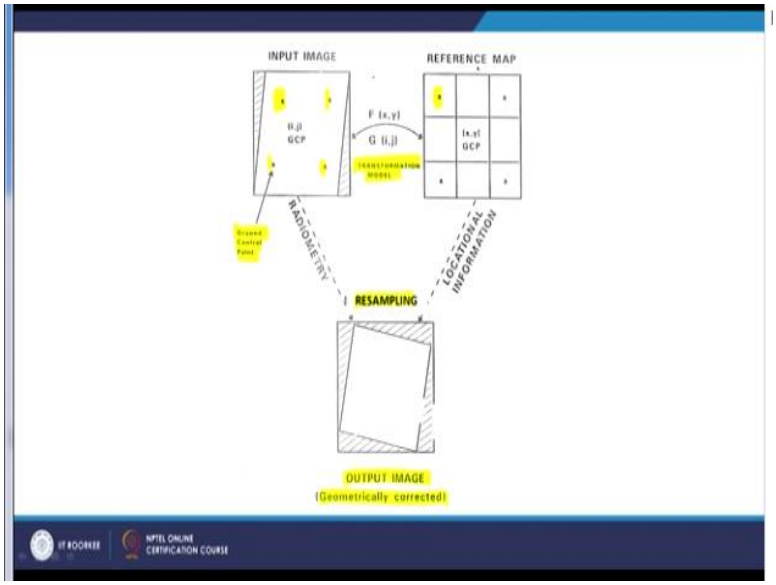

Now, I will be explaining how this registration part is, as you can see here that in the input image just this is because our understanding. So the only 4 coordinates have been or 4 GCP's are there ground control points as you can see here, and this is my target map or reference map. So in reference map, suppose this one and this one is showing the same feature, these are the common ground control points.

For example, there might be road crossing, there might be a railway bridge, there might be a coder, which I am also seeing in my satellite image. And the same time I am also seeing in my reference map or collected from the field the coordinates. So I will tie this coordinate with this

GCP, with this GCP and likewise all GCP's I will tie up and that after registration once I am having now the transformation function available to me.

I will do the resampling and will create a product output image which is geometrically corrected, so likewise I can achieve.

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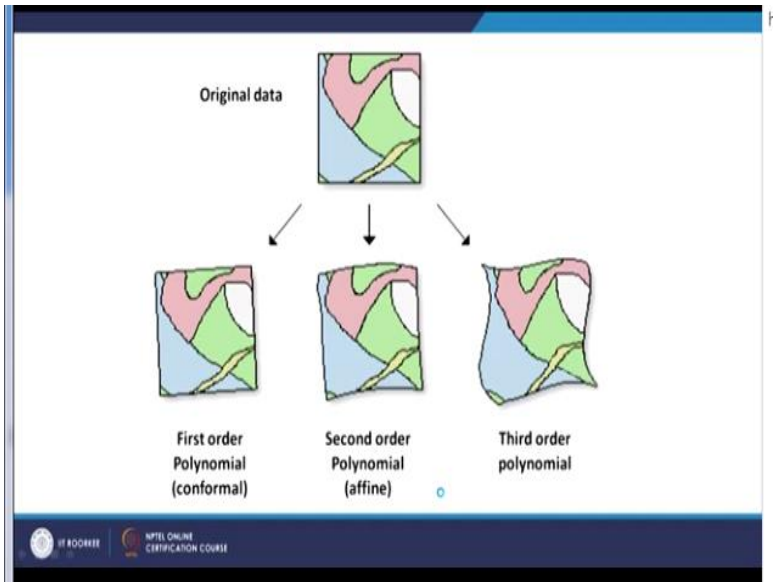

Now let us see, how to decide about the order of polynomial equation it is not too difficult the first one is the original image which is shown to in to the top. If image is just required or any map require just transformation from geometric domain to geographic domain without any change in scale or without rotation. Then first order polynomial or conformal transformation would be sufficient. That means transforming from geometric domain to geographic domain without any rotation without change in scale.

But if I want because one map is in different scale, my target map is in different scale. Therefore, I will be requiring some change in scale maybe some rotation also might be in one projection system here I am in another projection, map projections. And therefore, I will go for second order polynomial, so first order no change in a scale and no rotation, second order change in a scale and rotation.

And third order is change in a scale, rotation and warping, there might be a image which is covering a large part of the earth and which maybe representing the curve part of the earth curvatures part. And that may require the third order of polynomial transformation because I have to make it that representation in a flat in a 2D rather than in a curved curvature and therefore third order polynomial equation require.

If you go for as you go higher in order in most of these image processing GIS softwares up to third order things have been implemented. But there are also extensions and tools are available if somebody is going even I have seen up to 12th order there are utilities available by which you can do that transformation. But you know unless it is required, one should not go for very high order of polynomial equation selection.

Up to third order in most of the cases is more than sufficient for a because once you go higher in order the number of control points requirement of control point would increase. And this is how it will come in effect through this formula and this P is a stands basically for order of polynomial which I choose.

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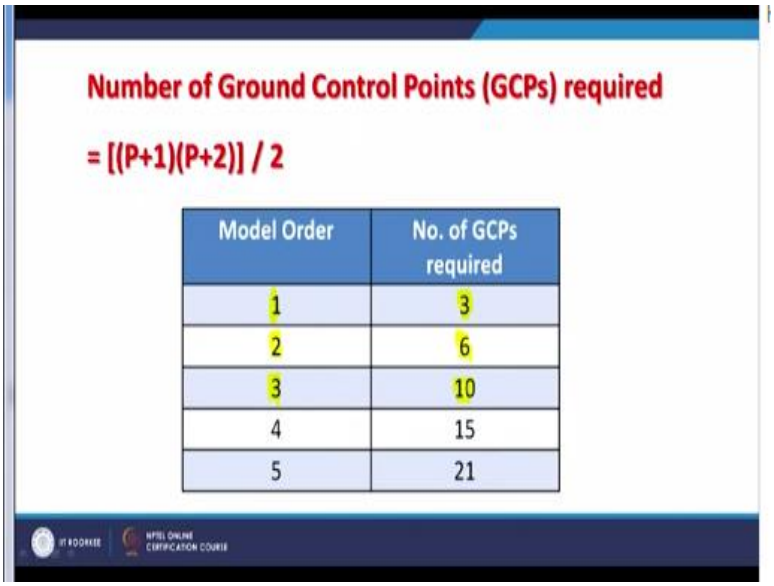

So if I put P = 1 then I am choosing first polynomial order and I would require only 3 control points to achieve a transformation. But if I go for a second order, I would require a double ground control points, if I go for third order I require then 10. So you go higher and higher order

the requirements of control points will increase significantly. If it is not really required only the you need to remove the warping change in a scale and rotation.

Then third order would be more than sufficient, standard software that is why they have implemented. In geo referencing tools they have implemented only up to third order of polynomial equation.

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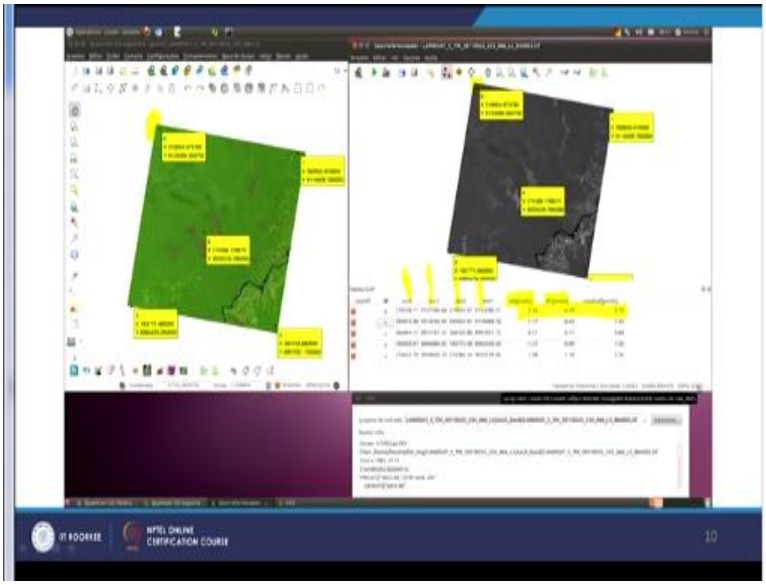

Now how we do it like a on the left side we are seeing an image this is a demonstration of a particular software. So on the left side you are seeing an image which is in geometric domain, on right side you are having an image which is in you know geographic domain. So I will be using the ground control points seeing that the common ground control point is also here.

And by doing this first step that is the registration I will get you know point one by one and I will be registering like this. While doing the registration you get these errors also and how much is a that error is dx and dy that also you will be reading here. So the first these 2 columns are showing the input coordinates these are showing the you know the reference coordinates and then others.

So this route mean is square errors can also be assessed at this stage and the points which you are giving larger errors can be recollected in the image and then can do it. But if somebody is not

having any standard image or geo reference image or map to collect GCP's or not even a GNSS. The other way nowadays is to use Google earth because it is already perfectly geo referenced.

So if the ground control points can be identified in Google earth and you can collect these geographic coordinates that is latitude longitude from Google earth and can feed those coordinates during your image registration. So by which very high resolution satellite images can also be registered using GCP's collected from Google earth. Now once the transformation is found then it is applied for every pixel in the input image.

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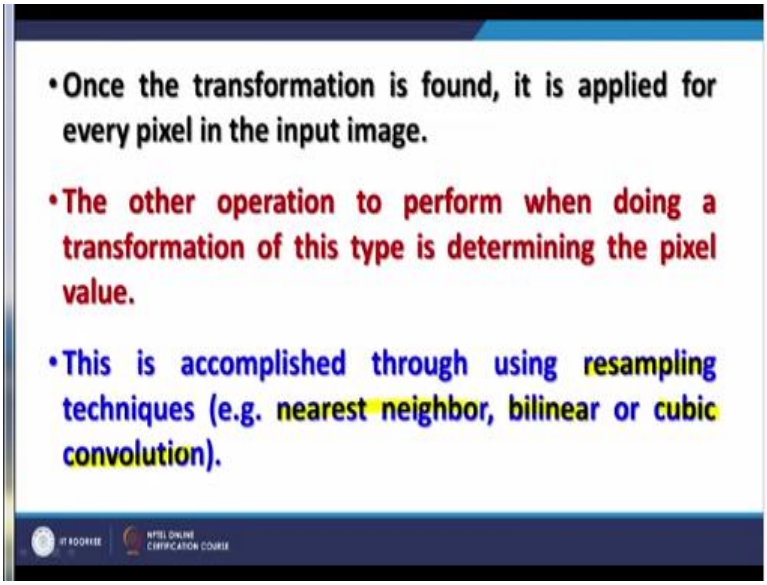

And then the other operation is to perform the transformation once the registration is done then we have to do the transformation. We have to determine the pixel value basically and the pixel value. So first is the registration, second is the transformation that means which pixel will go here. And third one is the what the value is of pixel would be for target pixel and that is achieved by doing resampling.

And there are 3 techniques so far, the simplest one is the nearest neighbor technique, we will be seeing details also. Second one is the bilinear technique and third one is the cubic convolution. So there are 3 resampling techniques and depending on our requirements and constraints, we should choose appropriately. Now the transformation equation polynomial of order of m is shown here.

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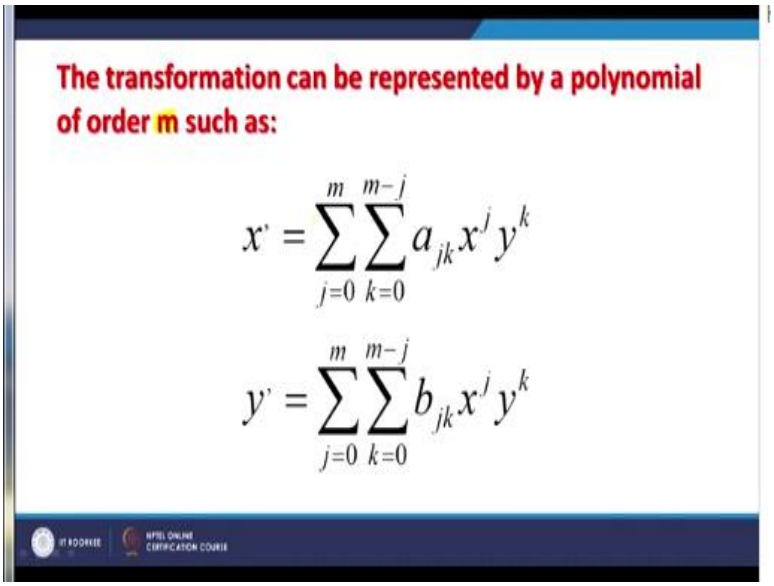

So if you replace with the say first order this becomes a very simple, if you go for second order, you will require more GCP's and second order 6 minimum 6, minimum 6 does not mean, minimum GCP does not mean that you will collect only 4 or 6 or 3. In practice normally it is better to collect more than double, what the polynomial equation is requiring. So if it is written 3 in first order collect at least 6, in second order if it is 6 collect 12.

Because we want to achieve a very high accurate geographic or this transformation function and for that purpose it is better always to go double of the minimum requirement of ground control points.

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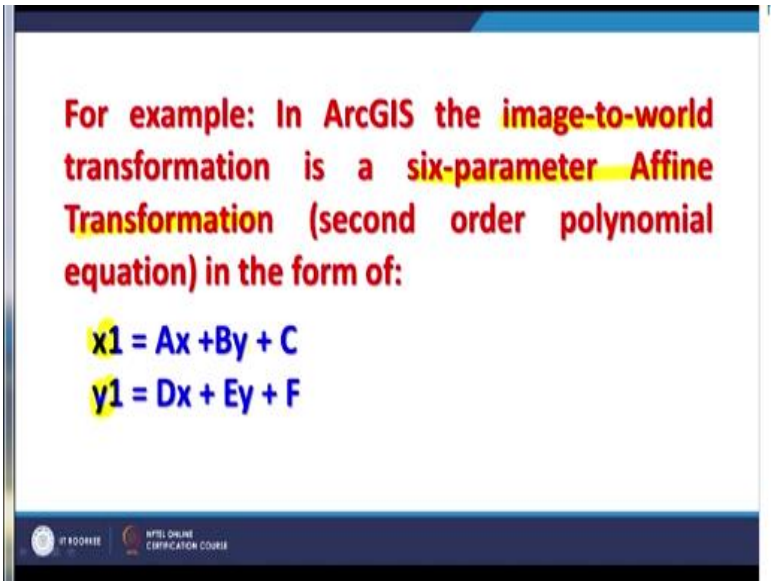

If I take the example of ArcGIS that image to word transformation is a 6 parameter affine transformation and that is second order polynomial equation in the form of like this. So we are going for a geographic coordinates, the output is an a input is from geometric domain and these CNF.

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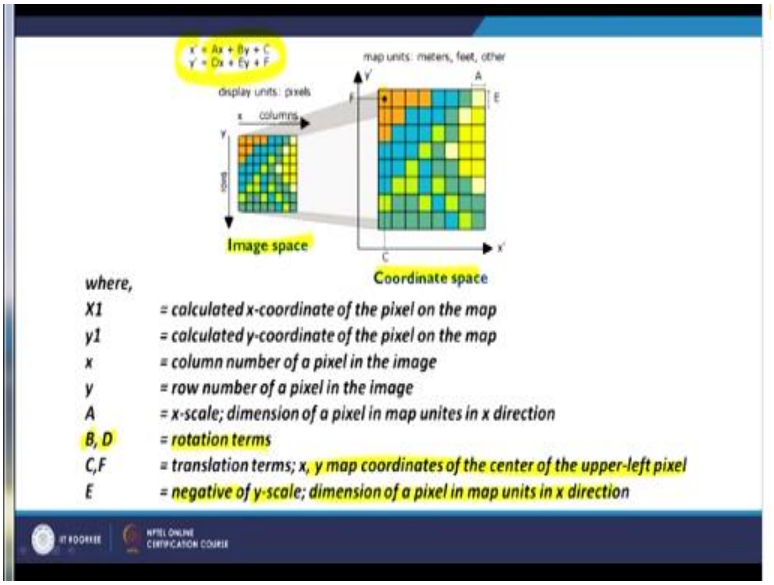

Like here this is image space and this is coordinate space, so this is my input image on the left side, this coordinate space and this equation is here. Now these what are these things, so x1 and y1 are also calculated x and y the target x and y which we are requiring geographic coordinate, simple x is the column number. Because here the coordinates in a raw image will start from top left corner.

So that is why it is column number of a pixel image and then row number of a pixel in the image x the A which will be here A is the x scale dimension of a pixel in a map. That is the basically spatial resolution in x direction of course that same would be in the y direction. And because pixel is always square in shape and B and D are the rotation terms because this is second order polynomial equation. Therefore image might require some rotation or change in a scale, so B and D are there which are here B and D.

So, in a second order transformation and C and F are the translation terms and that means x and y coordinates of the centre of upper left pixel. Because these are coming from there and we want to have image where geographic coordinates will start from bottom left. So translation terms are also used in form of C and F and then E is the negative which is also used here which is the negative because we are coming from top left corner to bottom left corner that is why say here, you have to change this y scale and that is negative.

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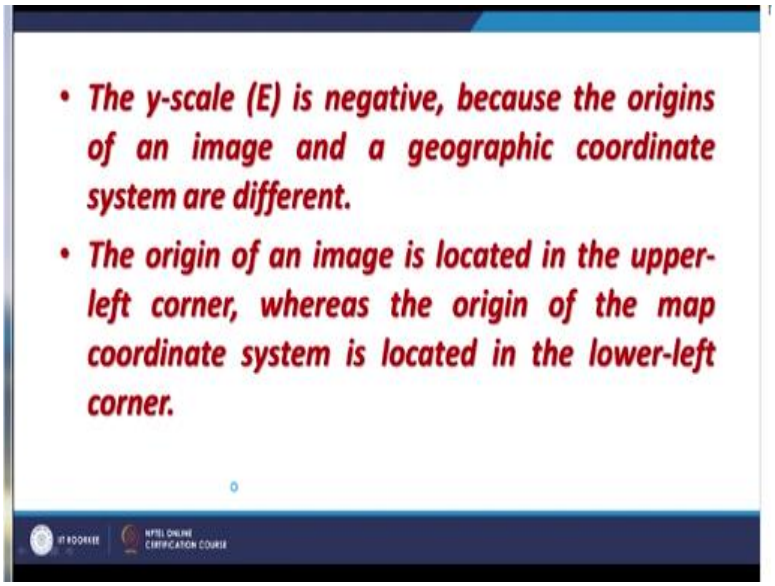

So this y scale E is negative I have already explained because the origin of the image and a geographic coordinate system are different. The origin of image is located in the upper left corner and whereas the origin of the map coordinate system is located on the lower left corner.

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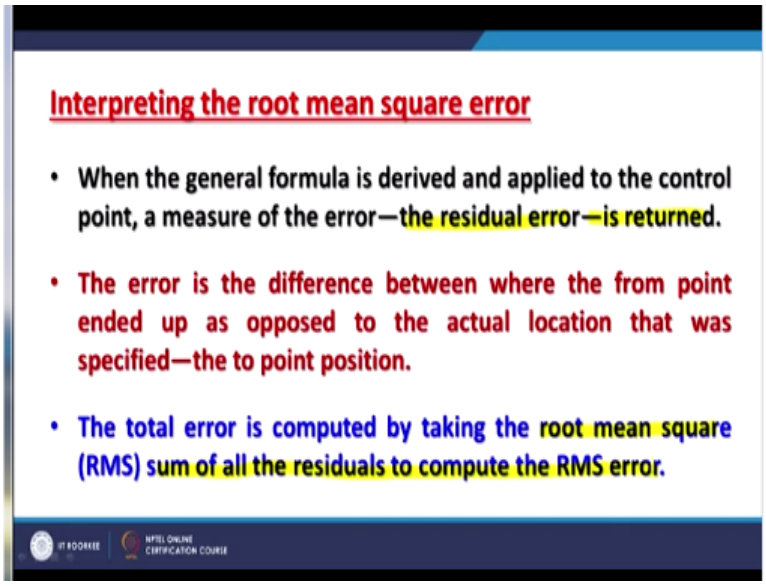

Now when you will be doing registration you get the root mean a square error. So how to interpret these errors very quickly when this formula is applied and then using control points a measure of error that is the residual error is returned. Large the residual error if you are getting a larger residual error, it is better to delete that GCP collect another one. If it is a small reasonably within the 1 pixel in terms of spatial resolution you can accepted.

So error basically as you know the difference between where the from point ended up as opposed to the actual location that was a specified at the point position. And the total error you can also have against the individual GCP's also a total mean a square error is computed by root mean square sum of all residuals to compute the RMS error. So total is important but individuals are important.

So while doing this registration, you would know that which individual GCP's are giving more errors and as I have said, those can be deleted and recollected at different location.

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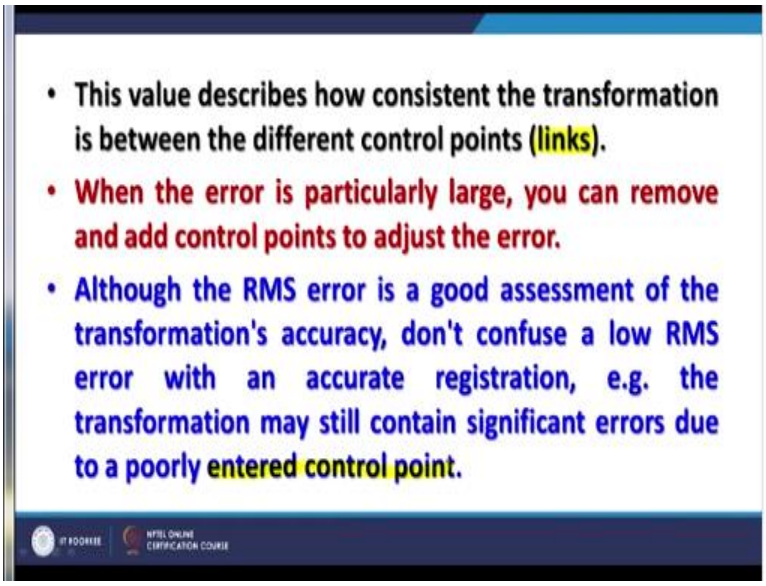

So this value describes how consistent the transformation is between the different control points line or also in ArcGIS per links it is called links. And when error is particularly large, if you know against individual, you can remove and add control points to adjust the error. So while doing this thing, you immediately know the errors. Once you have collected 3 points you go for fourth you start getting the errors.

And although this RMS error is a good assessment of the transformations accuracy but one should not get confuse because of low RMS error with an accurate registration. For example may still contain significant errors to a poorly entered control point because it is up to how reliable that control point is, that is very, very important in this registration process that is the first step of geo referencing.

So as I have already said more the control points more than double the requirement of minimum requirement. As per that formula that how much control points would be required against different polynomial equations. Like for second order 6 are required collect 12, so more the control points of equal quality. Quality, here it is important the quality has to be reliability of control point that what do you are considering as control point is really seen in raw image and master image or on Google earth.

That means you are seeing the same object that has not change, if there are a time difference between input image and master image then one has to be aware that might have changed that location.

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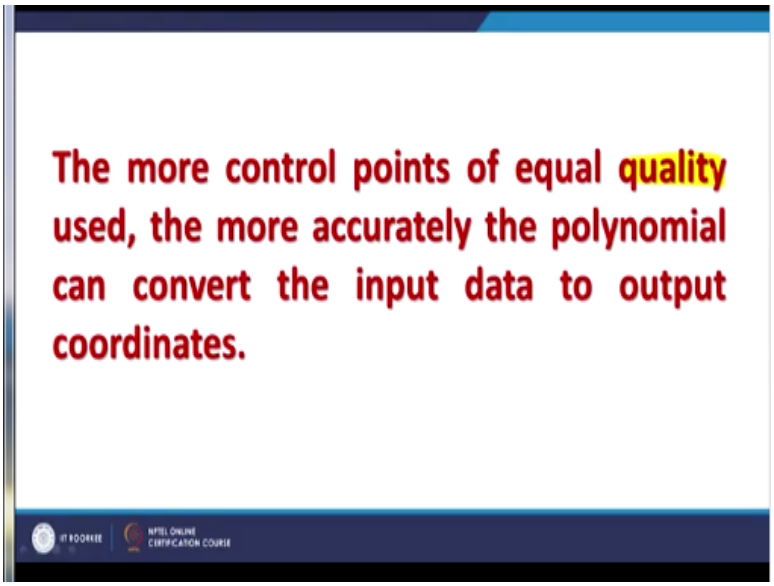

So the quality points are used and more accurately the polynomial can convert the input data to a output coordinate.

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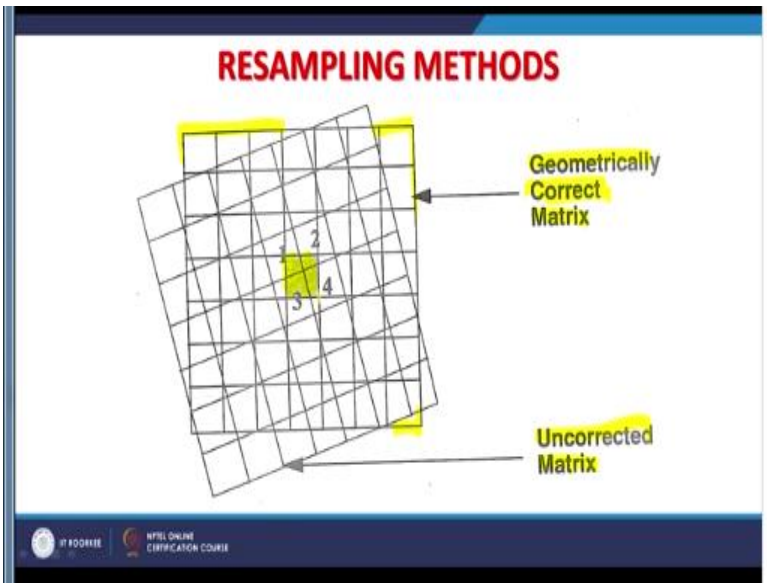

Now the third and last system in geo-referencing is the resampling method by this I will explain first all 3 methods very quickly when we will go in little detail also. So you see in the background this buyer mess which you are seeing in the background, there a grid has been

marked and that is one this one over that one cell is also marked. So from input image when I see this kind of arrangement that this one is the uncorrected image and this is my geometrically correct image that is the my target.

So in nearest neighbour method whichever the pixel is having largest overlap that will the value of that pixel will be transformed to the pixel which is in the geometry corrected matrix, that is so far blank. So the pixel value or the pixel which is having the highest overlap, largest overlap over this empty grid of geometrically corrected that pixel value will be transferred as it is without any modification to a new location.

And the location has already been decided through a transformation, so now what we are deciding the pixel value. If we go for bilinear resampling technique, then 4 surrounding pixels will be considered. Their weighted average will be taken, weighted average means, which pixel of input image is having maximum overlap towards the target pixel. Because location of target pixel is known now after second step, only the value is not known.

So word through resampling we are determining the value for the target pixel. So weighted average of say in this example pixel 1, 2, 3, 4 is taken and that weighted average is assigned to the target pixel and this is bilinear resampling technique. In cubic convolution technique you know 4 by 4 matrix 4 surrounding pixels that means total 16 pixels would be considered. And their weighted average from based on the distance from the target pixel is calculated and that is assigned to a target pixel.

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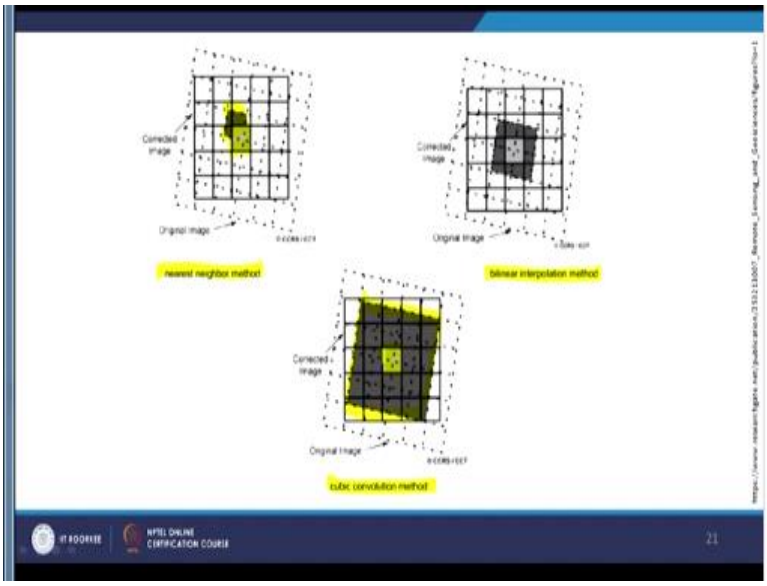

Now let us see individually, here is again here what you are seeing here in the solid lines is the corrected image are the target in the dashed lines you are seeing the raw image. And we want to transform this pixel value which is in dark colour to this one. And by seeing if I go for nearest neighbor then in this technique, this will be assess that which pixel is having maximum overlap with the target pixel and that value is assigned so this is nearest neighbour.

In case of bilinear 4 surrounding pixels weighted average will be taken based on the overlap. So, the one which is having maximum overlap will carry the maximum weight while determining the pixel value. And the pixel which is having the minimum overlap will have less say or less role in the determination of pixel value for target pixel. And in case of cubic convolution 4 by 4 matrix is used and that will be decided based on the distance the target for value for the target pixel.

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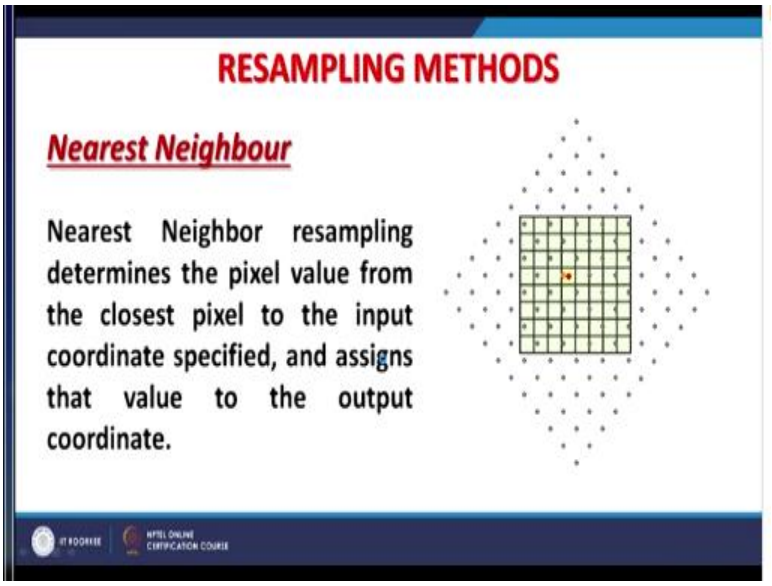

So in nearest neighbor sampling which determines the pixel value from the closest pixel to the input coordinate is specified. Assign that value to the output coordinate without any modification no weighted average, no average based on area overlap or distance nothing simple. Whichever the pixel is having maximum overlap with the target pixel, that pixel value of input image is assigned to the target.

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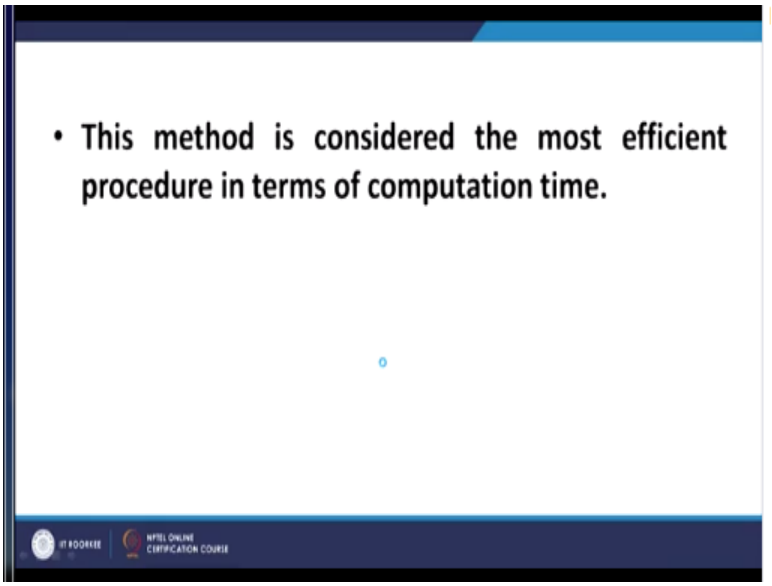

This method is most efficient because not no averaging is done, no measurement is done there is just one the overlapping part is done. And this, so therefore the computation time is less, nearest neighbor does not alter the picture this is very important. If you are going to take that output geo

referenced image for further processing like classification and other things then you must do with nearest neighbor rather than bilinear or cubic convolution.

Remember these 2 other 2 bilinear and cubic convolution will modify your original pixel value and may deteriorates the image quality as well. So if you take an image which is cubic convolution resampled image and perform a classification you may not achieve a very good classification. And contrary to this, if you take an same image in nearest neighbor resampled and do the classification you would achieve high accurate classification. So you to decide one and one can decide based on my purpose or target.

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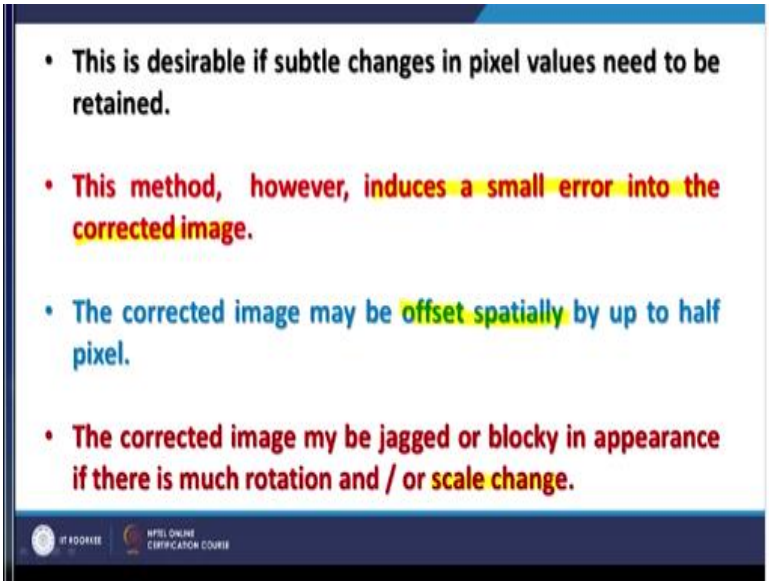

It is a desirable that is subtle changes in the pixel values need to be retained, in many applications it is required. I do not want to you know compromise on the quality of an image. And when this situation is there then nearest neighbor is the most appropriate resampling technique. However, there are some negative points are also associated with the nearest neighbor resampling, that it induces a small error into corrected image.

And what is that a small error is, that maybe offset is especially by up to a half pixel, as you know that if a pixel is occupying the maximum overlap is there, that value is assigned. So there might be an offset especially by half a pixel and that corrected image maybe jagged or blocky or

a stair step case in appearance because of rotation or a scale change which has taken place in second order polynomial transformation.

So that error in this resampling nearest neighbor resampling may come very visible. Otherwise that is a very simple, very efficient and good for if somebody going to use further that image for classification, now next technique is bilinear.

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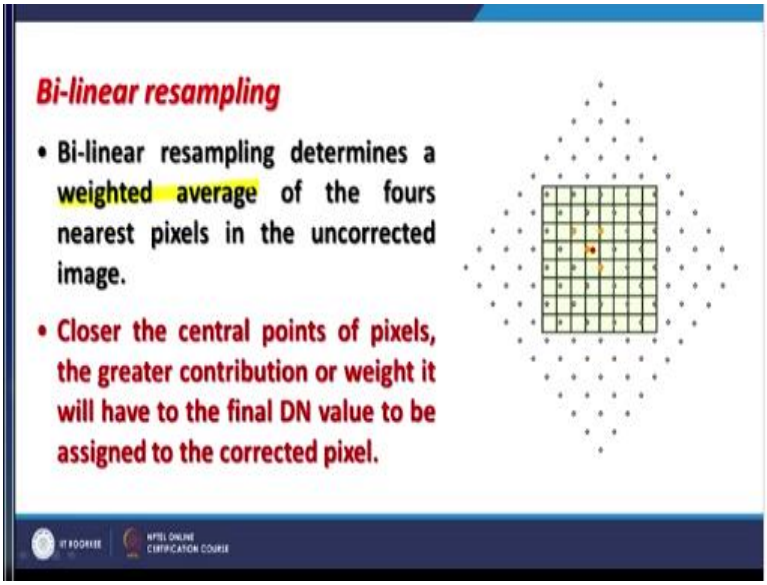

As mentioned it will consider now 4 surrounding pixels and will take it is weighted average and assign the pixel value to the target image. And as you know that the closer the centre point of the pixel or overlap, the greater coordinates are weight it will have to decide the final digital number to be assigned to the corrected pixel. Because the one which is having the nearest or having maximum more level will have maximum say while deciding the pixel value for target pixel.

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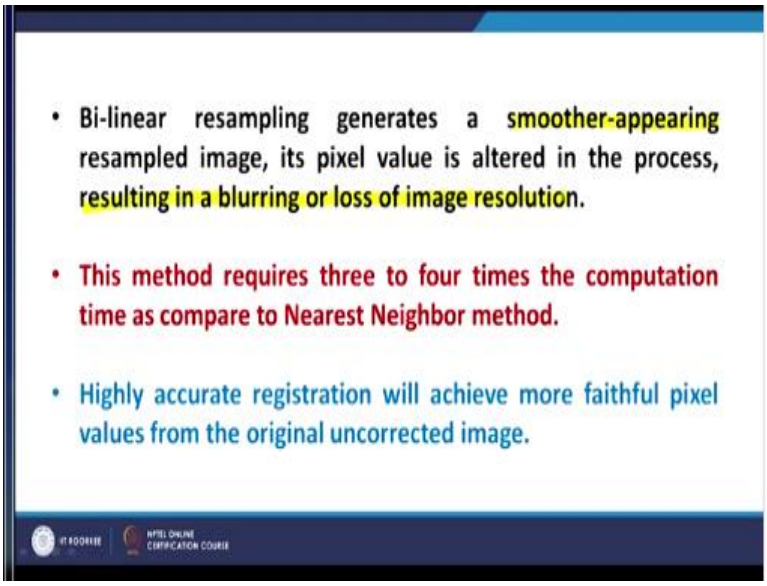

And bilinear resampling generates a better a smoother appearing relatively compared to nearest neighbor resampled image**.** Though the pixel value is altered in this process because weighted average or 4 surrounding pixels have been taken. And that may produce results having a blurred image or loss of image resolution. So one has to be there is what I can say is a trade off.

I am getting a more a smoother appearance image rather than jagged in case of nearest neighbor. But the same time I am getting maybe blurring or loss of resolution in the image. This method requires 3 to 4 times the computation time, obviously because in nearest neighbor no computation except that whichever is having maximum overlap that value is red and transformed to the target pixel.

But here 4 pixels are involved and then calculation which one is the nearest which one is the fairest and then weighted average is taken. So it takes time maybe 3, 4 times then what for nearest neighbor though highly accurate registration will achieve more faithful pixel values from the original uncorrected image. So if registration part is good, you have collected good quality of GCP's and multiple GCP's more than what is required. Then you may get a better output through bilinear resampling technique, the last here is the cubic convolution.

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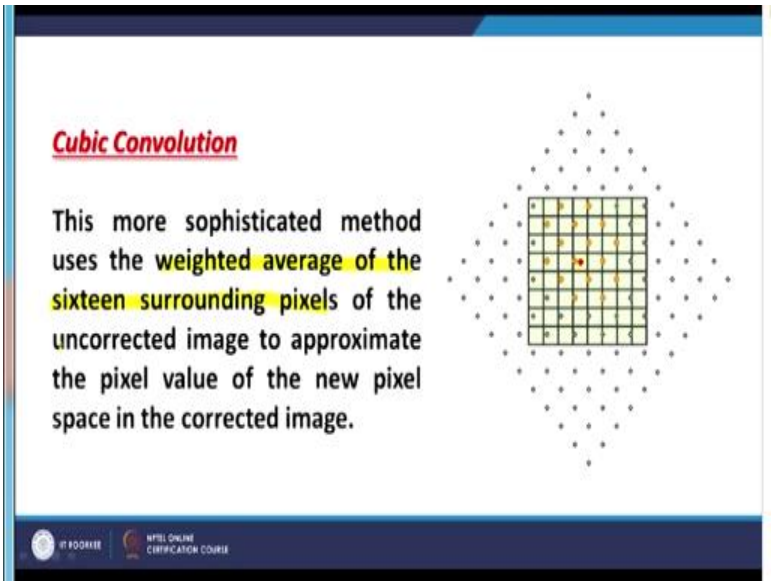

So this is little sophisticated compared to the other 2 techniques which we have discuss which takes the average weighted average of 16 surrounding pixels. As you can see in these pink colours and dots and these from and then a new value is assigned to the target pixel.

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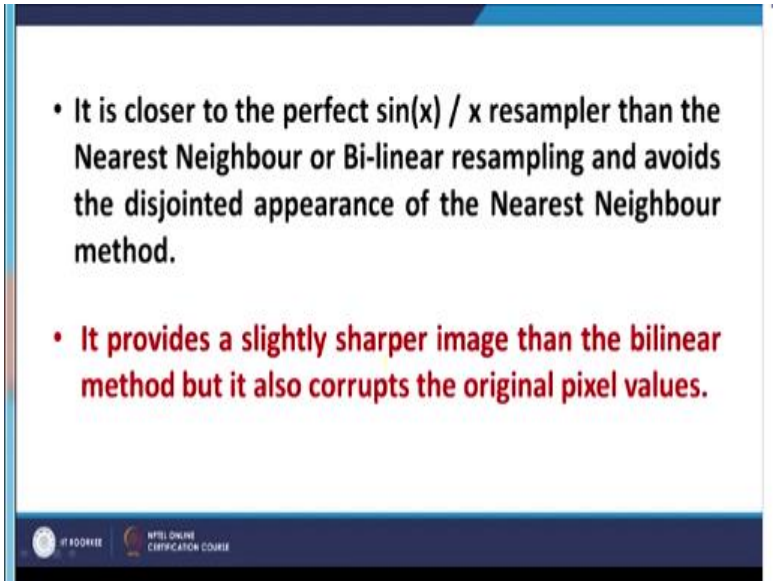

Again the same thing that closer the perfect sin x by x resampler than the nearest neighbor or bilinear resampling. This avoids the disjointed appearance like which is common in nearest neighbor and it provides a slightly sharper image compared to bilinear. But it also corrupts the original pixel value like bilinear. So nearest neighbor is the only resampling technique, which does not modify your original pixel value, whereas other 2 techniques bilinear and cubic convolution, these modifies your pixel value.

So if it these are acceptable in your further work then you use these bilinear or cubic convolution otherwise it is better to go for nearest neighbor.

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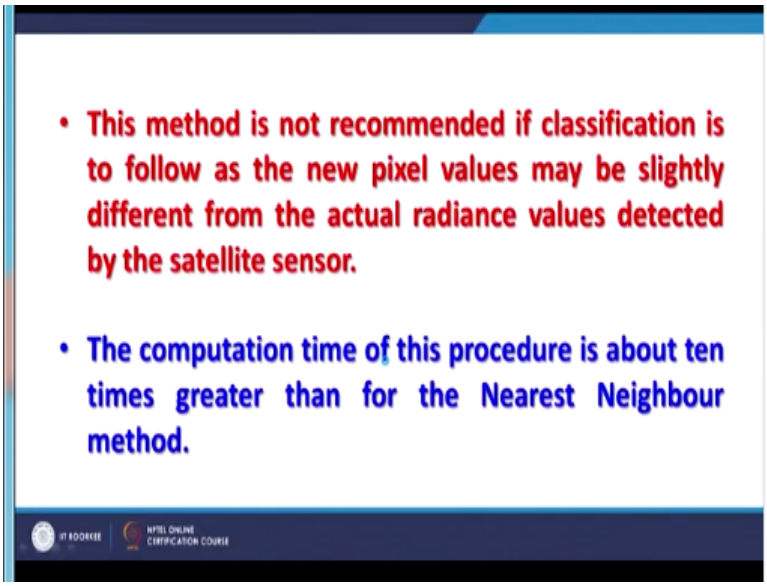

This point I have already discussed that this method that is cubic convolution or bilinear is not recommended for classification to follow. As new pixel values maybe slightly different from actual radiance value detected by the satellite sensor. And the computation time of course, it is going to take much more the nearest neighbor. Because in nearest neighbor only one overlapping pixel is involved, here 16 pixels, there distance is measured, then weighted average is taken.

Therefore it will take more computation time, so this brings to end of this important technique discussion on this important technique which is common in digital image processing as well as in GIS. And as accurately the underlying practice as accurately you would collect the GCP's, as reliable and high quality. You would achieve better registration, you would achieve better transformation and ultimately you would achieve better geo-referencing, so this brings to end off this discussion, thank you very much.