Remote Sensing: Principles and Applications
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Lecture – 19
RS Image Acquisition and RS Systems – Part 2

Hello everyone, welcome to today's lecture in the course remote sensing: principles and applications. We started discussing about different remote sensing systems and the ways of image acquisition. And in this lecture too, we are going to continue with that particular topic.

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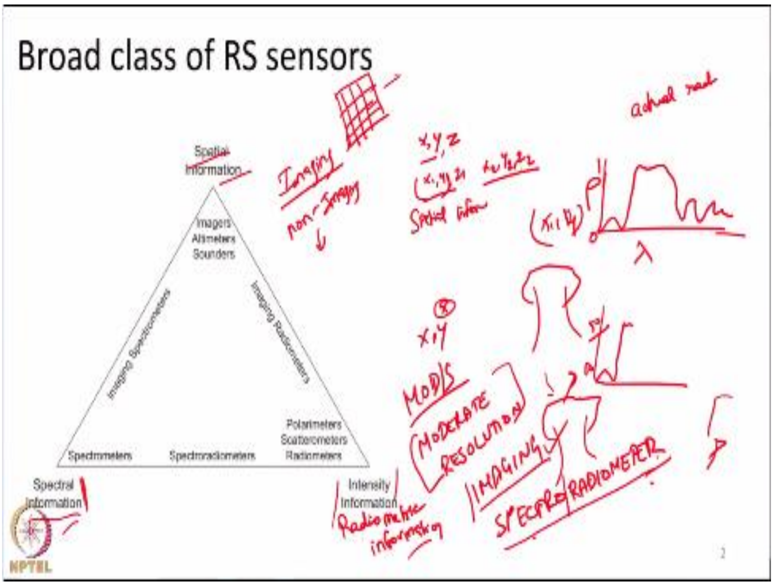

In the last class, we discussed briefly about the different types of remote sensing sensors which collects spatial information, spectral information and radiometric information. I also told you some of the most commonly used satellites from which we are acquiring data such as Landsat or MODIS, etcetera. They collect all sorts of information; they collect spatially; they collect spectral information and also they collect radiometric information.

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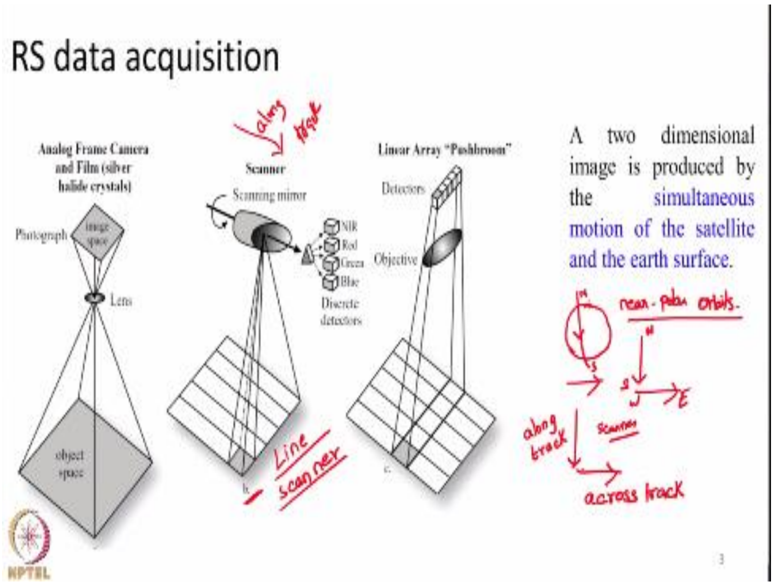

We also started to discuss about how photography was used in the earlier days. People will send the normal film cameras specifically designed for earth observations in aeroplanes or balloons whatever. It started with balloons and slowly progressed to aircraft. With the advent of aeroplanes, people will fly this, take photographs of the space and will use it for interpretation purposes. That is identifying what is there on earth's surface. And also for mapping it, that is a different field called photogrammetry. That is what I introduced to you in the last class.

This class, we will see how images are being acquired or how those systems work when the satellites are being launched. When satellites launched into space, they have to collect images, 2D images, how it is being done. I also told you like satellites are commonly launched into 2 kinds of orbits. One is called near polar orbit; one is called geostationary orbit. First, we will discuss about the image collection from satellites that are located in the near polar orbits. We will first see that. So, what a near polar orbit is? Say this is earth in space. So, Earth rotates from west to east, we know and the satellites will be rotating or revolving around the Earth from north to south around the poles.

So, most likely they will not exactly pass over the poles but they will be having a slight inclination away from the polar axis that is why we call this as near polar orbits. So, when satellites are placed in such near polar orbits, earth is moving in a direction that is almost perpendicular to the direction of satellite motion, satellite is moving like this, earth will be moving like this. So, north, south, east, west, this is how the orientation is.

So, the images will be collected in 1 dimension like in the direction in which the satellite is moving. The image will be collected due to satellite motion and in the direction perpendicular to it. The image will be collected by the motion of the sensor or the scanner attached with the satellite. First, we will see in detail how. But before we move on to that, 2 terms I would like to introduce. The direction in which the satellite is moving, we commonly refer it as along track direction and the direction perpendicular to satellite motion, we call it as across track direction. So, along track is along the direction of satellite motion across track is in a direction perpendicular to it. So, keeping this in mind, we move on to the figure labelled as B in this particular diagram. So, what it shows? It shows that the sensor or the satellite is moving in this particular direction.

Let us assume this is along track. So, in this particular direction, image will be collected by satellite motion. So, first of all, in earlier days, when satellites was launched, like digital camera technology was not as advanced as we are having it today like in the 70's and all, early 70's period. So what they did is, they developed small detectors, send the detectors to space and that detectors will be attached with what is known as a scanning element.

So, the detectors are like a simplest version of the camera we are using. So, it will be attached with the scanning element. So, what it will do? The satellite will be orbiting in space, let us assume the satellite is now moving towards in this particular direction like coming in towards your screen. So, when this is moving, there will be a detector attached within it and there will be a element known as a scanner. So, what the scanner will do? The scanner will be oscillating in a direction perpendicular to satellite motion. Satellite is moving like this and the scanner will be oscillating like this. The detector is like only one chip or one detector element will be there in the sensor or in the satellite.

Satellite will be moving like this, the scanner through its motion in a direction perpendicular to it will collect all the energy in the across track direction. That is this is land surface, this is how satellite is moving, so, the scanner will be scanning from this side to the exact nadir point and move to the side. So, what will happen? Whatever the energy coming in from the ground, it will be collected by the scanner and that will be passed on to the detector for recording purposes.

So, the detector will convert that energy to DN and store it in form of an image. So, that is how it was building. So, the scanner essentially provides the data collection in the across track direction. And as the satellite is moving in along track, a 2 dimensional image will be formed. That is just imagine starting from here energy is coming like this, so, it will be keep on collecting energy coming from the earth’s surface. So, it will cover certain distance in the across track.

So, one line of image has been formed. If you take a photograph as a 2D space, it is built up of several rows. So, now it has collected one full row of data, one line of image, then the satellite will move to the next line. Again, the scanner will collect the data for that particular line that is how it was collecting the data in the earlier stages. So, we call that type of scanner as line scanner. A line scanner essentially has one detector element per band. So, let us say the satellite is collecting data in 4 bands. Blue, green, red and NIR for an example, I am telling. So, it will have 4 detector elements for collecting data in each band. So, 4 detector chips. Now, the scanner is actually collecting the data and passing it to detectors inside. Each detector will store the energy coming in that particular bandwidth.

This type of scanner will build the image line by line, one line in across track direction, then the satellite will move to the next line, then the second line will be imaged, then the satellite will move to third line then the third line will be imaged. So, line by line the image is formed. Such scanners were known as line scanners. They collected image line by line.

This type of operation having only one detector per band will be disadvantageous, disadvantageous in the sense, the time available for the data collection by the scanner is extremely low in the order of microseconds, we will see how it is in the later part of slides. But since that time is very low, what people thought is instead of putting one detector per band, can we add more detectors in each band and send it to space.

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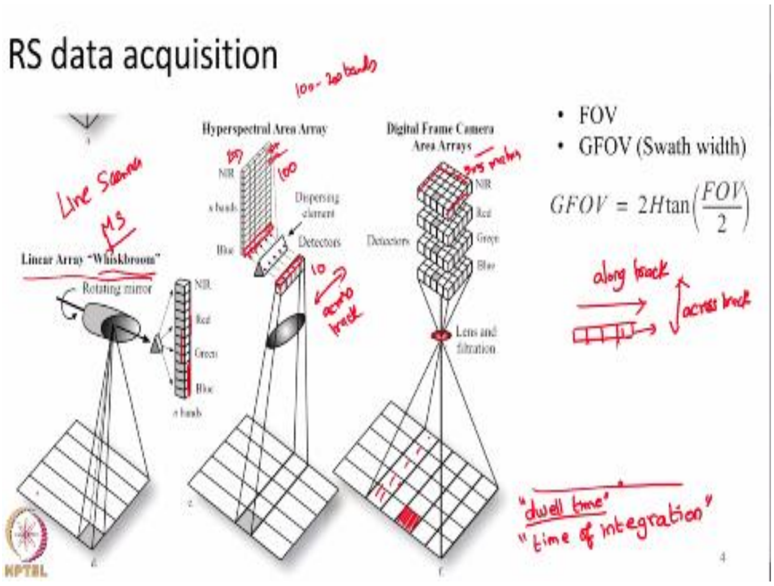

In this figure what is shown is Whiskbroom scanner. So, what exactly is the Whiskbroom scanner? Let us assume that data is being collected in 4 different bands blue, green, red and NIR but instead of having just one detector element per band, now we are having 4 detectors elements per band. So, this 4 is for blue, the next 4 is for green, again it is for red like that.

So, 4 or whatever it will be like equal number of detector elements will be spaced 4 or 3 or whatever. There will be more than one detector per band for collecting the data. So, what will happen when data is being collected? Instead of the scanner having to collect each line completely like the satellite is moving, the scanner is moving into across track direction. So, the scanner has to complete that one full line before the satellite moves to the next line. Only that amount of time it has and the scanner has to rotate extremely fast. But if it has 3, 4 detectors behind it, rather than just having one detector element, now it has say 4 detectors per band are aligned in the along track direction. So, now the scanner has somewhat more time like 4 times now, because of presence of 4 detectors, it has 4 x time.

If it was 5 microseconds before, now it is 4 into 5 microseconds, 20 microseconds time it has. So, schematically, I will explain it in this slide. Let us assume this is the along track direction. So, there will now be instead of having one detector element, let us say we have 4 detector element per band and the scanner will be rotating in this axis. This is across track. So, what will happen?

First, this scanner will be looking at one particular place, collecting data over it and whatever data is coming from this particular point will be collected by detector number 1. Then after it passes, now, detector number 2 will be overhead of this and this will collect the data from the same point, then detector number 3 will be there, it will collect data from the same point, then detector number 4.

So, essentially what happens is, each ground point is now being imaged by 4 detectors one after the other. So, that is why as the number of detectors in the along track direction grows, the time available for imaging certain pixel or certain area on the ground is increasing by the number of detectors times. So, if you have 4 detectors, now the time is increased by 4 times. If you have 6 detectors, the time is now increased by 6 times in comparison to when you have only one detector element per band. So, here you note, in the earlier case, in the line scanner, we had only one detector element per band. In case of this type of scanner which is known as Whiskbroom scanner, we have, 4, 6, 10 whatever depends on sensor configuration people will have different number of detectors elements.

Different number of detectors elements will be aligned along the along track direction. In the along track, the satellite is moving like this, the detectors will be oriented along the direction of satellite motion and they will scan together. So, they will be attached to scanner. Now, the scanner will be collecting data together for all the detectors. So, as the detectors or the scanners is moving, each ground point will now be imaged by n number of detectors 4, 6, 10 etcetera that increases the time available for data collection. So, such scanners, which has more than one detector element per band in the along track direction and which scans the ground surface using a scanner or known as Whiskbroom scanners that is given here in this particular slide, whiskbroom.

Again, we will note in the later part of the slides that even for Whiskbroom scanners, the amount of time collected is in the order of few microseconds only, but still it is higher than the line scanner. In order to overcome this, people thought instead of having detectors in the along track direction and putting it in form of a scanner, can’t we change its orientation? because what will happen is first of all, the time of data collection is very small in the order of microseconds. And also, as the scanner is moving, a lot of geometric distortions, geometric distortions means the features on the earth’s surface will not be imaged properly, there will be some distortions. We will see again later in this particular lecture topic, but there will be lot of geometry distortions because of this scanning and this scanning has a lot of limitations attached to it.

So, what people thought is, can we remove the scanner part? Because scanner is a mechanical mover. There is some element which is moving mechanically. If the scanner system fails, let us assume the worst case scenario, if the scanner fails, then the detectors are almost like useless. They cannot scroll without the help of the scanner. They will be just moving along with the satellite.

So, they will be just collecting a small amount of data along the direction in which the satellite is moving, that is all. They will not be able to collect data in the across track direction. So, they will be just limited to one line over which the satellite is moving. So, without the scanner, the satellite, the detector will not be able to collect data. Some mechanical movement is there, which affects the satellite system basically.

So, people thought, can we remove the scanning part? We do not want the scanning part. Because scanner always having mechanical movement inside the satellite which is not recommended. It may cause some problem in the later stages. So, people thought instead of putting say 4, 6 or 10 detectors in the along track direction, people decided to put many number of detectors in the order of like say 1000 also in the across track direction.

That is now, you have a large number of detectors per band in order of say 100’s or even 1000’s in the across track direction and the satellite will be moving like this. So, each detector will be collecting energy from certain area on the ground continuously. So, there will be like 1000’s of detectors in across track direction, they will be moving like this collecting data from the ground simultaneously at the same time, you just compare this with scanner.

If the scanner is here, it will collect data only coming in from this point. If the scanner here, it will collect data coming only from this point. If the scanner is here, same thing. But if you have some 1000 detectors in the across track, no scanner involved, all the 1000 detectors are seeing the ground at the same time means all the detectors will be collecting energy simultaneously from different, different points on the ground.

So, as the satellite is moving like this, all detectors will be keep on collecting data and building a 2 dimensional image. So, such systems where there is no scanning element, but you have

100’s or 1000s of detectors in across that direction. And while it is moving, it is collecting data in 2 dimensions. such scanners are called Pushbroom scanners.

So, it will have say n number of detectors in the across track direction, they will be collecting image from all the pixels in this line together simultaneously. Collecting data in this form, in Pushbroom form has a lot of advantages. First thing, the time available for observing each and every ground area is increased many folds. Like for many Pushbroom scanners, the time for data collection will be in the order of milliseconds.

Earlier for the line scanner or Whiskbroom scanner the time available was in the order of microseconds whereas now, the time will be in the order of milliseconds. We will see later and also the geometry distortions will be reduced significantly for a Pushbroom scanner. So, Pushbroom scanner has several advantages. So, 3 different types of scanners we have seen. One is line scanner putting only one detector element attach a scanner to it, which will oscillate like this collecting data. Then we saw Whiskbroom, where you have more than one detector per band in the along track direction, which will provide say, if you have 4 detectors, will provide 4 times more observation of every point on the ground. On the other hand, Pushbroom sensors, they are not scanners. Pushbroom sensors will have large number of detectors aligned in the across track direction.

And they will be collecting image from entire line simultaneously and they will be moving like this. So, such sensors are called Pushbroom sensors. Then the digital era came, like many advancements happened in digital image acquisition, so, people thought of putting even if you put like a Pushbroom sensor still it collects one line per image. It collects line by line even if in case of Pushbroom still the amount of time available to collect data is increased manifold.

But with the advent of digital systems and sophisticated digital sensors and all, people moved on to developing a 2 dimensional array of detector elements what we now have in our normal cameras. So, if you open our normal cameras, we can see a 2 dimensional array of detector elements. So, essentially what are we doing? We are having something in front of our eyes, we are focusing our camera towards it and it have a 2 dimensional matrix.

Let us say, 100 by 100 detector elements are there, 100 rows by 100 columns. So, it is essentially 10,000 detectors arranged in form of a square matrix. So, those 10,000 detectors will simultaneously observe 10,000 ground points that is on the object space and it will form a 2D image. So, such systems when sent to space and used to collect information we call such detector as digital frame arrays.

So, that is explained in this particular slide, digital frame camera array areas labelled here. So, that will have our 2 dimensional detector elements. So, here in this example, we have a 5 by 5 matrix detector elements per band. So, blue, green, red, NIR for 4 band, you have 4 2D arrays, So, essentially what will happen? So, it is like almost similar to taking photograph the simple analogy.

So, here is the lens. So, each of these 5 by 5 detector elements will observe 25 ground points simultaneously together, it will collect data and store it in each band. This further increases the time of observation. So, now, I am going to introduce you to one particular technical term known as dwell time. I am repeatedly telling time of observation for each pixel or what is the time available for data collection over each ground area and technically, that time is known as dwell time or time of integration.

The time available for observing one particular ground area, we call dwell time or time of integration. So, if you look at these 4 types of sensors, line scanner, Whiskbroom scanner, Pushbroom sensor and the sensor with 2 dimensional array detector element. So, that dwell time will be increasing in order; dwell time will be least for lines scanner; dwell time will be a little bit higher for Whiskbroom scanner; much higher for Pushbroom sensor and still higher for a 2 dimensional array type of detector sensor.

But a sensor with a 2 dimensional array will have some sort of memory limitations. Like now, we will experiment, with the availability of large format digital cameras, now, we will be experiencing each image will be like several MB's in size. If you take even a short video with high resolution cameras, it will be like going to gigabytes. So, it is very easy to fill the memory of our memory card that we are using now.

So, this will be the constraint with respect to using a 2 dimensional array camera. It will collect a lot of information together. It will fill the memory of the system and also there will be time to transmit the data because satellite is not in the ground. It is in space and the data has to be transmitted from the satellite to the ground remotely without any wired communication. So, it will take a lot of time and that would be a major disturbance.

So, mostly, the 2 dimensional array of detectors are essentially limited to aerial remote sensing, not to satellites. Still most of the satellites are using this Whiskbroom or Pushbroom technology. Most other satellites are now using Pushbroom sensor type. But having like a 2 dimensional array matrix for each band is essentially limited to remote sensing from aircrafts because of this memory limitation, quickly the memory will fill up.

There will be a lot of time taken for transmitting the data from space to ground, which will be a problem essentially for satellites that are farther in space. And now, till now, we were talking about just 4 bands, blue, green, red, NIR. As an example, there is a class of sensor known as hyperspectral sensors. Hyperspectral sensors means they will collect data over a large number of bands say, 100, 200 bands at the same time.

Instead of collecting data from 0.4 to 0.5 in the entire blue band, it will collect data in 0.4 to 0.41, 0.41 to 0.42 and so on. Sensors having large number of continuous bands with much smaller bandwidth are called hyperspectral sensors. So, which actually improved the way in which we collected images and identified objects on the ground space. So, such sensors will have large number of bands and data will be collected in large number of bands simultaneously.

For such sensors, how the data is being collected? One such example again given in the slide. So, for hyperspectral sensors, I told you there will be say, 100 to 200 bands. So, they will use a Pushbroom type of sensor. So let us say, we have 10 detectors elements in the across track direction and let us assume, we have 100 bands in the hyperspectral sensors. So, what it will have?

It will have a detector array. It is also a 2D array, but, each row will correspond to this 10 detector elements in the across track direction like each element in one row, whereas, different, different rows correspond to different, different bands say, this is band 1, this is band 2 and so on. That is one row will collect data in one particular band. So, if there are 10 detector elements in the across track direction, 10 different ground points will be imaged simultaneously and the sensor will have 10 detectors per band.

So, it is 10 detector per band and if there are 100 bands, it is 10 x 100, 1,000 detector elements. So, this is an example for data collection for hyperspectral sensors. So, essentially, the data can be collected in several ways either having a scanning mechanism or having multiple detector elements.

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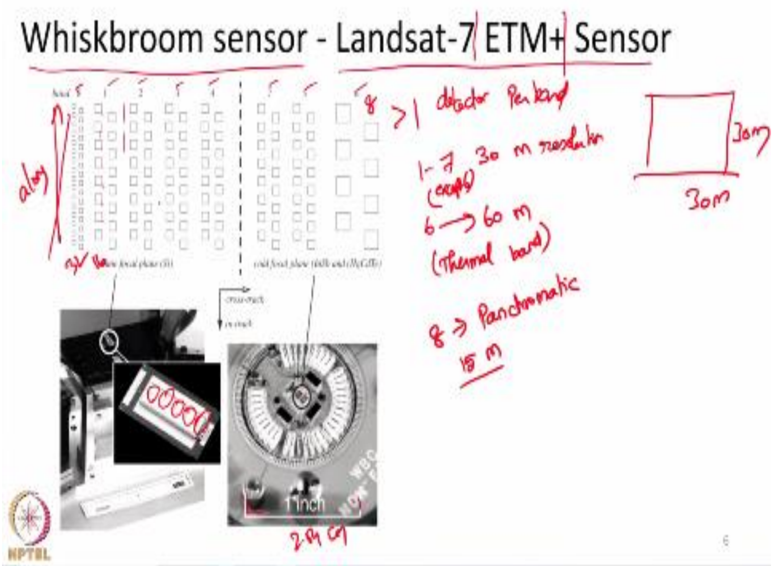

So, we will see few examples of such scanner sensor, scanning elements or hyperspectral array elements and so on. So, if you look at this particular slide, here we are showing the sensor or detector arrangement for a sensor known as Landsat 7 ETM plus. Landsat 7 is the name of satellite, this is the name of the sensor enhanced Thematic Mapper plus. It was a Whiskbroom scanner.

Whiskbroom scanner means, it has more than one detector element per band. It collected data in 8 different bands. So, here you have 1, 2, 3, 4, 5, 6, 7, 8. 8 bands, it collected data. The spatial resolution is, here, from bands 1 to 7, the data was collected at 30 metres resolution that is each ground area will roughly be 30 metre by 30 metre and then band 6, data was collected at 60 metre resolution. So, this is a thermal infrared band.

And band 8 was the panchromatic band, which collected data at 15 metre resolution. So, you can see, for each, this will be aligned in the along track sorry, this will be the along track. So, in the along track, you have 1, 2, 3, 4, 5, 6, 7, 8, 16 detector elements arranged in the along track direction. Similarly, you have for bands 1, 2, 3, 4, 5 and 7, you have 16 detector elements. In band 6, you have a 8director elements.

In band 8, you will have 32 detector elements because of this variation in spatial resolution. So, this looks like extremely tiny detector size. They are extremely tiny, when they are arranged on the space, you can see the scale here, this is 1 inch, roughly 2.54 centimetres. All the detector elements are arranged within this 2.54 centimetres. So, this will be like in example band 1, there are like 16 detector.

So, 16 detector will be put in the along track direction. There will be a scanner attached to it, it will scan like this. So, each ground point will be absorbed by each one of the 16 detector elements thereby increasing the dwell time.

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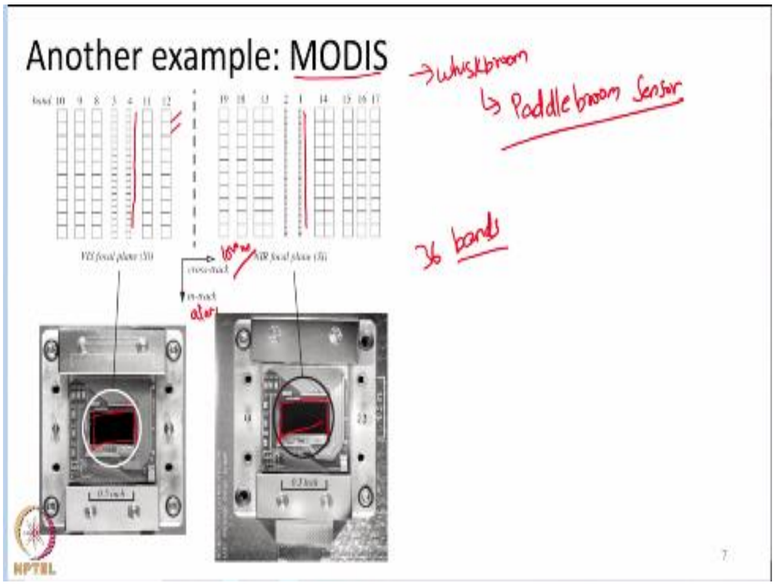

This slide shows another example of a sensor known as MODIS, which is again famously used sensor. The way MODIS works is very similar to Whiskbroom methodology. But there is a slight difference we call this MODIS sensor as a Paddlebroom. In MODIS what they have done is, they have attached the scanner with mirrors on both the sides. There will be a very highly polished mirror here on the bottom, similar mirror on the top. So, this will be continuously rotating instead of scanning like this. It will be rotating like this. So, what essentially happens? As the mirror rotates, it will collect data in the line. Now, the bottom mirror will go to top, top mirror will come to bottom, it will collect the next line.

Now, it will again rotate. So, that data collection happened in one direction only. Next the mirror will turn upside down, again the next thing like this. So, it is not like oscillating scanner, but a rotating scanning element fitted with a mirror on both sides. We call it as Paddlebroom. So, MODIS is attached with such Paddlebroom. Essentially, it is still a scanner. It is doing scanning only, but scanning happens in only one direction with detector attached in both the sides, mirror attaching both the sides.

So, MODIS also has many number of detectors per band. Here we can see band 1 and 2 with 250 metre resolution, then band 3, 4 collects data at 500 metre resolution, other bands collect data at 1000 metre resolution and so on. So, this will be the entire detector array chip. It collects data in 36 different bands. So, this is along track, this is across tracks.

So, each detector element per band is aligned in the along track direction and each band is oriented in the across track direction for MODIS.

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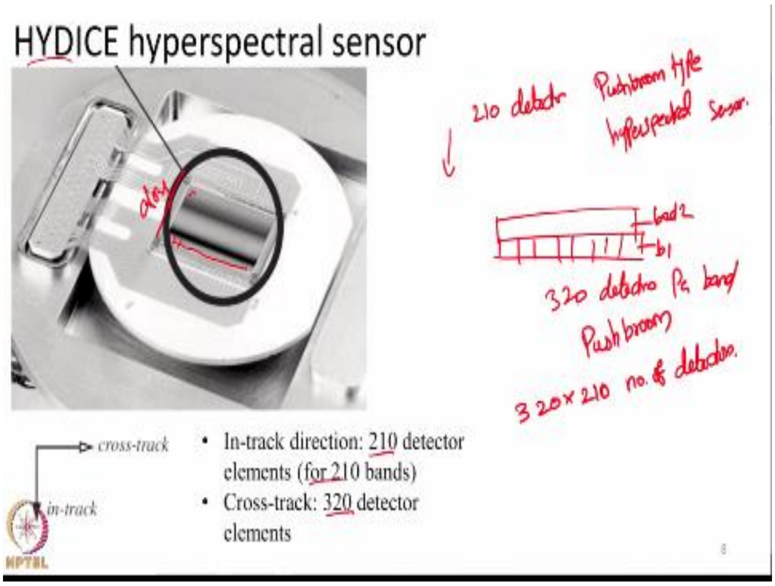

Now, this slide shows an example of an hyperspectral sensor. Where it will be like in the along track direction, there are 210 detector elements, in along track like this. So, there are 210 detector elements. In the across track, we have 320 detector elements. So, that is each band has 320 detectors, 320 detectors per band. Essentially, this is a Pushbroom type of sensor and for each band, there will be one row detector.

This is band 1, this is band 2, each band will have 320 detectors unlike this, there are 220 bands. So, essentially 320 x 210 number of detectors. This is a Pushbroom type of hyperspectral sensor because it collected data in 210 bands simultaneously.

So, just as a summary of what we have done in this lecture, in this lecture, we have seen how data is being collected from satellites in the near polar orbit. That is earth will be moving in west to east, satellite will be moving north to south. For satellites in such orbits, the satellite motion will be in the along track direction and data will be collected in 2 dimensions either by using some scanning elements or by using multiple detectors per band aligned in along track or across track direction. With this, we conclude this lecture.

Thank you very much.