Remote Sensing: Principles and Applications
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Lecture – 22
RS Image Acquisition and RS Systems – Part 5 (Spatial Resolution)

Hello, everyone, welcome to the next lecture in the course remote sensing principles and applications. In the last class, we have discussed about the important concepts of spatial resolution, pixel size, how these 2 can vary and what effects it will have on the image. In this particular lecture, we will go a little bit deeper into the concept of how certain properties of objects space helps us to identify the objects more clearly.

In the last class, I told you that our ability to resolve features depends on the GIFOV. As the GIFOV increases, a lot of spatial averaging will be occurring and hence, our ability to resolve features will be decreasing. Also, if we go and ask a common person, what they think about the term spatial resolution, it is very normal for us to say, the smallest size of the object that can be detected in image is spatial resolution. This is the most common definition one can expect from any common person. It is intuition. But it is not the case, because we saw the complex nature of remote sensing image acquisition system, how different elements play a role in our ability to identify objects. So, essentially, does the smaller size of the object will determine the spatial resolution? No.

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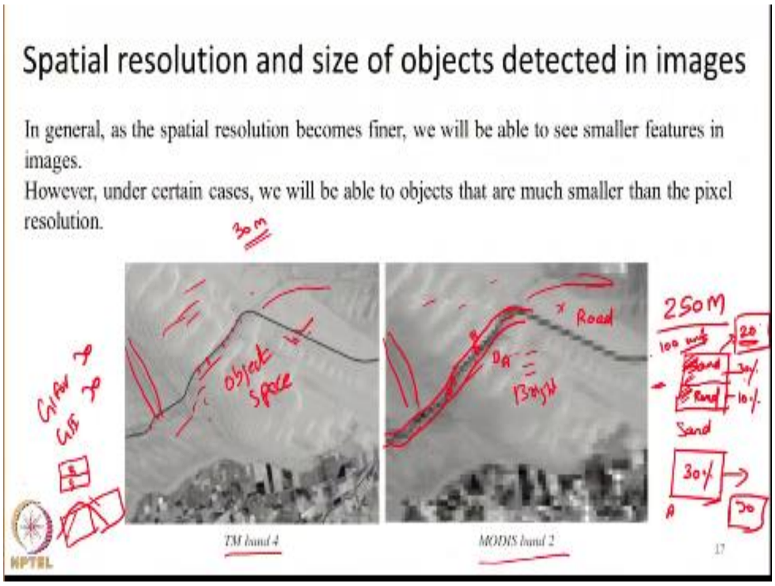

Most of the times, we may not be able to determine smaller objects, with the pixel sizes say 30 metres, we may not be able to identify objects of the size say, 10 metre by 10 metre, most likely. But under certain circumstances, we may be able to clearly identify objects that have or that has a much smaller size than the pixel size, as well as the GIFOV size of the system. When it can happen? Example is given in this particular slide.

Let us take an example of this. So, this is taken from a sensor called Landsat 5 Thematic Mapper where GIFOV and pixel size are 30 metres. So here, GIFOV is 30, GSI is also 30. This is MODIS band 2 where each pixel corresponds to 250 metres of data. So, here one pixel corresponds to data from 30 metres by 30 metres of ground space; here, one pixel corresponds to 250 metre by 250 metre of ground space.

Look these 2 images. Though, this image appears much more average, much more pixelated as everything, still we are able to see certain features. This road is clearly visible in this image and this is also visible to some extent in this image. Though, we are not able to clearly distinguish what is there, still we are having some signal. But this road is highly visible. Similarly, this line.

Most likely a road or a canal, most likely a canal maybe. They are visible clearly. What exactly happens here? If you take a road size definitely it will not be 250 metres, even it may not be 30 metres. The road size may be less than 30 metre in dimension, 30 metre in width, but still it is visible in Landsat image. That is fine. A road maybe say 10 metre, 20 metre in width, so, it is more than half a pixel, it is seen there. Fine.

Here also, it is being seen at a much coarser resolution. How is that possible? It is possible because of certain properties of the object space. So, this is we call it as object space, where the actual object is located on the earth's surface. What characteristics?

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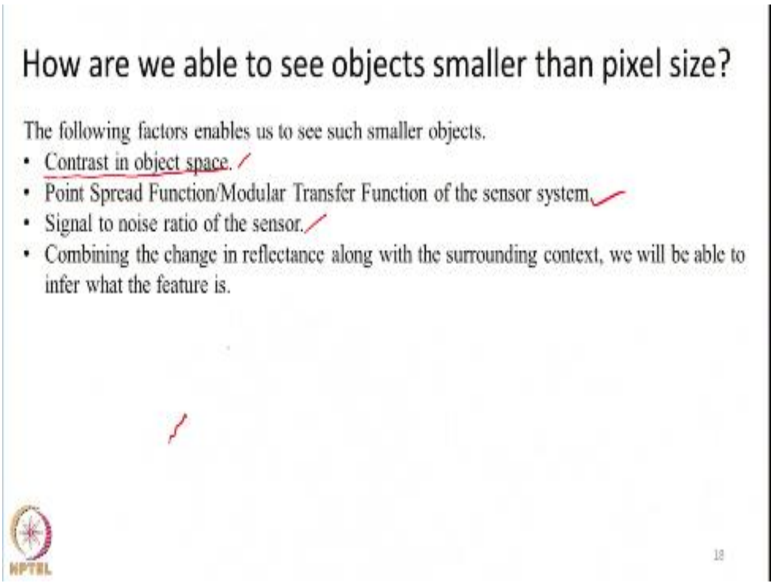

The first major characteristics is the contrast in the object space. What is contrast in the object space? Let us go back to the previous example. Let us take one GIFOV element. This is one GIFOV element by any one detector. So, the energy contained or the energy sensed by a single detector element is actually determined by what is coming out from each of the feature located within that particular GIFOV.

Let us say one GIFOV is located here in this particular sand, pure sand. This is one GFOV, let us assume. So, the entire GIFOV is filled with signals from sand, more or less uniform values. So, it will appear bright normally in visible bands or NIR bands and all, sand will have a somewhat brighter reflectance. So, it is appearing bright. Even if you look at beach sand, it appears bright to our eyes sight, because it can reflect a good portion of energy.

But let us take one GIFOV which has a mix of this road and sand. So, here this is sand. So, let us take a pixel example from here, a mix of road plus sand. In this case, what will happen? Let us say the sand has reflected back 30% of incoming energy. Now, this road has a very poor reflectance. Let us say the reflectance is 10%. Whatever be the band, let us say the reflectance is 10%.

So, this portion of the land surface will reflect only 10% of energy. This portion of the pixel where there is sand will reflect 30% of its energy. Let us assume the incoming energy is same for the entire GIFOV element. Say if the incoming energy is some 100 units for this pure sand pixel, pixel A, the outgoing energy will be 30 units because 30% of its energy is reflected back.

For this particular pixel, pixel B which contains a mix of sand and road, the outgoing energy will be average of these 2. Let us say both of them occupies half a pixel, half a pixel. So, it will be 20% of energy. So, outgoing energy will be just 20. Let us say everything is equally distributed. Half pixel, half a GIFOV is covered with road, half a GIFOV is covered with sand and both of them aligned in the same direction.

So, the outgoing energy will be 20 units for this pixel, the outgoing energy will be 30 units for this pure sand pixel. So, most of the pure sand pixels here, will be having a high incoming energy. Because of its pure sand content, it may have more or less uniform incoming energy. On the other hand, the GIFOV elements which are covering both sand and road will have a lower incoming energy in the sensor. I am talking from the perspective of sensor.

At the sensor the GIFOV covering a mix of road and sand will have a lesser value of incoming radiance than pixels of this pure sand all this time. So, if you try to plot it in a 2 dimensional space, the DN along this particular road element will be actually lower than or the incoming radiance at the sensor from these elements will be lower than the incoming radiance from all these space.

Because of this smaller radiance received for these pixels, they will appear darker to our eyes, because the entire surrounding area is bright. This particular portion alone is dark. So, we will have somewhat darker pixels. And just by seeing those darker pixels aligned along one particular line, we are able to understand or we are able to infer that it may be a road feature because it appears linear, it appears dark, it is smooth and so on.

But just remember one thing, here the road appears much sharper, here the road does not appear much sharper, because of the much larger GIFOV, that is, say the road may not be distributed like this. It may be something like one portion may have a larger sand component, another portion have a larger road component and so on. So, it may differ.

The orientation of the road within a GIFOV may vary, the percentage occupancy of the road within a pixel may vary, but whatever be, even if some small portion of the pixel is occupied by the road, definitely there will be a influence on the outgoing radiance from that particular GIFOV which will affect the DN of that particular GIFOV. Hence, the road width and those things may not be inferred from this practically, it is not possible.

Here it is much clearer, the exact space of the road and all is much clear here rather than this particular part. So, essentially what enabled us to identify this road? The contrast between the GIFOV are the pixels containing a mix of road and sand and the pure pixels containing only sand. It is the contrast in object space. So, on almost all pixels along the road, we have a mixed pixel. We call mixed pixel when more than one feature is present within the pixel.

So, there will be always be a fraction of road plus fraction of sand visible in the GIFOVs covering that particular area. And because of this presence of 2 features, the outgoing radiance will be less because of the difference in reflectance in comparison to the surrounding pure sand pixels. So, here we get a clear contrast that one line appears much darker in comparison to the surrounding sandy areas, which helps us to identify the objects clearly.

So, this is the important concept of contrast in the object space. Here the sand is much brighter than the road, the contrast is much higher. This enabled us to identify that small road in a much coarser pixel size of 250 metres. The next important concepts which helps us to identify smaller objects in a coarser pixel sizes is known as the Point Spread Function or the MTF Modular Transfer Function.

These 2 are related concepts. Point Spread Function is a concept, Modular Transfer Function is a concept. We are not going to go in depth into these concepts, but I will just introduce you what is what. So, essentially what a Point Spread Function is? Let us take a lens. So, let us say some energy light source is passed through the lens and the light source that is passing through the lens is coming from a point source, essentially just a single streak of light is passing through the lens.

Essentially when only one streak of light is passing through the lens, it should be imaged as a point. But it will not happen in reality. Almost all optic system, be it lens or whatever, they have certain limitation of imaging a point source. A point source will not be imaged as a point, but it will be imaged as if it is optical system, if it is lens or something, it will be imaged as a set of concentric circles, like example is given in this slide.

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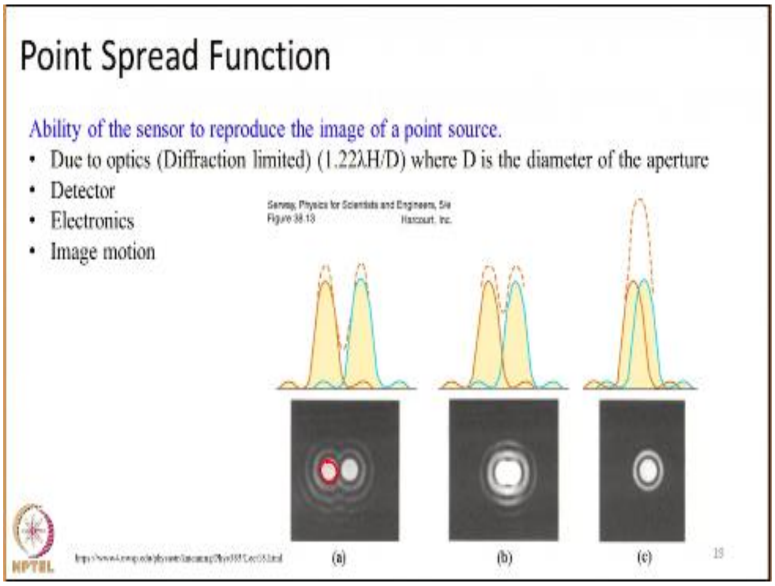

Say here you can see 2 points source rather than being imaged as 2 separate points, they are imaged as 2 set of concentric circles with a single central bright spot, a dark spot, a little bit more bright spot, a dark spot and so on. So, this is 2 different point sources, but they are appearing like as concentric circles. This is the limitation of any optics system. None of the optical system like lens, mirrors, the combinations, none of them are perfect. They will have some deficiency like this.

Essentially, a point will not be imaged as a point. This is one thing. Not only because of optic system, if you take a case of a remote sensing sensor, then there are lot more other system, in which optics is just one part of the sensor, the lens assembly and everything is just one part of the sensor. After the data is collected by lens, it is passed on to amplifier and electronics, then our detector basically.

After the detector senses the energy, it sends it to the amplifying system and electronics all those things. So, there are a lot of other components involved, which will further degrade the incoming signal. The detector has a finite size, it is not like again a point. Detector has a finite size that is whatever be the incoming energy, it will not be recorded in one point.

Since, the detector has a certain size, the incoming energy will spread over that particular area, which will essentially cover one particular full pixel in the image. So, because of the finite size of detectors, there may be a Point Spread Function happening. Because of limitations in electronics, how we sample, how we quantize, Point Spread Function may be happening and we also know that earth is moving underneath the satellite.

Satellite is moving like this, earth is moving like this and we have our experience with normal photography that when the object moves, when we are taking a photograph, there will be some sort of image blurring. Image will not be crisp, it will look blurred because of the movement of the object. So, earth is continuously moving, satellite is continuously moving.

So, both the camera or the sensor and the object is in continuous motion and which will cause small amount of blurring in the image. Even though, we may not be able to see it or visibly feel it, there will be some blurring in the image. So, all these things combined together will determine whether a single point in the object space is imaged as a single point in the image space, which will not be. Anyway we know that digital image will not be continuous.

A single point in object space will not be imaged as single point in the image space. It will not be the case. So, all these components taken together, the optical components, the detector, finite size of detector, the electronics involved, motion of earth and satellite in relation to each other, all these things will make a single point to spread over like a small area. So, each of the different, different points in the image is going to spread over like a small area, which will cause a small kind of blurring in image.

Image will not be crisp and all know if the image is blurred, our ability to identify objects within the image will go down. Higher the blurring our ability to identify small, small objects will go down. So, a system has to be perfect. A system has to reproduce whatever there in the object space exactly in the image space for us to identify it. In remote sensing sensors that will not happen. That will affect our ability to identify the objects in the object space.

But if some sensor is extremely good, where nowadays a lot of high spatial resolution sensors are there. They are extremely good in having very good system properties. We may be able to identify object clearly. Just an example, let us take 2 hypothetical systems. They have exactly same GIFOV, GSI, same look angles, scan angles, everything one and the same.

Only the difference is the PSF Point Spread Function components of system A is little bit poorer than system B. Let us say system B is having a better PSF. In that case, the image acquired from system B will be much sharper and we will be able to identify objects very clearly from image acquired by system B than system A.

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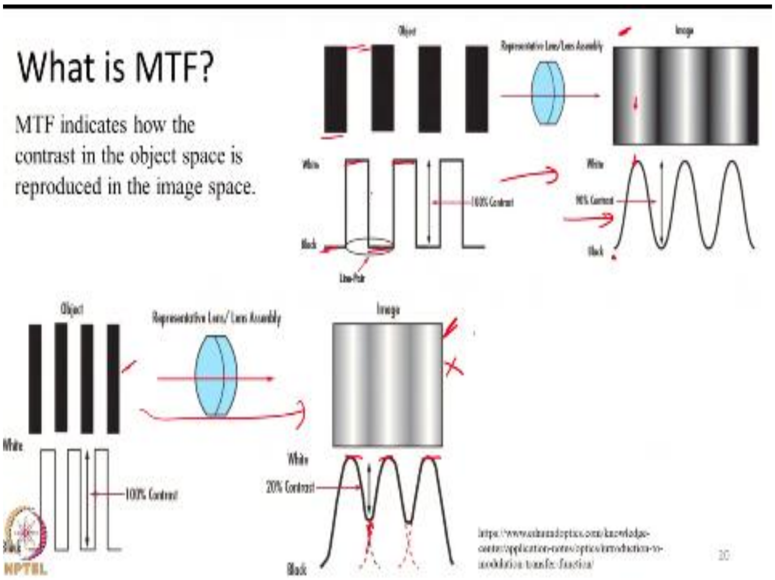

The next important concept, I told is MTF Modulation Transfer Function. Just to put it in a simple sense, how the contrast in the object space is being transferred to the image space, this is what will determine the MTF. We are not going in depth about the MTF concept, but just a simple example I will tell you. So, this is an object space. So, object space has bands of dark and white patches.

So, essentially if you take an image signal from this, so, here it will be 0 signal. It is extremely dark. Here it will be 100% signal, extremely white, again 0, 100. So, it is a very high contrast object space. Let us say, it is now being transferred to a system. So, optics, electronics everything is, the signal is passed on to this. When the image is being produced, let us say because of the limitation in system, this particular object space, this signal is being reproduced like this.

The contrast has now decreased. So, the black has become grey and the white has become a little bit dull or brighter version of grey, it is not pure white. So, the contrast in the system is now totally reduced. Just take this example. The contrast, the same object, but the contrast here is much reduced. The black appears a still a lot brighter grey and the white again appears like a lower version of or impure white brightness something like that.

So, here you can see, whatever be the object here is not represented properly here. So, this will say how clearly the contrast in the object space is reproduced in the image space. So, if the contrast is maintained properly, if the black and white tones in object space are maintained exactly as black and white tones, it is fine. But as I told, all sensor elements comes with their own limitation.

There will be like variation in the grey tones. Everything is in grey tones. Black is extreme low value, white is extreme high value but in between, there is just grey tones. So, in the image space, the grey tones are not reproduced properly. This will determine the MTF. And as we know if the MTF goes lower and lower, this MTF is a little bit higher than this particular MTF.

So, our ability to identify the objects will also depend on the MTF of a system. So, these 2 characteristics, Point Spread Function and MTF will together define our ability to see smaller objects in the object space. So, in the properties, we have seen contrast in object space, Point Spread Function, MTF Modular Transfer Function of the system. Then is the signal to noise ratio of the sensor. Each sensor will have a characteristic noise being produced within it.

So, none of the system is again is perfect. So, there will always be some amount of noise that is being produced inside the system. So, that will always mix with the incoming signal from the ground, they will be recorded together. If the signal component is much larger than noise, it is fine. Actually, that is the aim of the Landsat MSS. They want to increase the signal in terms of system noise that is why they made the GIFOV much larger than GSI. That is one of the reasons.

So, signal to noise ratio, the amount of signal to the amount of noise in a simpler sense. So, if the noise is low, S/N ratio will be high. Or if the signal is much higher for a constant N, still S/N will be higher. So, increasing this S/N ratio either by increasing the signal or reducing the noise produced by the system within the system will help us to improving the image qualities.

So, all these things combined, the contrast, Point Spread Function, Modular Transfer Function, signal to noise ratio, all these things combined together will help us to identify objects that are much smaller than the pixel size of the particular sensor system. If there is very high contrast between the object space and the system is able to reproduce everything perfectly, then we will be able to see even much smaller objects.

And just by looking at the contrast in the image, you will also be able to decipher what that object is. Say, in the example of that road and sand, the desert example, we were able to identify or interpret that linear features as a road by looking at it is not only its colour, but also its shape, how it is oriented a lot of other features. So, essentially by studying this variation is contrast in respect to the spatial context, we will be able to interpret what feature is present there.

So, essentially, what have you seen in today’s class is, it is not necessary that the smallest size of the object should be treated as spatial resolution that definition is not true. Like most of the people will tell that the smallest size of the object that is seen in an image is a spatial resolution of a system. That is not true.

Under certain circumstances, we will be able to see certain features that are much smaller than the pixel size or GIFOV size of the sensor and what factors control these is what we have seen in today’s class. We will continue with the rest of the topics in the coming lectures.

Thank you very much.