Remote Sensing: Principles and Applications
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Lecture – 23
RS Image Acquisition and RS Systems – Part 6 (Spatial Resolution)

Hello everyone, welcome to today's lecture in the course remote sensing principles and applications. Over the last few lectures, we are discussing about the characteristics of remote sensing systems, how images are acquired, and how the characteristic of the system will affect our data and all these concepts. So, today, we are going to continue with these concepts.

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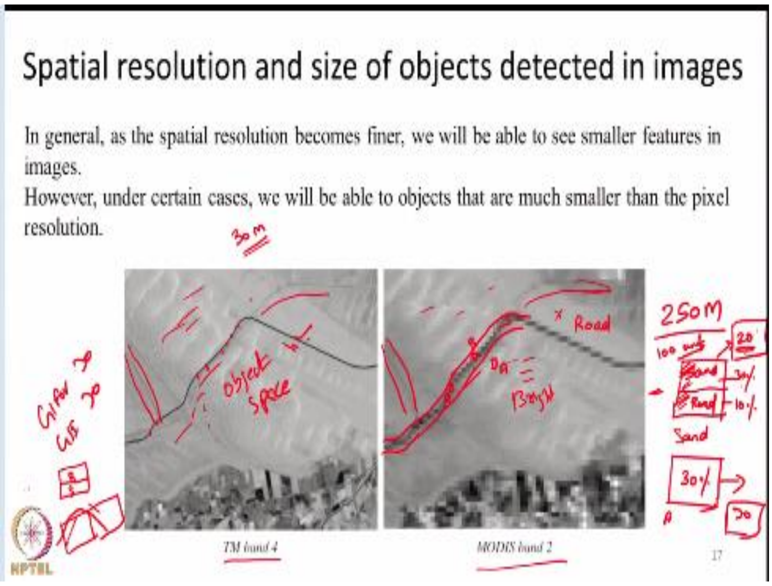

In the last lecture, we discussed about how the spatial resolution of an object like objects that are smaller in size than the pixel size or than the GIFOV are detected in one particular pixel.

So, some basic concepts we have seen and we also noted the factors that enable us to see objects that are smaller than the GIFOV that is the contrast in the object space, the point spread function or MTF, Modular Transfer Function of the sensor, the signal to noise ratio of the sensor and also the spatial context in which the feature is located.

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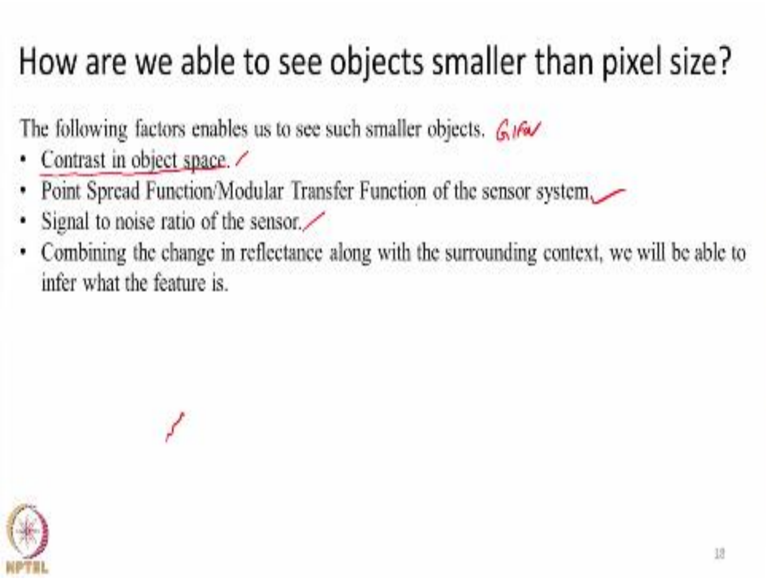

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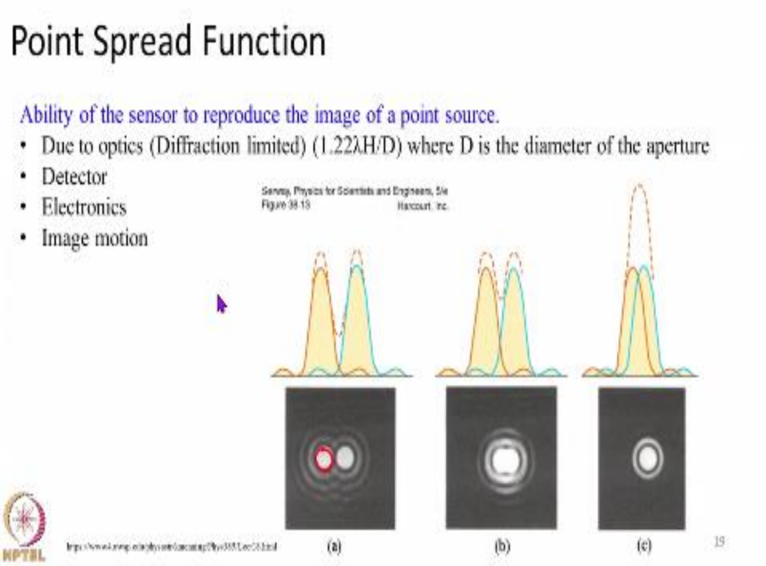

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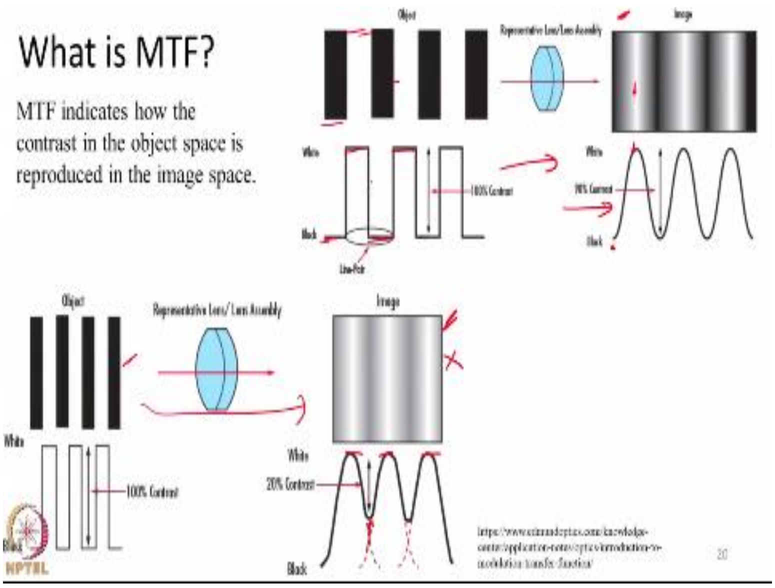
We saw what point spread function is, a basic explanation I gave. Similarly, what MTF, again another basic explanation I gave.



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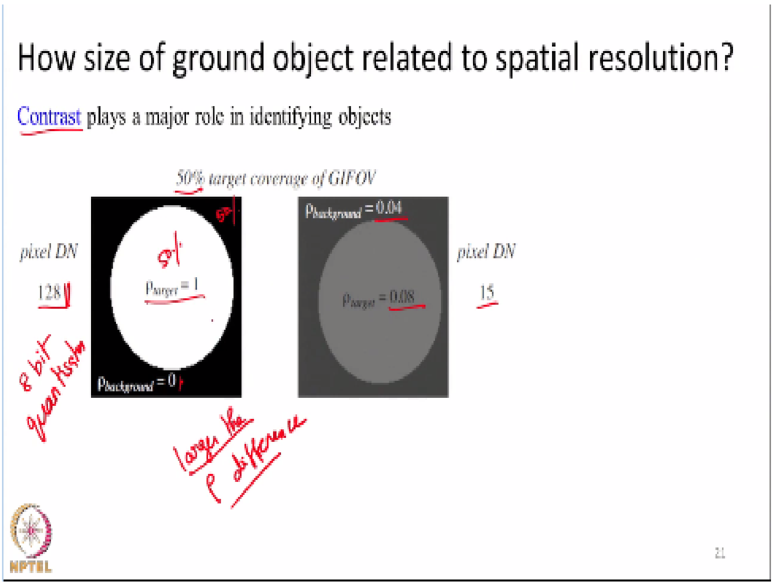

So, today, we are going to continue with the further details about how objects smaller than a pixel size can be detected. So, already I explained you clearly that contrast plays a major role in identifying an object. So, this slide gives a very good example where the reflectance of the background and the target is given. So, here background is 0, target is 1. Here, the background is 0.04, for target reflectance is 0.08. Assuming both of them cover 50% each of the GIFOV. So, this covers 50% of GIFOV, this covers 50% of GIFOV and so on.

So, the average reflectance or the average DN that will be produced in this case is 128, assuming an 8 bit quantization whereas for this particular pixel, where the difference in the reflectance is pretty low, will be 15. So, how contrast the background and the feature is going to play a major role. The larger the contrast difference or larger the reflectance difference between the background and the feature of our interest, we will be able to identify the object more clearly. Actually, that is what happened in this particular example, which I showed you in the last class, there is a very large difference in the reflectance between the sand and this particular road. Because of the large difference in reflectance or the large contrast between the object of interest in the background, we are able to infer or interpret this particular road properly even in a coarse resolution image such as MODIS.

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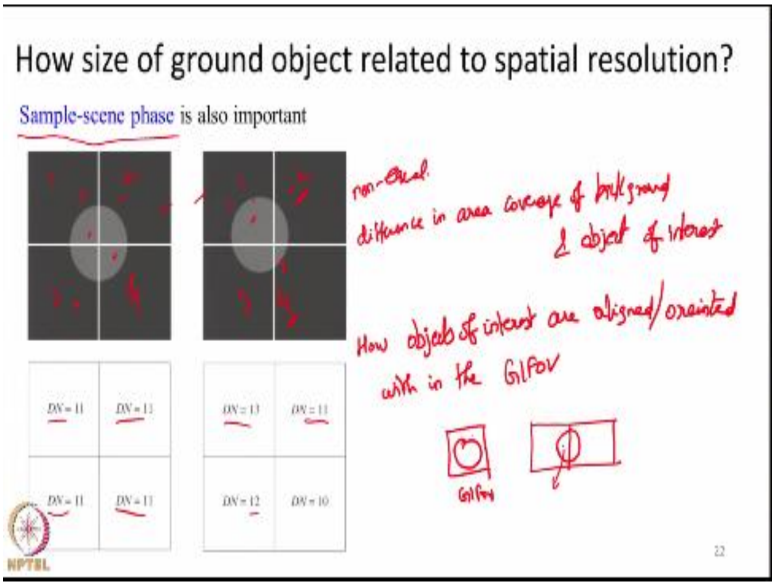

And also one more thing we have to notice, in addition to the contrast between the background and object, the sample scene phase is also important. Sample scene phase means how the object of our interest is oriented with respect to different pixels. Say for example, this is 4 adjacent GIFOV elements, a single feature of our interest oriented like this. It is equally distributed among this 4 pixels, 4 GIFOV elements. Whereas here, the same object is now distributed in a non-equal fashion in the 4 GIFOV.

So, essentially, what will happen? The DN values finally that is being produced is going to be different because of the change or the difference in area coverage of background and object of interest. See, this is our object of interest. This covers uniform area in all these 4 pixels. Whereas here the same object of interest is not covering uniform area in all the 4 pixels.

It has a larger coverage in this particular pixel, very low aerial coverage in pixel number 4, again, limited aerial coverage in pixel number 2 and so on. So, when we get our final image, our ability to identify this particular feature will vary between these 2 images because of how the objects are orienting itself with respect to image.

So, that is basically how objects of interest are aligned or oriented within the GIFOV. So, say for example, if this is one pixel, say one GIFOV and this is the object of our interest, so, our object of interest will be much clearly seen in the GIFOV provided there is a very high contrast. But let us imagine this particular example having 50-50% contrast difference.

Even in this case, if the bright object is oriented like this, instead of being oriented in one pixel, then the DN values for these 2 pixels will differ. And our ability to identify this object of our interest will change. So, essentially, under some circumstances, we will be able to identify objects that are smaller than GIFOV. It is possible. So, some of the factors we have already seen. In addition to all these factors, the alignment or the orientation of the object of our interest in the image space or in the GIFOV elements, whether it is occupying one full GIFOV or it is distributed among many different GIFOV in small, small areal extent and so on, are going to control our ability to identify that particular object. Till now, we have discussed in detail about the concepts of spatial resolution and so on.

So, now, we will go back a little and understand some characteristics about Whiskbroom scanning and Pushbroom scanning, some more characteristics. So, I said in Whiskbroom scanning, satellite will be moving in the along track direction and the scanner will be scanning in across track direction. So, I was repeatedly telling some terms such as dwell time or time of integration and so on.

I also told you that the dwell time in Whiskbroom scanning will be very low and it will be little bit higher in Pushbroom scanning. So now we are going to see, what is the concept of dwell time and how this will vary with respect to each type of scanning.

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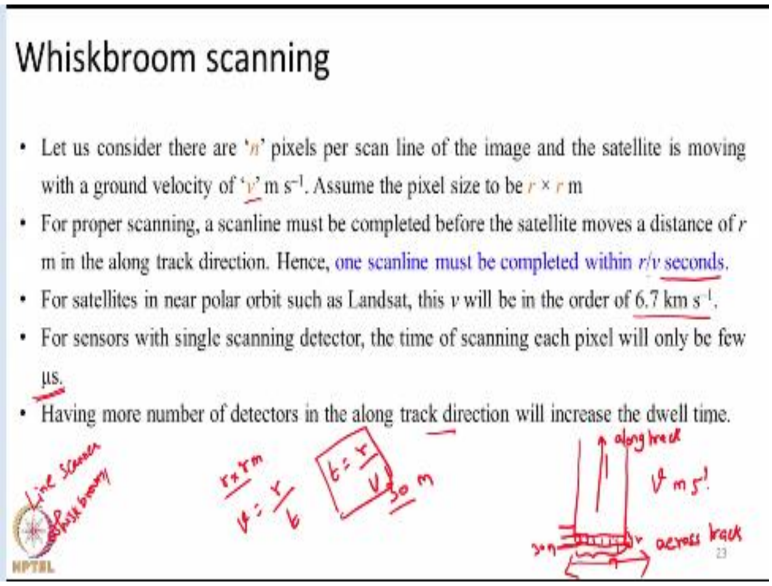

So, let us consider there are n pixels per scan line of the image. Let us say, the satellite is moving in the along track direction and the scanner will be scanning in the across track direction. And let us assume there are n pixels in one scan line. The satellite is moving with a ground velocity of v m/s and assume the pixel size to be r×r. The satellite is constantly moving and hence the scan line must be completed before the satellite moves ahead by a distance of r. Let us take, for example, the case of Landsat 7 whose pixel size is 30 meters.

So, the entire scan line along this particular across track direction must be scanned completely before the satellite moves a distance of 30 meters. Then only there will not be any data gaps. Else if the satellite is moving at a faster rate than the scanning rate, then some pixels here will not be scanned properly. So, in order for us to collect all the data without any missing points, it is necessary that the scanning is completed before the satellite moves ahead by one pixel size, that is by r meters. Here in the example of Landsat, the scan line must be completed before the satellite moves 30 meters. So, what is the time taken for one full scan line? One scan line must be completed within r/v seconds, that is, velocity = distance/time.

So, the distance has to be covered is r divided by time, so, time = r/v seconds. So, within this particular time interval, this scan line must be completed. So, for satellites in near polar orbits such as Landsat, velocity will be around 6.5 to 7 kilometres per second that is, every second the satellite will be moving with a velocity close to 6.7 kilometres per second, which is pretty high.

And hence, for line scanner, which has only one detector element or Whiskbroom scanner, which has a small number of detectors will have a very small dwell time in the order of microseconds. So, having more number of detectors in the along track direction will increase the dwell time by some extent.

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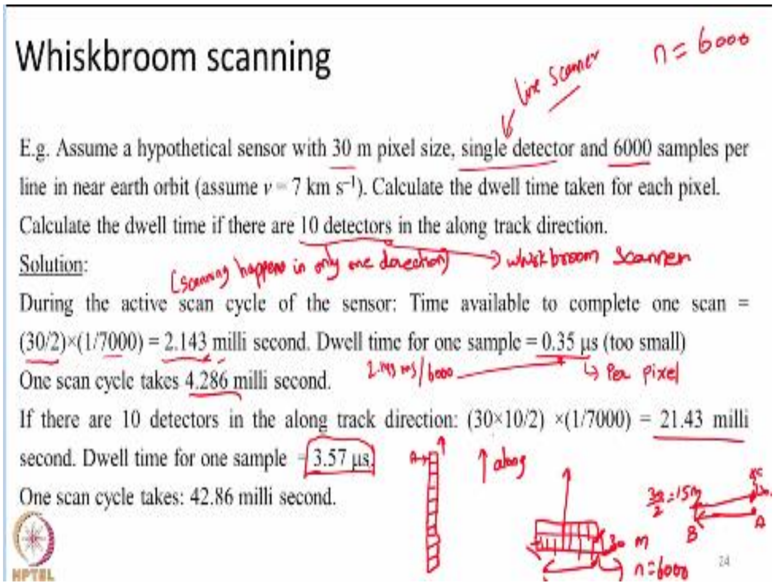

So, here in this example, assume a hypothetical sensor with 30 meter pixel size single detector, so, this is essentially a line scanner. It has only one detector. And 6000 samples per line that is in the last theoretical explanation I gave, n is 6000. 6000 samples per line in the nearer orbit assume v is equal to 7 kilometre per second. Calculate the dwell time taken for each pixel. So, now, for a line scanner, we are going to calculate the dwell time.

So, traditionally, before the satellite moves one pixel distance ahead, the scanning should be complete. In some scanners, the scanner can scan in both the directions. It will start from here, scan one full line, then it will scan the next line and so on. Because it scans one line the satellite moves, it scans the next line the satellite moves. This is possible in some scanners.

In some olden day scanners, the satellite or the sensor can scan in only one direction that is, it scans like this, it covers one full line. It has to come back again to its starting position before the satellite moves to the next position that is, full scan, come back, satellite moves to the next pixel, full scan, come back like that it will scan. I told you that time taken or time available for scanning is r/v second. But if the satellite can scan in only one direction like olden day Landsat satellites which can scan in only one direction. It has to go back to its starting position before it can scan the second line. If that is the case, the time available per scan line will be not r/v, but it will be r/2v.

So, the time is now even reduced by half. This is called active scan phase or active scan time. scanning is happening, so one line is scanned. Now, it has to go back without doing any scanning. So, it has to go back. So, that is called dormant time, dormant, it is not scanning actually. So it scans, it goes back; next line it scans, it goes back; next line it scans and so on, it proceeds.

For such sensors, the time taken will be r/2v. So, the time available is still half. So, here, we will see what will be the time available if the scan is happening in only one direction. So, here, during the active scan cycle, we are assuming scanning happens in only one direction. So, the time available to complete one scan is 30/2. Here, I am bringing in the factor of 2 that is, the pixel size is 30 metres.

So, essentially the satellite is moving like this, let us assume the scan starts from here and it moves here. It has 6000 pixels, n is equal to 6000. So, before the satellite moves to this second line, the scanner should start from here, scan to the end of this line. And again, it should go back to this point, the satellite would have moved by a distance of 30 metres. The scan should start from this end and it should reach this end before, the satellite moves a distance of 30/2 that is, 15 metres. Then only, for the remaining 15 metres, this point can go back here and be ready in the starting position again. So, here it is (30/2)/velocity is 7000 metres per second, everything we are converting into metres.

So, this gives 2.143 milliseconds that is to start from this point A and end the scanner B, the active scan is 2.143 millisecond whereas the total scan time, start from A to B, and end at point C at the end of 30 metres is twice of it, 4.286 millisecond. So, before the satellite moves one distance of 30 metres, it should complete this scan, go back to its initial state and be ready for its next scan lining. So, the total time available for this entire cycle to be completed, once scan go back to the starting point and be ready, this entire process is 4.286 milliseconds.

So, in one scan of 2.1 milliseconds, it has to now collect 6000 samples. Hence 2.143 milliseconds divided by 6000 samples will give you 0.35 microseconds per pixel. Hence, to collect data about one pixel, the sensor has a time of 0.35 microseconds extremely small value. This is assuming a single detector and scanning takes place only in one direction.

So, this is like highly restrictive whatever I said. Now, we will see what will happen if we have 10 detectors in the along direction that is for Whiskbroom, we spoke about line scanner. Now, we will talk about Whiskbroom. What will happen if we have 10 detectors in the along track direction? Assuming, there are 10 detectors in along track and the scanning takes place only in one direction, like the active scan time is half the total time. Then the time available for active scanners 2.143×10, because here for one detector, we got 2.143 milliseconds multiplied with 10, we will get 21.43 milliseconds. Because, as the number of detectors increases, the time available for data collection will increase.

let us assume, there is a point A here. So, first detector number 1, we will see point A. Now, the satellite will move to one pixel detector B will again see same point A and the signal will be sent to the corresponding pixel in the image. Similarly, third detector will again see point A, but the signal again will be saved here for the same pixel on the ground. So, the concept is very simple, the same point on the ground are seen multiple times by different, different detectors.

And all the signals are combined together to produce the signal for one pixel. So, the same ground point A will be seen by a series of detectors as the satellite moves. And all the signals collected for that particular ground point will be processed and saved together for one ground point, which implies that instead of collecting signal with only one detector, we are now collecting signal with 10 detectors over the same point which increases our time available by 10-fold.

If we have six detectors, we have six x more time. If we have 16 detectors like Landsat had 16 detectors, then we will have 16 x or 16 times more time available than the time taken by one detector that is the idea. So, same ground point can be imaged by different, different detectors as the satellite moves in the along track direction that is how Whiskbroom scanning works conceptually.

So, if we consider 10 detectors in Whiskbroom direction, then the time available for one scan line, one active scan line is 21.43 milliseconds, 10 times more than our line scanner case. And hence, the time available for one sample is 3.57 microseconds, which is higher than 0.35 microseconds, 10 times higher than 0.35. So, having more number of detectors in the along track direction that is Whiskbroom scanning will help us to get more dwell time than having only one detector called the line scanner.

One more problem or one more issue with the Whiskbroom scanner is, scanning is happening simultaneously when the satellite is moving forward. So, what we assumed here in the last example problem, we assume the scanning will be over, satellite will move to the next point. Scanning will be over, satellite will move that is how we assumed and did the problem. In reality, scanning will happen simultaneously as a satellite moves. So, as the scanner scanning, the satellite will be moving forward.

So, the scan will not happen like this in a perfect perpendicular direction, it will happen like in a skewed direction, that is, the satellite will be moving together and scanning will be happening like this.

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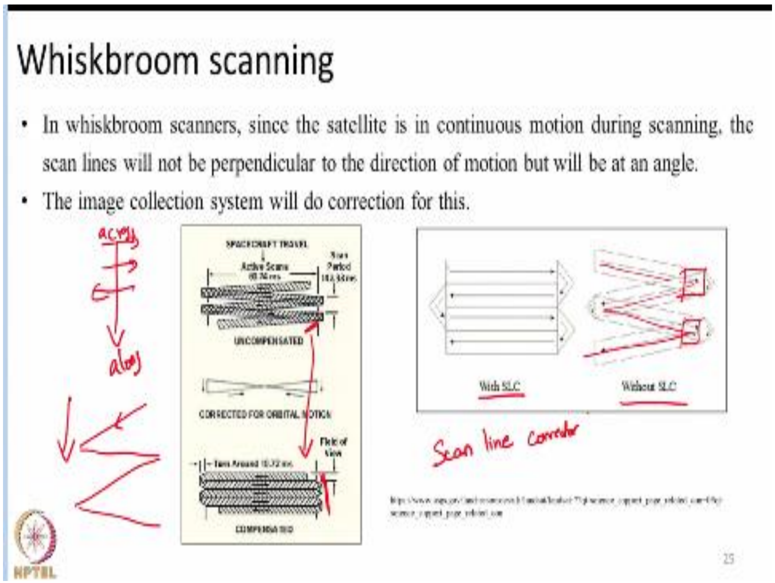

So, look at this particular figure in the diagram. So, the scanning will not happen like this. This is along track and this is across track. Scanning will not happen like this, but it will happen like this because the satellite is moving as the scanner is doing its scan. So, essentially, people who design the sensors will adjust for all those things.

Like, they will ensure there is no data gap. There is no gap on the ground before the scanner completes one scan line. So, there must be some sort of correction mechanism as the satellite is continuously moving like this, but finally when we get an image, we get a proper image with all the pixels in its space. So, essentially some sort of image correction has to be done to convert this non-perpendicular scanning geometry into a proper image. So, we call it as a scan line correction.

So, most of Whiskbroom scanners will have a scan line corrector. Especially for satellites like Landsat 7 and all, the scan line correction becomes even more important, that is, the nature of the skewed data acquisition must be corrected. And we must be in a position to create a proper image without any gaps. So, this sort of image must be corrected to get this sort of image. That is, with the scan line corrector on, we will have image properly aligned like this. But without the scan line corrector, the scan line will look something like this zigzag manner with lot of of overlapping pixels.

In order to correct this, there will always be a scan line correctors, some mechanism to correct for this geometrical effect. So, in Landsat 7 satellite which was launched in 1999, the scan line correctors failed in the year 2003, hence, the NASA and USGS people were not able to correct the image for this scan line in geometry.

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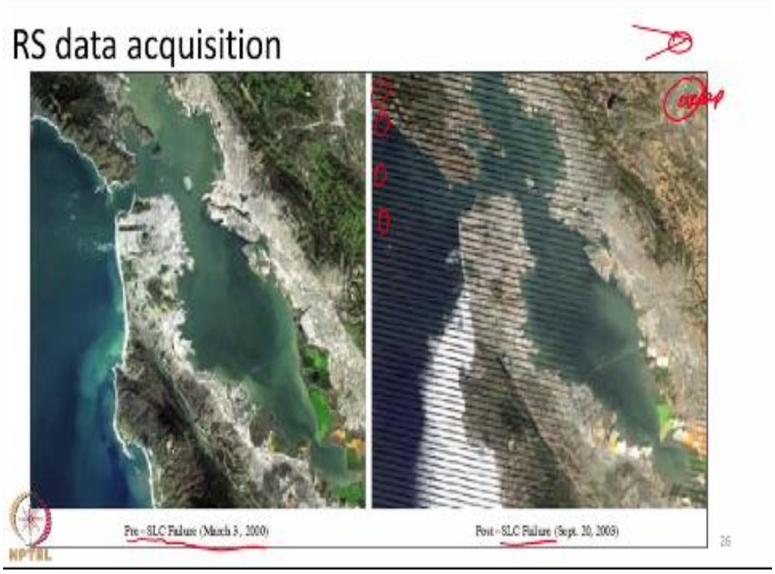

And the image was something like this. This is pre-scan line corrector failure March 3, 2000. We can see all the images are perfectly aligned, all the pixels are there without any data gaps. Here after the scan line corrector failed, you can see here, there is kind of gaps in the data, because of non availability of scan line corrector element. So, a scan line corrector must be available in order to correct for the scan line geometry effect. So, we saw now about the Whiskbroom scanner. Then we will move to Pushbroom scanners.

So, in Whiskbroom scanner the pixel size or the GSI the ground projected sample interval is identified or it is defined by our time of sample collection, I told you what interval we collect the samples from the continuous stream of signals coming in. I told you that defines in both along track as well as across track direction. In both the direction, there is continuous motion, continuous stream of energy will be coming in; radiations will be coming in. There will be always some sort of sampling occurring in both x and y directions. In case of Pushbroom detectors, no need to scan in the across track, there are like n number of detectors in the across track direction. So, the pixel size is defined by the distance between these 2 detectors.

The pixel size in Pushbroom sensors are defined by the distance between 2 adjacent detectors. So, they will define it and in the along track, there will be a sampling because as the satellite is moving like this, they will make sure that data is collected every line that is the sample is collected as soon as the satellite moves one pixel distance ahead. So, they will make sure the pixel size in the along track and across track directions are the same. So, essentially, GIFOV will be mostly equal to GSI for Pushbroom scanners. This is one thing and in Pushbroom scanners, let us take the example of 6000 samples, we have to collect.

Let us assume, we have to collect 6000 samples. If it is a Pushbroom scanner, then there will be 6000 detectors in the across track direction. So, what is the time available for us? The time available for us to complete one line is 4.2 milliseconds that is, satellite has a time of 4.2 millisecond to move from starting point to 30 metres ahead. So, it can collect data for the entire 4.2 milliseconds. In case of Whiskbroom scanner, since the scanner is moving, we had a trouble. The time available was very less, but let us imagine for Pushbroom. For a Pushbroom sensor, if this is the case, there will be 6000 detectors in the across track direction. Hence, all the ground points will be imaged simultaneously.

So for the whole 4.2 milliseconds, there is no scanning involved; for the whole 4.2 milliseconds, sensors can see the ground continuously, which will ensure that all the 6000 pixels, the data are collected for the whole 4.2 milliseconds, hence Pushbroom scanner has a much larger dwell time than Whiskbroom scanners. Because in the Whiskbroom, the time we got is like something close to 35 microseconds per pixel.

Whereas in case of Pushbroom, since there are no scanning element is involved, each detector can see each point on the ground continuously for the whole 4 milliseconds. Just see the time difference, there we had 35 microseconds, here we have 4 milliseconds for data to be collected. So, the time available for data collection in Pushbroom sensor is much higher than the time available for data collection in Whiskbroom scanner or line scanner.

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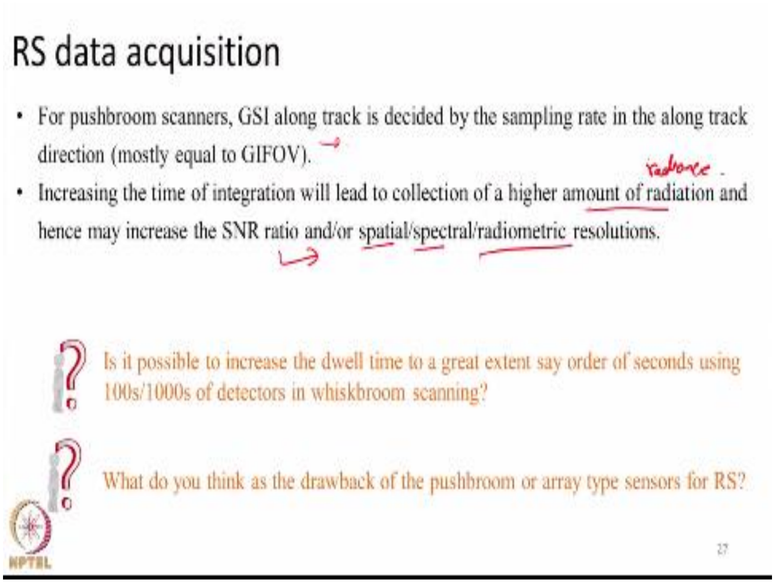

So, that is what is mentioned in this particular slide. Increasing the time will lead to collection of high amount of radiation that is, radiance basically, which will increase the signal to noise ratio and which can be translated to improve the spatial, spectral or radiometric resolution of the data. That is higher the amount of signal collected will lead to high SNR ratio.

And hence, we can use this improved SNR for increasing either spatial or spectral or radiometric resolutions. So, we have just covered in detail about the spatial resolution, we will see about spectral and radiometric resolutions in the coming lectures. So before we close down this lecture, I want to ask you 2 questions. So, after each question, please pause the video for a few seconds, think over and check the video for your answer.

The first question is, is it possible to increase the dwell time to a great extent say order of seconds using 1000s of detectors in Whiskbroom scanning? That is, I told you when we had 10 detectors, the time increased by 10-folds, from 0.3 microseconds it became 3 microseconds. Can we put 1000 detectors in the along track and do Whiskbroom scanning?

Is it possible? Just think over and let me know. The answer is No. We cannot keep on increasing the number of detectors in the along track direction for Whiskbroom scanners. Because, it is not only the scanner is moving; also, the earth is moving underneath it. If you have 10 detectors, all the 10 detectors one by one will see the point A, which will be processed as one single point. So, the same ground point will be imaged by 10 detectors. Let us assume, we have 1000 detectors. So, this point A as the detector is moving like this along track direction, due to earth's motion underneath, now, the point A would have moved somewhere here under new ground point from here more example B would have come here. So, as earth is moving underneath continuously, we cannot keep on increasing the number of detectors in the along track direction for Whiskbroom, because even before one line is completed or the same point is imaged multiple times, earth underneath would have moved.

It is a problem in sensors, as the dwell time increases, even in case of Pushbroom or 2D array; as a dwell time increases, the earth's motion becomes a major problem. Earth is constantly moving at a much faster rate. So, the ground points will be keep on moving, which will actually degrade the image quality and also may produce geometric errors.

As before the scanning completes if the ground point underneath moves means the sensor will be wrongly imaging a different point rather thinking that it is point A, we will now be imaging point B, which is not correct. So, it is not possible to keep on adding the detectors in the along track direction. As the dwell time increases, even in case of Pushbroom scanners, earth's motion becomes important, which will cause image degradation.

Image will blur a lot because we know that with a normal photography as the object moves, we get a blurred image. I mage will not be sharp. Same thing will happen. As we are looking at the same pixel for a very long time, the ground point underneath will be constantly moving. So, as we keep the sensor here for more dwell time, the point will be moving it may move away after some time. We will be wrongly looking at it. So, the image motion or earth's motion, we have to always account for, when we plan to increase the dwell time. The dwell time should be increased keeping in mind, it cannot be a very long. It should be short such that data over one ground point should be collected before the ground point moves away because of earth's rotation. Say, we cannot keep a sensor permanently fixed; earth will be constantly moving with it. So, the image should be collected before the ground point moves away due to earth's rotation. Keep this in mind.

Second question what I want to ask is, what do you think as a drawback of Pushbroom or array type sensor RS? I told you they have lots of benefits in increased dwell time, which causes improve the signal to noise ratio and limited distortions and so on.

But, we need to always take care about one thing. When we have more number of detectors say, n number of detectors, when we talked about image acquisition process or image formation process I told you, the radiance are stored as DN values in the image. When this happens, there will be a calibration phase, $(L_{max} - L_{min})/(D_{max} - D_{min})$ which is essentially, relating the radiance observed with the DN value that is produced. So, having multiple detectors means, all the multiple detectors must be calibrated exactly to the same point.

So, there should not be any difference between them, because in case of more number of detectors, whatever be the number of detectors, when they see the ground for a same amount of radiance, they must produce the same DN. Then only image quality will be proper. If say each sensor has a different, different calibration factors, then the DN in the image will be changed because of this difference.

So, when the number of detectors increase either in Pushbroom or Whiskbroom whatever, the relative calibration between them must be properly done. All the detectors whether it is 10 or 16 or 100 or 1000, all detectors in a given band must produce same DN for same radiance received. That check or that kind of calibration is not very easy to do. Doing relative calibration of all the sensor is a quite difficult task that is why, in olden days sensors were not Pushbroom type. They were mostly having the scanning mechanism but limited number of detectors, but now with advanced technology, people are going for Pushbroom and even 2D arrays because the calibration can be done rigorously. But remember, having more number of detectors means more calibration must be done. All detectors must be calibrated to the same point such that they produce the same output for the same input.

So, as summary in today's class, we have discussed in detail about the characteristics of Whiskbroom systems, Pushbroom systems, calculation of dwell time and concepts such as how to increase dwell time and so on. With this, we end this lecture.

Thank you very much.