Remote Sensing: Principles and Applications

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Lecture – 21
RS Image Acquisition and RS systems – Part 4

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. Today, we are again going to continue with our topic of remote sensing image acquisitions and characteristics of remote sensing system. In the last class, we discussed about how images acquired from satellites that are in geostationary orbits have the scanner to move in both the north-south as well as east-west direction in order to acquire a 2 dimensional image.

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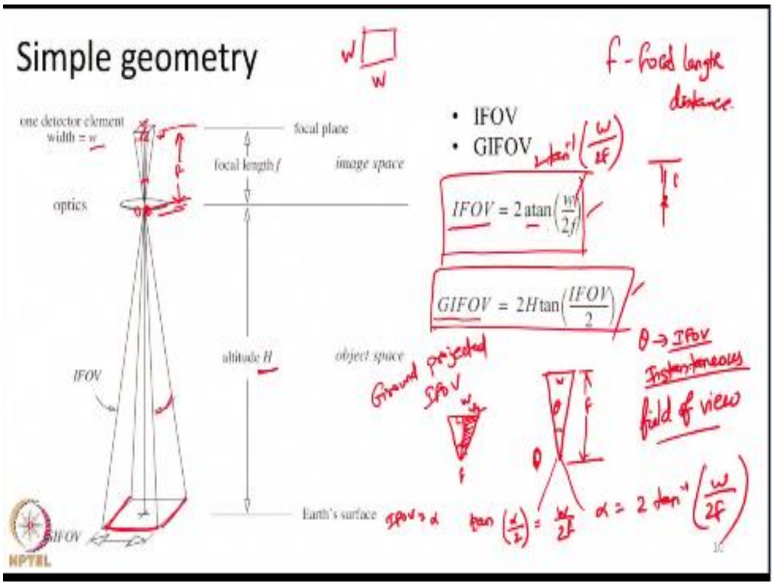

Simple geometry

- IFOV
- GIFOV

$IFOV = 2\,\text{atan}\left(\frac{w}{2f}\right)$

$GIFOV = 2H\tan\left(\frac{IFOV}{2}\right)$

Then, we saw, some important concepts such as, IFOV, GIFOV, FOV and GFOV. So, IFOV is related to the angle subtended by single detector element at the point of its objective space where the ray from the earth's surface enters the lens system or the optical system, optical point. So, the angle subtended by a single detector is called IFOV. And, if you take in the effect of the orbital height into picture and combined with this IFOV, we will get the ground size subtended by each of the detector element.

So, each corresponding detector element with a particular size will have a corresponding ground size that is determined by the IFOV angle and the orbital height. We call that as GIFOV ground projected IFOV. So, whatever be the features within that particular GIFOV size, all those radiances will be averaged out and will be recorded as one single value in that particular detector.

Then the next important concept, we saw, is FOV and GFOV. So, the total scan angle subtended by the scanner or if you take the case of a Pushbroom sensor, the total angle subtended by all the detectors in the across direction at the optical point where the light ray enters from the earth’s surface is FOV. And correspondingly if you take the orbital height of the satellite, we will get what is known as the swath width of the satellite.

Today, we are going to see an important concept about spatial resolution. So, what exactly spatial resolution is? There is no clear cut definition for spatial resolution. But, it can be explained as our ability to resolve something or distinguish between 2 features in the spatial domain. That is if there are 2 different objects on the earth’s surface, that are next to each other and you take a photograph from it. Are we able to distinguish these 2 objects separately or not? will tell us information about the spatial resolution of the system. So, how close an object should be to be resolved? Or how far the object should be to get resolved? All these depends on the spatial resolution.

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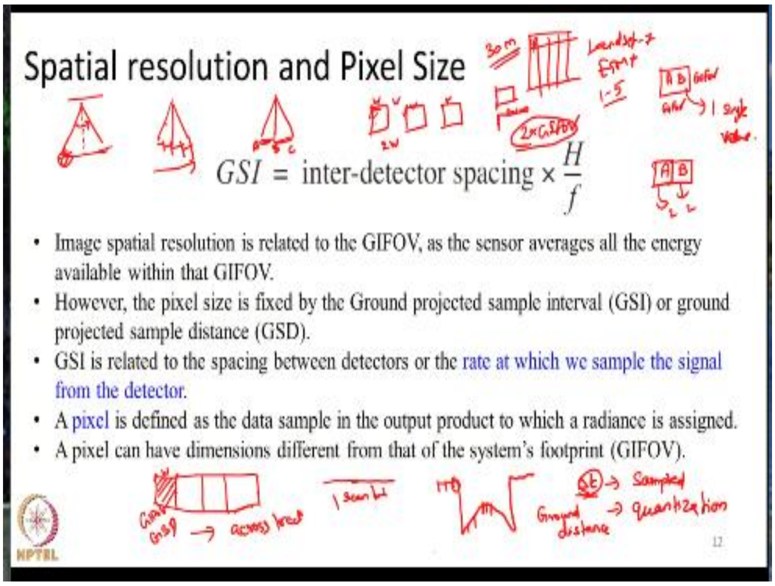

Spatial resolution and Pixel Size

$$GSI = \text{inter-detector spacing} \times \frac{H}{f}$$

- Image spatial resolution is related to the GIFOV, as the sensor averages all the energy available within that GIFOV.
- However, the pixel size is fixed by the Ground projected sample interval (GSI) or ground projected sample distance (GSD).
- GSI is related to the spacing between detectors or the rate at which we sample the signal from the detector.
- A pixel is defined as the data sample in the output product to which a radiance is assigned.
- A pixel can have dimensions different from that of the system’s footprint (GIFOV).

So, if you look at this meaning, like our ability to resolve, then our ability to resolve 2 features in the spatial domain will improve, when the objects are far apart that is one case. Or the IFOV of the system is smaller in size, that is say, there are 2 different objects, object A, object B. If the IFOV of the system covers the entire area surrounding these 2 objects together, so, this is

GIFOV, then the radiance coming out from these 2 objects will be collected together and it will be recorded in the sensor as one single value.

So, it is highly possible that we may not be able to distinguish these 2 features. They may appear as one single different signal in the image rather than appearing as 2 different features. On the other hand, if these 2 features are there A, B and if the GIFOV is something like this, then the energy coming out of these 2 objects will be recorded as 2 separate values using which we will be able to determine these 2 objects separately.

So, the spatial resolution is in turn determined or influenced to a large extent by the GIFOV of the system. Our ability to resolve features on the image is highly dependent on the GIFOV size. If the GIFOV is coarser, say in order of 500 metres, 1 kilometre, 5 kilometres and so on, the radiance from many different earth's surface features will be averaged out and our ability to resolve them separately may decrease. Or if the GIFOV is finer, our ability to distinguish features on earth's surface may increase. This is one thing.

The next concept is pixel size in the image. Normally, whenever we download a satellite image, they will say each pixel is 30 metres, 500 metres and so on. Depending on the sensor, we will have a characteristic size of a pixel that is, each pixel in the image represents a certain area on the ground. See, this is one Landsat image, I take an example, from Landsat 7 ETM plus sensor. In band 1 to 5, if you take any bands, each pixel sizes roughly 30 metres. So, that means each pixel corresponds to a ground area of 30 metre on x axis, 30 metre on y axis. It is like a square pixel. So, that is the meaning of pixel size. But, what determines this pixel size? Does GIFOV determine the pixel size means the answer is no. GIFOV does not determine the pixel size.

The pixel size is determined by our scanning sampling time. In case of line scanner or whiskbroom scanner or in case of a Pushbroom scanner, the pixel size is determined by the distance between 2 adjacent detector elements. I will make it clear with an explanation, let us take an example, there is Whiskbroom scanner like this, scanning the ground from this point to this point. So, this is nadir. When the Whiskbroom sensor scans the ground surface, what it will do? First, it will subtend a small GIFOV collect all the data from it. Then it will move a little, collect another GIFOV signal. So, like this, the movement of the scanner is continuous and it will be collecting energy continuously from the ground surface.

While it is moving, continuously it will be collecting whatever energy. So, each time it will subtend a small GIFOV on the ground. Whatever energy coming within the GIFOV will be collected, but it will be a continuous process without any gaps. So, the signal coming out of a scanner will be a continuous signal. The signal may be coming something like this. Actually, I am drawing the signal from one of the examples we saw earlier in image acquisition process. So, let us say, the signal coming from the ground for each one particular scan line on the earth’s surface looks like this. So, here there is very high amount of incoming radiance, here it suddenly drops then it slowly increases drops again. So, it is a continuous stream of energy across one entire scan line.

So, this is one scan line, but digital systems cannot store this energy continuously, we already saw and it will do, what is known as sampling. So, at definite time intervals delta t, the incoming energy will be sampled and that particular energy will be sent to the electronics part for amplification and quantization. This, we already saw in the previous classes when we discussed about image acquisition or image formation process.

So, this continuous stream of incoming energy will be sampled at certain time interval delta t. And that value alone will be sent to the electronics for quantization and saving as image. So, within this time delta t, the scanner would have moved a certain distance on the ground. That is, for each delta t time period the scanner would have moved some distance here, next delta t scanner would have moved here like this.

So, the scanner will be continuously moving when for each elapsed delta t time period, when the sampling occurs. So, corresponding to this particular delta t, there will be a ground distance the sensor or the scanner that covers. Let the scanner be here at point A. After delta t, the scanner moved to point B. After delta t times, the scanner moved to point C, etcetera. So, there is certain amount of distance the scanner moves for each delta t time period. And the sampling that occurs after each delta t and the corresponding ground distance moved by the scanner will determine the pixel size.

That is say, at delta t instant, the scanner moves a distance of 30 metres on the ground. So, one sample is being collected for a distance of 30 metres. So, next delta t, that is 2 delta t, the scanner moves. The scanner would have moved further 30 metres along the across track direction, so, another sample is collected. So, every 30 metres on the ground distance, we are collecting one, one sample. Hence, the pixel size will be 30 metres, the pixel size is determined by our sampling interval or the corresponding ground distance covered by the scanner during that sampling interval. This is known as GSD ground sampling distance or GSI ground sampling interval.

GSI refers to the time taken for sampling, say in the order of few microseconds, in case of whiskbroom scanners. So, maybe in order of a 6 microseconds, every 6 microseconds, one sample is collected or every 10 milliseconds, one sample is collected and so on. That is GSI. But, for that time interval delta t, what is the ground distance covered? GSD ground sampling distance, within the time interval of, say 6 microseconds since the scanner has moved a distance of 30 metres in the across track direction. So, 1 delta t 30 metres, 2 delta t another 30 metres, another 30 metres and so on.

So, that GSD, the distance travelled by the sensor will determine the pixel size of the Whiskbroom or line scanners. In case of Pushbroom scanners, where there will be no scanning involved, there will be multiple detector involved. What will determine the pixel size? The pixel size will be determined by the distance between 2 adjacent detector points. Let us, take an example, Pushbroom sensor is looking like this. This is the across track direction.

Let us say, we have some 4 detectors. So, each detector element from the top left point to the top left point of the next detector, what is the distance? That will determine the pixel size. If the detectors are arranged just next to each other without any gap, then essentially the distance between them is actually the size of the detector element. So, this will determine the pixel size, this will be the GFOV for that particular pixel. And that will also determine the GSI or GSD. Let us say one hypothetical example, where one detector element is here, say width of w, then there is a gap w without any detectors. Then there is another detector with width of w, there is a gap, then there is a third detector and so on.

If a hypothetical sensor is designed like this, with gaps in between detectors, the detectors are not placed continuously, then the pixel size in the image will be determined by this distance to this distance. That is each pixel will have a size of 2 w or it is corresponding GIFOV. If we talk in terms of GIFOV is 2 times the GIFOV, because there is one detector element, there is a gap.

So, whatever the data coming in, will not be detected. So, the same energy collected by this particular pixel has to be saved for these 2 detector elements or corresponding GIFOV terms. If you talk about detector size or if you talk in terms of ground distance, each detector element will have a GIFOV size. So, the pixel size will be 2 times the GIFOV. We call this as inter detector spacing.

What is the distance between 2 detector elements? But most likely in Pushbroom sensors, they will arrange everything together such that there will not be any gap in between the detector elements, because we need to collect continuous stream of data without any gaps on the earth surface. And hence, the detector element size will be equal to the GSD or GSI. But in hypothetical case if there is a gap in between two detectors, then the actual detector size plus that gap together will determine the pixel size in case of Pushbroom scanners.

So, the pixel size is not actually determined by GIFOV, GIFOV is different. That is the area covered by one single look of the detector on the ground. Whereas GSI is determined by the inter detector spacing in case of Pushbroom scanner or our sampling interval in case of line scanner or with Whiskbroom scanner. So, a pixel and the GIFOV need not be related. The GIFOV can be different, a pixel size can be different.

Are there any practical examples? Yes, there are. One such a good example is the earlier Landsat satellite, which was launched into space.

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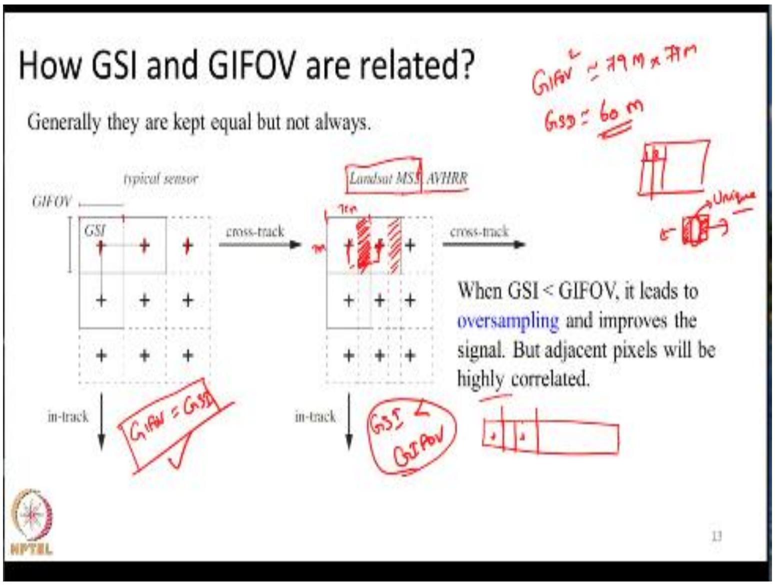

How GSI and GIFOV are related?

Generally they are kept equal but not always.

When GSI < GIFOV, it leads to oversampling and improves the signal. But adjacent pixels will be highly correlated.

This is example of Landsat MSS multispectral scanner, the earlier Landsat satellites that were launched into space or a sensor called AVHRR. Let us take example of Landsat MSS, Landsat multispectral scanner. The GIFOV of the Landsat MSS sensor was approximately 79 metres by 79 metres like GIFOV squared I say, that is each sizes is 79 metres GIFOV.

On the other hand, the sampling time was set such that the GSD was equal to 60 metres. That is each GIFOV will cover area of 79 metres by 79 metres, but, the GSD the distance between 2 plus marks will be 60 metres. So, what essentially will happen? Let us take one such scan line. So, the GIFOV will look one large area, a sample will be collected in 60 metres interval.

The GIFOV will have overlap; the second GIFOV will look between this point and this point. Another sample might be collected here. So, what the sensor did is over sampling. The energy was averaged over a much larger area, but the sampling occurred at a much shorter distance 60 metre by 60 metres. So, each pixel was 60 metre by 60 metre in size, but GIFOV was in the order of 79 metres.

So, if you take 2 neighbouring pixels, pixel 1 and pixel 2, there will always be some overlapping region, what I am highlighting here. This region will be commonly overlapping between those 2 pixels because of the larger size of GIFOV. So, each pixel will have some common information with its neighbouring pixel, in both the direction. That is a middle pixel here, will have certain portion of overlapping with its pixel to the left, similarly, certain portion overlapping with its pixel to the right. So, only one particular portion of the image or one particular portion of the pixel will be unique. The rest of these 2 sides will have a strong overlap with the adjacent pixels. This is called over sampling.

Why over sampling was done? Over sampling was done to increase the amount of signal that came in to the sensor. It will improve the signal to noise ratio in one sense and also the image quality will be better. In order to improve the image quality, they design the system like this. But one drawback is, due to this common information between adjacent pixels, each pixel is not independent of each other. There is always some common data available between 2 adjacent pixels that means, the pixels will be highly correlated in space. That is whatever information contained in pixel A will be highly related with pixel information contained in B. Similarly, the information contained between B and C will be highly correlated and so on. So, it leads to over sampling. This is an example of over sampling and it is done in order to improve the incoming signal quality, but it resulted in a lot of correlation between the pixels.

A normal system nowadays, what are launched will not have this kind of over sampling issue, will have the GSD set equal to GIFOV. The example is given here. So, whatever the GIFOV of the sensor, the GSI will be set exactly to sample that particular distance. So, there will not be any overlapping information nor there will not be any gaps. So, GIFOV and GSI will be made equal in a typical remote sensing system. So, that is an example of GSI size smaller than GIFOV. This is always preferred. This was done just to improve the signal quality, but adjacent pixels will be highly correlated. So, next we are going to see this in little bit more detail through an example.

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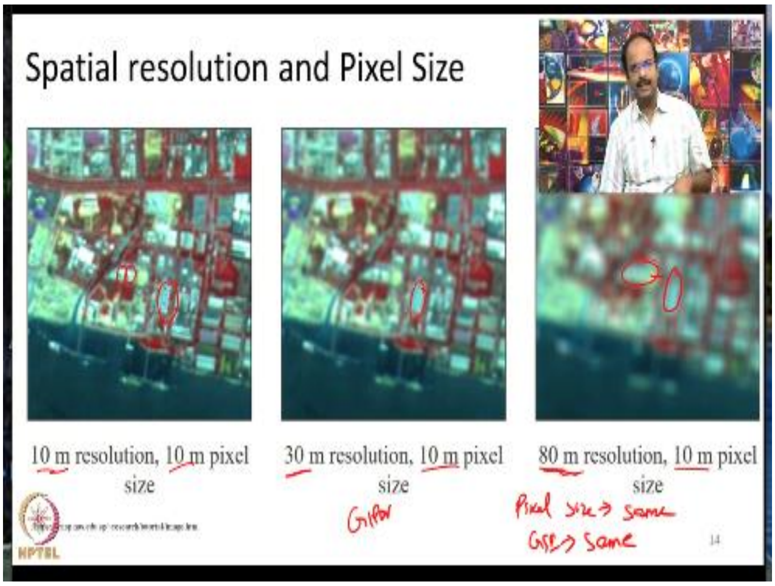

Spatial resolution and Pixel Size

10 m resolution, 10 m pixel size

30 m resolution, 10 m pixel size

80 m resolution, 10 m pixel size

GIFOV

Pixel size → same
GSI → Same

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So, these pictures show image of same area processed using some digital image processing techniques where the GIFOV size was changed for each image, here a GIFOV was 10 metres, here the GIFOV size of 30 metres, here the GIFOV size of 80 metres. But the pixel size in each image is just 10 metres. So, the pixel size is the same. That is effectively the GSI is same.

But GIFOV kept on progressively becoming coarser and coarser 10 metre, 30 metre and 80 metre. From this image, we can see that even though the pixel size is the same, the amount of information we can get from these images actually decreases. That is in this image, we are able to resolve a lot of features. Here, there are 2 structures, we are able to resolve. Here, there are lots of small structures that we are able to resolve and all.

But here, we are not able to resolve them; they appear as single feature. In this image, nothing is clearly visible for us. Everything appears smudged because of the larger GIFOV and the averaging effect of this 80 metre resolution size. Hence, the size of GFOV will influence our ability to resolve features. But, GSI will determine the pixel size. They can be different. They are not one on the same. They need not be one of the same. They can be different.

But in most remote sensing systems, the GIFOV and GSI are set equal such that whatever the GIFOV size is, a sample will be made in the corresponding distance inside the sensor system. But they can be different that is the aim of this particular example. We have seen an example that GSI size was smaller than GIFOV. But, can the reverse may also happen? Yes, it can happen that is the GSI can be occurring at a larger distance than GIFOV. We will see an example for that.

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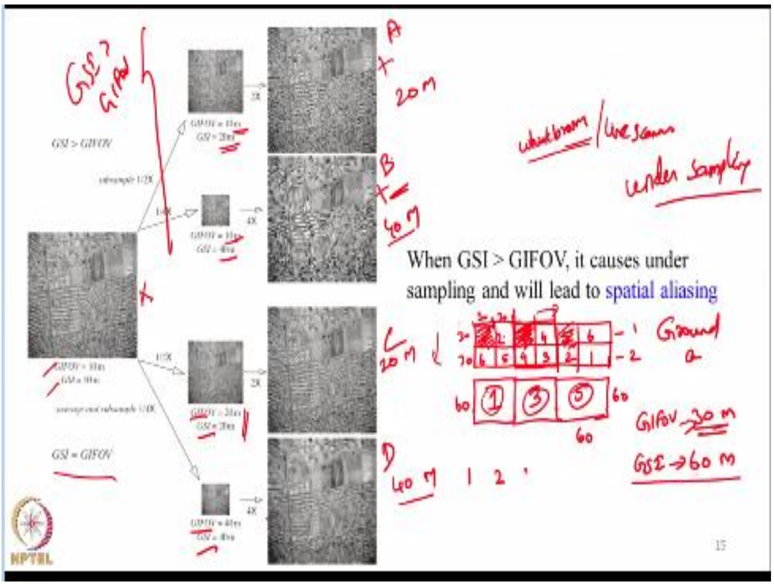

When GSI > GIFOV, it causes under sampling and will lead to spatial aliasing

Let us take an example we have data arranged like this, 2 scan lines. So, this is scan line 1; this is scan line 2. Now, I am going to have a Whiskbrooms sensor where the sampling has to occur in both the direction, because the satellite across track is moving like this, satellite is also moving like this in the along track direction.

So, continuous stream of energy will always be coming in. Hence, the sampling has to occur in 2 dimensions, whereas in case of Pushbroom sensors, the sampling occurs only in the along track. In the across track, it is determined by the inter spacing, the spacing between the adjacent detectors. But, the along track direction, a sampling will occur, because satellite motion is continuous.

It will produce a continuous stream of energy as the satellite moves, hence sampling has to be done. In case of Whiskbroom or line scanner, sampling has to be done in both the cases, because here also, the scanning happens continuously without any brake. System will sample certain points. Satellite was also moving continuously without any break. Hence, system has to do sampling in along track direction also. Hence, sampling occurs in both the directions that is why we get a GSI.

It is possible to produce a rectangular GSI also. The sampling interval is different between a across track and along track direction. It is highly possible for us to get a rectangular pixel. Most likely, we will get a square pixel. Because the sampling interval is same in both along track and across track directions. In case of Pushbroom, the sampling interval in the along track direction will be made equal to the distance between the 2 adjacent detectors. There are also, we can have rectangular pixels. So, here, let us assume, we have a Whiskbroom or some sort of line scanner. The features, let us say for example and taking 1, 2, 3, 4, 5, 6; 6, 5, 4, 3, 2, 1. Let us say, each sizes 30 metre. The GIFOV system let us say, is 30 metres which covers each area. So, this is 30 metres, this is 30 metres and so on a hypothetical example.

On the other hand, the GSI is set at 60 metres in both x and y direction. So, what will happen? Because GSI set is 60 metres in both x and y direction, the pixels rather than having 30 metre size will now have a 60 metre size in the both x and y direction because of the GSI. So, this will be the size of pixel in both x and y direction. So, let us take an example a sampling is starting from here. Since the GIFOV is 30 metres in the both along track and across our direction. All these numbers 1, 2, 5, 6 will be collected, data will be collected by the scanner because of GIFOV size.

But, since the GSI is set at 60 metres, only one sample for this large area will be collected, it will be collected as 1. Let us not take the centre of pixels and we will not enter into that sort of argument. We will make it simpler. So, let us say one sample is collected. So, this sample is collected here. For the next pixel, the sensor would have collected samples and the next GIFOV will be here, it will collect 2. Then it will move to 3. If you take these pixels, then essentially, the sample 3 will be recorded here. Similarly, here the sample 5 will be recorded, because we are sampling only one. Our GSI is much larger twice in both the x and y direction, but GIFOV is much smaller. So, the detector will effectively collect data from 1, 2, 3, 4 everything separately, but we are not sampling it like that.

In this particular direction, our sampling will take only 1, 3, 5; in this direction, there will be no sampling because of the GSI set. That is how it is actually happening. That is scanner is continuously scanning but the data is not being sampled properly. Data is being under sampled rather than collecting 4 samples. We are now collecting one sample like that. So, here we are doing what is known as an under sampling.

So, if you look at the pixel, there is a huge amount of loss of data. Instead of having like any one, at least the information should be averaged out. Let us say, there is a numerical averaging, the information should be averaged out and we should have an average result here, but that is also not there. We are having only certain data points. We are not collecting the actual average value also because of GSI much larger than GIFOV.

So, we are not averaging over a larger area, we are averaging energy over a smaller area. But we are missing in between area because of our poor sampling interval. The data is now collected being point 1 and it is sampled. Over point 2, data is collected but not sampled. Over point 3, data is collected and sampled and so on, because GIFOV is 30 metres, GSI is 60 metres. So, one ground point of GIFOV element is actually skipped by the sampling system.

So, instead of having 1, 2, 3, 4, 5, 6; we will have 1, 3, 5 and so on. It is actually a loss of data for us. So, having GSI larger than GIFOV will lead to under sampling. And it will also lead to a phenomenon known as spatial aliasing. So, spatial aliasing means, there may be some unwanted artifacts or the image may look completely different from what it is there on actual ground. We may have like a completely different features on the image than what is actually present on the ground. So, here we are doing under sampling and we may encounter a phenomenon known as spatial aliasing. Example is given here in this slide. So, here we are taken an image GIFOV equal to 10 metres, GSI equal to 10 metres. We are now using some image processing techniques.

We are converting the image here, GIFOV remain the same, but GSI is becoming coarser and coarser. Say, 10 metres, GSI sizes 20 metres. Here, GIFOV 10, GSI is 40 metres. You can see how the image looks here. So, here there is some loss of information from this image; this image looks a bit different; this image looks totally different here. So, this is a 20 metre pixel image; this is a 40 metre pixel image. This is also an example of a 20 metre pixel image and 40 metre pixel image, but the GIFOV size is made equal to GSI. So, here in these 2 cases, the GSI was much larger than GIFOV. In these cases, the GSI is equal to GIFOV. So, essentially, let us label this images of A, B, C, D. Pixel size of A and C are equal, but if you look at the image, C appears little bit better than A. A has a lot of points of discontinuities.

Similarly, if you look at image B and D both have same pixel size but, the image content, when you try to extract information out of image D, will provide you better information than image B, because in images A and B, the GSI is larger than GIFOV. Hence, we are doing under sampling and we are not representing the ground truly, whereas image C and D even though the pixel size is coarser because of larger GIFOV, we are actually collecting at least the average data

Let us see the example where we took pixels 1 and 2. If the GIFOV made equal to cover both 1 and 2, we will have an average of the energy stored in the sensor. So, let us say for a numerical average, you would have stored 1.5 instead of 1, because the sensor is doing a proper averaging. So, by making equal GIFOV and GSI, we are actually preserving the information. Even though we are making large scale averaging. But having a larger GSI and having a smaller GIFOV may cause data loss and may cause a phenomenon known as spatial aliasing.

So, in this particular lecture, we have covered the important concept of spatial resolution. What spatial resolution means? And what a pixel size means? And what determines this spatial resolution? So, essentially, our ability to resolve is determined by GIFOV, but the pixel size is determined by GSI. So, there is no clear cut definition of the term spatial resolution because everything combined together will finally determine our ability to identify objects in the image. When we finally get an image, we will not have knowledge of what happened inside the system? We have to just look at the image collect information out of it.

And all these things, the GSI, GIFOV and all other sensors or scanning geometric properties will determine our ability to identify objects in the image space. So, there is no single point of definition for the term spatial resolution. But, GIFOV determines our ability to distinguish objects and GSI determines the pixel size.

In next class, we will further go deeper into the topic and discuss about how our ability to identify objects changes with different properties contained within the image itself. With this we end this lecture.

Thank you very much.