REMOTE SENSING FOR NATURAL HAZARD STUDIES

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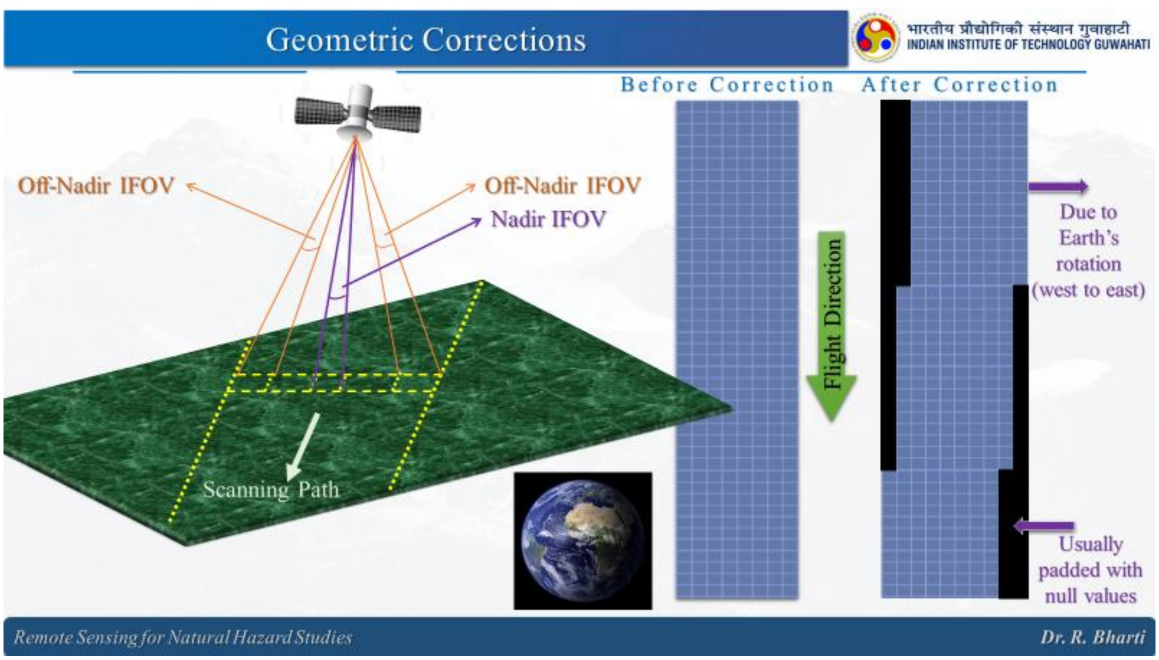
Lecture 3b: Errors in Remote Sensing Part B

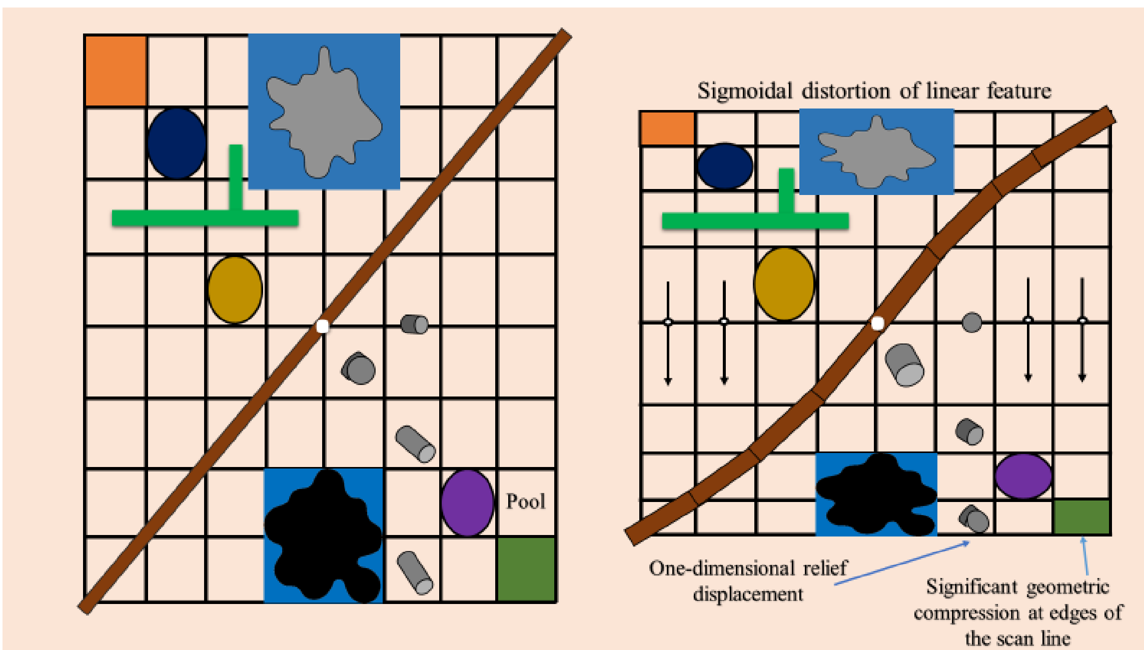
Hello everyone, this is Lecture 3 of the NPTEL course on Remote Sensing for Natural Hazard Studies; this is Part 2. So, we will continue our discussion on geometric errors. So, geometric distortion in remote sensing images that we have already discussed, and now we are discussing what the impact is, or what the benefits of geometric correction are. As we discussed, geometric correction will help you remove the geometric distortion, place the individual pixels in their proper map locations, and also allow us to estimate the accurate distance, area, and direction information. Now we will try to see how this distance, area, and direction information is actually estimated. So, let us say, this is the satellite image produced by this particular sensor. Now these images are basically nothing but pixels arranged in an array, right? So, these pixels are generated by individual detectors which are here. Right, and we call it IFOV. This is IFOV, and let us say that within this field of view, you have this kind of topography. So, what will happen to this particular pixel? This will have less area or maybe a larger area, depending on the topography covered within this. But we generally say this satellite image has a resolution of 30×30 meters, 1 by 1 meter, or 0.5 by 0.5 meters, right? So, in such a situation, what will happen is that the role of this topography is very, very critical, right, or the curvature of the Earth? So, what we do in this particular geometric correction is try to provide accurate shape and size information to our pixels and also their locations. So, if we say that this is 30×30 meters. So, this actually represents the 30×30 meter area, and the features captured in this particular pixel actually match the features present on the ground.

So, if you overlay these images together, they will match with each other. So, that is very, very important, and once you have the appropriate size of the pixel, that means you can say that 4 pixels cover the water body. So, the 4 pixels mean 4 times 30×30 meters, which is the area covered by the water body. So, the area estimation is very easy when you have the proper map location and the size of the pixel. Now, another thing from here to here: if you want to go, whether you have to take this path or that path, the directional information is also very, very important here. So, this is the concept that is used in Google Maps when you try to search how much time it will take to reach a particular location; it will find the available routes and then show how much time it takes to reach a particular location at a particular velocity. So, in such a situation, this geometric correction is very, very important. Geometrically corrected images can be used directly as input in geographic information systems and spatial decision support systems because we are supposed to remove the geometric errors, and then the images will be free from geometric errors. and that can directly go as an input in our GIS or SDSS platform. Better cartographic accuracy is useful for analyzing temporal images from different sensors of different resolutions. Let us say 1 pixel is 30×30 meters. Right, another pixel is 0.5×0.5 meters. So, when we have the proper map location and the shape of the pixel, what will happen is that this will go and sit over its own position. So, it will not occupy this 30×30 meter space; it will just go and sit in its own location. So, the next pixel will be here like this; it will make 0.5 meters that will fit into this 30×30 meter area. So, depending on the size, the number of pixels will be accommodated within the 30×30 meter. Geometric errors in satellite images are grouped into internal and external errors.

Internal and external errors can be introduced by systematic sources, which are predictable because if something is systematic, we already know about it, and we can model them, as well as by non-systematic, or random, sources. So, the random sources are very, very hard to identify and hard to remove. The systematic errors are comparatively easier to identify and correct than non-systematic errors because non-systematic errors are the random ones.

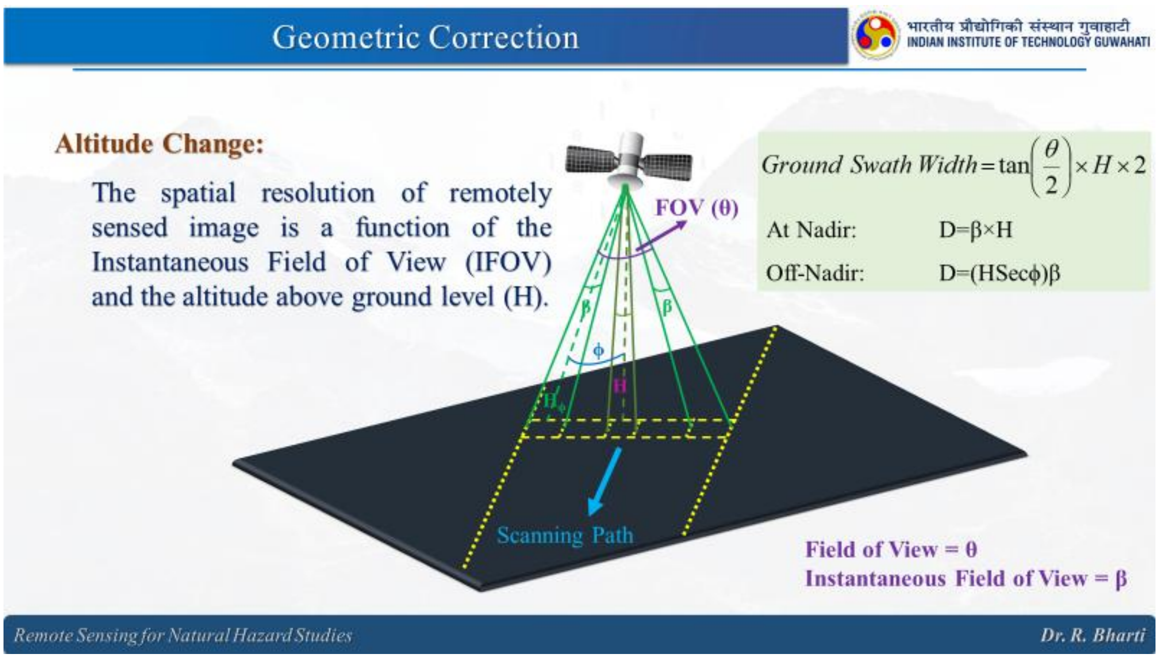


Here you can see that this particular sensor is looking at this particular ground, and before correction, your image will look like this; here you can see. This is the before-correction image. So, you will get a strip, and then in this, you will have all these pixels, right, and associated values. But remember, the Earth is rotating and your sensor is moving from one place to another, isn't it? So, your sensor is moving in an orbit, and the Earth is moving in this direction. So, what will happen after the correction is that you will find that due to the movement of the Earth and the satellite in their orbits, this kind of error was expected. It is not present in the raw data that you have to correct; it is because of the Earth's rotation. So, what we do is try to generate the corrected image, and these columns will have null values; similarly, here all these will have null values. So, this is nadir IFOV, this is Off Nadir IFOV, and here you can see the size of the ground captured by this particular detector at the nadir; it is smaller than the Off Nadir IFOV, right? So, you will have this kind of problem before the geometric correction; once you apply the geometric correction, all the pixels are at the same spatial resolution. This slide explains what happens because of the Earth's rotation and the rotation of the sensor. So, this was supposed to be like that. So, this is the area that is supposed to be captured, but because of the Earth's rotation, you see the road is coming like this, which has some curvature.



This kind of error is being removed because of the geometric correction, right? So, the variation in ground resolution that we have already seen at nadir will be smaller, and off nadir it will be more elliptical, and because of that, your coverage will be greater here than this one, right? Here you can find the best fit square. So, the pixel at nadir will have no geometric distortion; as we go away from nadir, the pixel size will change depending on the flight altitude and IFOV. The relief displacement objects at the nadir will have only their tops visible, while the top and side of off-nadir objects will be visible because when viewed from this side, this side will be visible. Here, only the top view will be visible for this object. If the objects are tall or far away from the center of the image, the distortion and positional error will be larger. This results in the compression of the image features at points away from the nadir; this is called tangential scale distortion. So, here you can see this is a very good example when you have the nadir looking pixel; only the top will be visible, and you can easily find which pixels are off nadir. So, here you can see the off-nadir. So, here the sides of the objects are visible. So, now we will talk about the external geometric error; it is introduced by the random movement of the aircraft or spacecraft, which may vary in nature through space and time.

So, here you can see this spacecraft or aircraft; it can change its direction at these angles. So, this is very, very important to understand that changes in altitude and changes in attitude are affecting our remote sensing data. This kind of error is more prevalent in the airborne survey because the flights are manually operated, whereas in spacecraft, the orbit is fixed. So, there are very few chances of getting any changes in the altitude or attitude, right? So, the altitude changes if you are changing the altitude; what happens? So, if you consider this satellite here, which is looking at this particular ground, and here you have 1 pixel, let us say this is 1 pixel, this is at 100 meters from sea level, right? What if this label is due to the topography? It is 200 meters from MSL because IFOV is fixed; this is IFOV. Altitude is fixed because we are talking about the spacecraft's measurement.



So, this is, let us say, 3000 kilometers. So, when we have the IFOV and altitude fixed, we can estimate how much area it will cover, but actually, because of the variation in the topography, this was not constant at 3000. So, in such a situation, you will have a problem with the object captured within the field of view of one detector, right? So, this is called ground swath width at nadir, and off nadir, what will happen is the field of view is **θ,** here, and IFOV is **β.** So, this is very clear from this diagram. The spatial resolution of remotely sensed images is a function of the IFOV and altitude, right? Now we will talk about attitude changes. So, airborne platforms are significantly influenced by atmospheric turbulence and wind because the turbulence and wind cause changes in the altitude of the sensor, which leads to changes in pixel size.

Due to different wind directions, remote sensing platforms may rotate randomly about three different axes: roll, pitch, and yaw, as represented here. Airborne remote sensing systems have gyro-stabilization units that minimize or remove the effects of pitch, roll, and yaw. So, in addition, remote sensing images with such distortion can be corrected using ground control points. So, now this ground control point is very important.

So, we also call it GCP. So, a GCP is a location on the surface of the earth with known latitude and longitude that can be identified easily and accurately on the remote sensing image and map. Let's say you have a satellite image, which has pixels, and these pixels have latitude, longitude, and DN values. Now, with the DN value, you can enter those latitude and longitude coordinates into your mobile phone or GPS, and then it can show you where you need to go to find that particular point. So, that will be the center of this particular pixel. So, this is called a ground control point. So, when we have one location, which is from the ground, let us say this is a temple or mosque.

So, we can note this location through our mobile phone or GPS, and then we try to locate where it is in this particular image. So, that is called a ground control point. So, here is one example: this is the satellite image, and this is a toposheet. Now, in this satellite image, this is the boundary of this particular object; here, this is the boundary of this particular object. So, this particular corner and this particular corner are both the same.

So we can easily identify them. This is not done visually; when you input the values automatically, your remote sensing software will tell you exactly where it is in your remote sensing image. So, selecting the location of a GCP is very, very critical because over time, the GCP should not change. If you are collecting a GCP, let us say today, and you are trying to use it after 10 years, then you have to make sure that those GCPs you are going to use after 10 years are constant through time and are not changing. So, choose features that are stationary and unlikely to move.

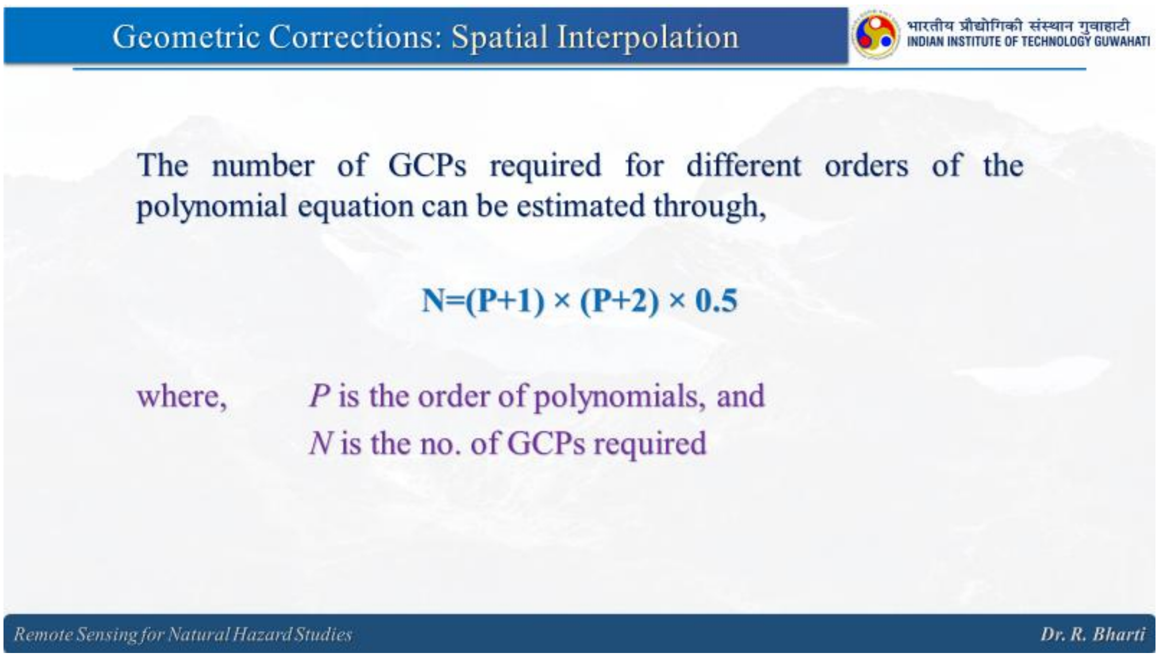
High contrast features with the surroundings are important because they will be easy to locate in your image. Features should not be very big or very small so that their exact location can be easily pinpointed in a single pixel. So, you have to take care of those features that are not recommended, as the first one is the riverbank or course, because over time, they change; the lake boundary also changes, the forest boundary also changes, and political boundaries may change. Agricultural landmarks are changing very frequently because if one person sells, the next person may merge with some other plots, and then the boundary will change. Then, what are the different sources of GCP? The first one is the topographic map, the toposheet, which is generated by the Survey of India.

So, that can be used as your reference map or georeferenced digital image, which is the image that you have already georeferenced, and then that can be used later as a reference for correcting new data. Then the global positioning system (GPS) information on the mobile phone, or the latitude and longitude measured with your mobile phone, is not accurate. So, in remote sensing, when we are trying to do qualitative or quantitative analysis, we generally prefer this GPS, right? Now we will talk about the types of geometric correction: the first one is map rectification, and the other one is image-to-image registration. So, as I mentioned, toposheets are basically generated by the Survey of India, and they have some latitude and longitude marked on these soft copies or hard copies of maps. So, these maps will be used, or these latitudes and longitudes will be used to correct the geometric error of this particular toposheet.

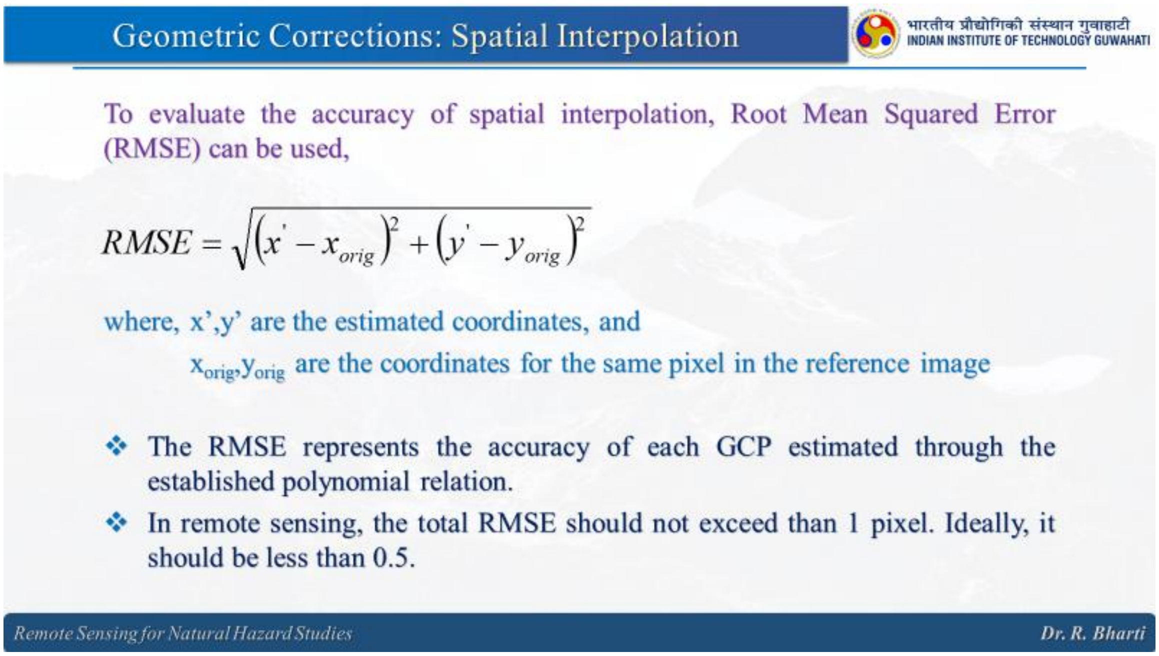
Once we have this rectified map, we can use it as an image-to-image. So, here this image will be your reference image. So, first, we will proceed with the map rectification if you have only one toposheet. And if you are trying to correct your satellite image, then first you need to have a reference map; it can be directly from your GPS, or it can be from a toposheet. To estimate the accurate area, direction, and distance information, it requires GCP or registered map coordinates corresponding to the unregistered map coordinates, which means your image captured by a satellite is basically unregistered and then you have the GCP from the field or maybe a registered map from one of the examples, which is a toposheet, that you will be using to correct these unregistered image coordinates. The reference and target images of the same topographic area and aerial extent are needed. So, the spatial extent of the toposheet and the satellite image should both be the same. Through the translation and rotation alignment process, the target image will be adjusted for each pixel with respect to a reference image or provided ground control points. Geometric registration of images: the process of projecting two or more images of an area acquired by different sensors into a single coordinate system based on the transformation parameters and producing the best match at the pixel level.

So, here we have two parts of the geometric rectification. So, the first one is spatial interpolation, and the next one is intensity interpolation. So, in spatial interpolation, we are basically trying to reorient our pixel, right? So, the same feature in both the reference and target images must be identified. So, now you have a toposheet that is corrected, and all these points are known. Right, and then this is your unregistered map, which is basically your satellite image. So, the same feature in both the reference and target should be used. So, let us say that here you have a building which is not going to move, and here is the building, right? So, I am selecting this particular pixel here and this particular location on the map. The coordinates of the target image pixel are referred to as x', y', and the corresponding pixel coordinate in the reference image is x, y. So, this is x, y, and this is x', y'. Using such information, a relationship between the reference and the target image is established, which is used for the geometric coordinate transformation.

Now suppose this is the first ground control point that we are taking from the toposheet. Another one is, let us say, this is one feature; this is another feature, right? So, the second point we have taken. So, this will be x1 y1, this will be x' y', and then this is the second point. Similarly, you will have to identify a good number of points so that you can generate a correlation between these two. Polynomial equations based on the least squares criterion are used to establish the relationship between the reference and target image coordinates. Depending on the degree of distortion in the target image, the number of GCPs and the order of polynomial equations are decided. So, here you can see that this is the first order, the blue one; the second one is here, this is the third order, yellow is the fourth order, and this one is the fifth order. So, the fifth order represents this data variation very nicely. So, depending on the degree of distortion in the target image, the number of GCPs and the order of polynomials are decided. Geometric coordinate transformation addresses the following types of distortions in remote sensing images.



The first one is translation in xy, then scale changes in xy, then skewness, and then rotation. All of these will be addressed in the geometric correction. The number of GCP required for different orders of the polynomial equation can be estimated through this equation, which is $N=(P+1)\times(P+2)\times0.5$. So, P is the order of the polynomial, and N is the number of GCPs required. It is very important that you select an appropriate number of GCPs depending on the polynomial equation that you are going to use for spatial interpolation. To evaluate the accuracy of the spatial interpolation, the root mean square error (RMSE) is used. So, this is the general formula for RMSE. But here is one thing that is very, very important: if your RMSE is 0.5 or if your RMSE is 1.5. So, what will the difference be? So, it says that if your processing has an RMSE of 0.5, that means the object that was supposed to be within this particular pixel might be diverted from its original position by 0.5, which means half of the pixel. It is within this particular pixel, but when we say 1.5, that means it is going beyond this boundary, and it is getting located in the next pixel. So, it is a rule of thumb that this RMSE should not be more than 1 pixel. So, this is very, very important because if it is more than 1 pixel or if it is more than 1, what will happen is that the feature is getting shifted to another pixel. Now, we will talk about intensity interpolation. So, this process involves extracting the brightness value from the target image. So, what is happening now? From the spatial interpolation we did, we have reoriented the pixels so that their shape and size are consistent.



Now, this is the raw data, let us say, and here you have the pixel values. So, which pixel value will be located here: whether it will go here, or whether it will go here after the spatial interpolation? So, for that, we have to do this intensity interpolation. So here, basically, we are talking about the DN number and how it will be placed in a particular pixel. So, the pixel value from the target image can be extracted using the following resampling technique. The first one is the nearest neighbor, the next one is bilinear, and the third one is cubic convolution. So, the nearest neighbor resampling technique says that it will use the closest pixel value, right? So, it will be using the closest pixel. So, this is the target; this is the rectified image, right? Now, when we talk about the bilinear, what will we do? We will be using the average of 4 adjacent pixels, and that value will be placed here. What happens in cubic convolution? We are using 4×4 pixels to calculate the average, and then it will be placed in the target or in the final output. So, the difference between cubic bilinear and nearest neighbor is the resampling and averaging of the pixel values. So, now suppose your objective of remote sensing is to identify the material characteristics or whether it is present or not based on the characteristic absorption feature.

Now, if you have used the bilinear interpolation or the cubic convolution, what will happen? You are using the average one; you are using the average value. So, the real value captured by the sensor is changing, and this averaging has equal weight from all these pixels. So, if it is averaged, the real value is lost, and that value cannot be used for any quantitative analysis. You cannot use any image that is corrected through cubic convolution for material identification using the characteristic absorption feature correctly. So, you have to be very, very careful. Now this is an example of your geometric correction. So this was the input image, and this is the output image. Now we will talk about radiometric error. So the response of the remote sensing sensor cannot be linear, right? So one thing that we discussed is that this is the sensitivity of a detector, right? So, it says that it can absorb or sense energy with a wavelength of 400 to 500 nanometers, but if you look at this particular region, it does not have good sensitivity. So it cannot be linear.

The sensor launched for remote sensing essentially goes through prelaunch and in-orbit calibration. In a remote sensing image, noise error can be introduced at several stages. Radiometric noise is one of the noises introduced by the sensor system to the remotely sensed image. It results when an individual or set of detectors does not function properly or is improperly calibrated. So, the radiometric errors are generally introduced in the remote sensing system by mechanical, electrical, or communication failures. Sometimes the detector stops working; sometimes it is for a moment, sometimes it is for a longer period, and sometimes, during the data transfer to the ground station, there is a loss of signal, which may cause a change in the value or result in missing values in your image. These are the unwanted disturbances or noise in the final image due to flaws in the remote sensing instrument, electronic disturbances between the sensor components, and potential distortion in the data recording processes. So, there are different types of radiometric errors. The first one is a random bad pixel, then line start or stop problems, line or column dropouts, partial line or column dropouts, line or column stripping, smiles and artifacts, and adjacency effects.

These are the errors due to the radiometry. Now, this is one of the examples of line or column dropout; here, you can see this particular line, which is an error. So, this is one of the detectors that stopped working. So, we have removed anything from this particular image; you cannot find anything here. So, this kind of radiometric correction takes place in remotely sensed images. This is another example; here you have N line stripping. So, you can see these white lines. Right here, and these are the radiometric errors; this is called N-line stripping. So, after correction, this can be removed.

That is all about the errors in the remote sensing data; with this, we are finishing this lecture.

Thank you.