Remote Sensing: Principles and Applications
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Lecture-47
Active Microwave Remote Sensing-Radar-Part-4

Hello everyone, welcome to the next lecture in the topic active microwave remote sensing, where we are discussing about the imaging radar. The last lecture we discussed about the resolution concepts of imaging radar system especially the real aperture radar, what are the limitations with it and briefly got introduced to the concept of synthetic aperture radar. So, in this lecture we will discuss about the geometrical characteristics of the images acquired by synthetic aperture radar systems.

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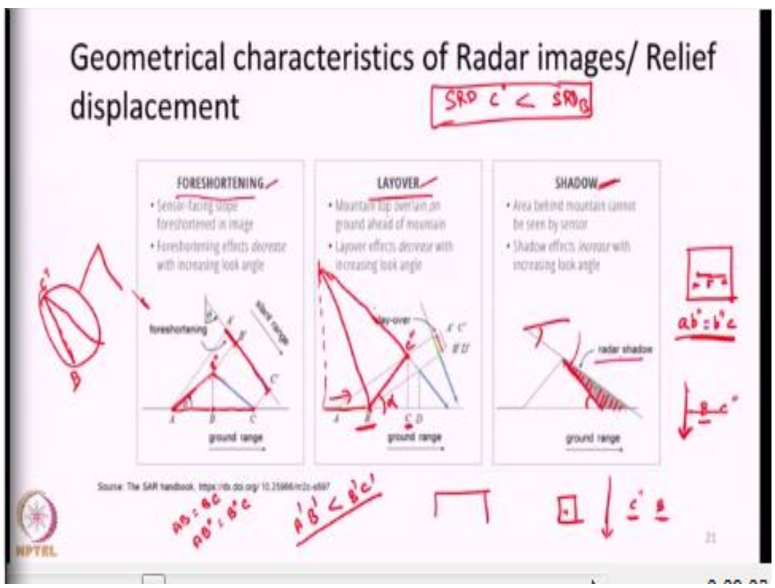

So, geometrical characteristics of image, basically means what sort of distortions may occur, how features may appear? So, we are going to discuss briefly about that. So, consider this in analogy with the distortions we discussed in the optical remote sensing when we discussed about the scanner elements, like whiskbroom scanners, push broom sensors and all. There I told for whiskbroom sensors the GIFOV will be keep on increasing and it will become coarser and coarser as the scanning angle increases which will cause image distortions. Similar concepts apply to radar remote sensing also, but here it will be occurring in a different sense. So, I told you that radar measures distance in the slant range, so the slant range distance can be converted to ground range distance easily if the surface is flat. But most of the surfaces are not flat and will have some sort of topography. So, presence of such topographic features like a small hill will change how land surface feature appears in the radar images. So, that is what we are going to discuss now. Here in this slide I have marked 3 concepts or 3 ways in which images or features will appear distorted in radar images.

First thing is foreshortening, then it is layover, then it is shadow, what exactly foreshortening is? Let us say we have a mountain or hill, so antenna or the radar system is somewhere here. So, the ground point here is A, the ground point here is B, the ground point here is C, the top of the hill is labeled as B ‘‘. Let us say the length AB ‘‘ is the slope is same as B ‘‘ C. Similarly, the horizontal distance is also the same, that is horizontal distance AB = BC. Similarly, even the sloping distance AB ‘‘ = B ‘‘ C, so let us assume it like symmetrical mountain, symmetrical hill. Now if the radar system is here, this slope AB ‘‘ is facing the radar antenna and B ‘‘ C is facing away from the antenna. The length of these 2 slopes AB ‘‘ and B ‘‘ C are same. So, naturally we will think in the image they appear symmetrical. But in radar images, this will not be the case, due to the slant range image acquisition, the radar signal that is coming in will compress the foreslope. Foreslope means the slope facing the antenna. So, the length of the foreslope will become shorter than the slope that is facing away from the antenna. So, the slope distances that normally we will see in radar images it will not be the same. Even though the hills are symmetrical in our example, the image distance A’B’ will be much shorter than B’C’. So, this concept of shortening the length of the slope facing the antenna is called as foreshortening. This foreshortening effect decrease with increasing look angle**.** So in radar image the length of the topographic features having slope facing the radar antenna will appear shorter than the length of the slope facing away from the antenna.

The next concept is layover, here there is like a gentle slope AB‘‘. Let us say there is another hill which is relatively steeper, so this maybe labelled as C‘‘. At B the angle is a much steeper, so when the radar signal is coming in, the slant range distance between the top point C will be shorter than this ground point B**,** or C‘‘**.** The slant range distance for point C‘‘ will be less than the slant range distance measured for point B, then the radar system will image as if point C is near to the system than point B, so when the image is formed, in the azimuth direction first this point C‘‘ will be mapped, then point B will be mapped. But in real, if we walk from nadir to the hill, we will first encounter the ground point B then only we will be able to encounter this point C**.** So, essentially the image also should look like this. But for radar since the slant range distance of C‘‘ is smaller than slant range distance of B, C‘‘ or the top of the hill will be image first then the bottom of the hill will be image later. So, in the image when you look it will appear as if the top is laying over the bottom. The mountain will be sloping like this rather than looking like this**.** So, this is what we call as layover, mountain top over laying on ground ahead of mountain like the base.

Next the shadow effect will occur, if the back slope is actually much steeper. Let us say the back slope that is the slope facing away from the antenna is steeper than this particular depression angle then the slope facing away from the radar may not get illuminated by the radar pulse. And hence whatever portion that does not get illuminated by radar pulse will appear much darker in the radar image and this is called radar shadow.

So these are the 3 types of relief displacement, foreshortening, layover and shadow. Foreshortening means the length of the slope facing the antenna will appear shorter than the length of the slope that is facing away from the antenna. Layover means an extreme case of foreshortening, that is the top will appear in front of the bottom of a topographic feature. Then shadow is for slopes facing away from the radar antenna in the direction opposite to it, some parts of the slope may not be illuminated properly by the radar signal and they may produce a black portion in the image without any radar input. So, some portions will appear completely dark, this is called shadow.

In the below example, we can see foreshortening naturally happens when the slopes are gentle. The point A, B appears like a short steep slope, so it will produce a bright signal. Because let us say whatever features are present within the slope, everything will be compressed in a very short distance in the image. So, this will produce a bright signal but for a shorter length. So, this is called foreshortening. In case of layover the foreslope facing the antenna is steeper than when we compare with the look angle of the system. Under such circumstances the top will be image first and then the bottom will be imaged, giving an impression that top is lay over the bottom. If the backward slope is much steeper when we compare with the depression angle of the system, then whatever portion that is lying between this depression angle point and the ground point will not receive any radar signals and hence will produce a completely dark signal in the image. This is called shadow.

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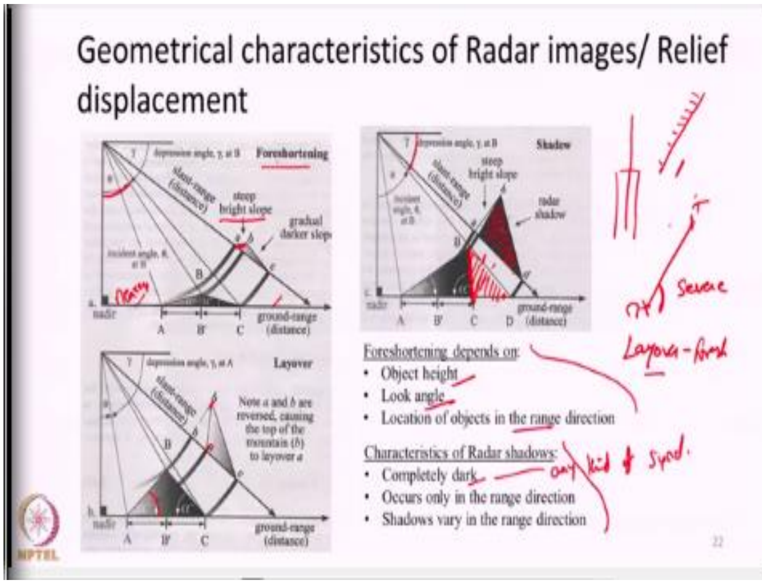

Some characteristics of the foreshortening depends on object height. Taller the object or taller the top of the object when compared with the bottom, foreshortening effect will be severe. And if it crosses a certain threshold then it will translate into layover like an extreme case of foreshortening. So, if the top is much taller than the bottom of the topographic feature, say there is a huge tower standing. Under certain circumstances foreshortening will become very extreme and gets converted to layover. Then with respect to look angle the foreshortening and the layover effects will be severe in the near range than in the far range. So, the foreshortening effects decrease with increasing look angle. That is in near range when the look angle is shorter, the foreshortening effects will be much stronger. That is slopes will be foreshortened to a greater extent in the near range than slopes that are in the far range**.** So, the look angle and the location of the objects will affect foreshortening and layover.

Then let us see some characteristics of radar shadows. They will be completely dark and will not have any kind of signal, pitch black. Just think it in analogy with our optical remote sensing. When we discuss optical remote sensing we saw that even when direct sunlight is not falling on an object, the diffuse skylight can irradiate that object to some extent, that is the diffuse skylight present in the atmosphere will eliminate whatever features present there, so we will get some image of objects that are present within the shadow in optical remote sensing. That is not the case in radar remote sensing. In radar remote sensing we are not receiving or measuring any outside signals, whatever we send only we will receive it back. So, if the objects are not illuminated by the microwave pulses that were transmitted by the radar antenna, they will not reflect anything back. And hence whatever portions that do not receive any radar illumination will appear completely dark, no other external source of energy is present, the radar shadows will be pitch dark.

And also the radar shadows appear only in the range direction. That is say if the flight is flying like this, shadows will be cast only in the range direction. This is because in the azimuth direction there is no concept of shadow. If a topographic feature standing here, when the flight is flying like this, then the shadows will fall only in range direction. So, by looking in the direction in which the shadows are aligned we will be able to get some information about the flight direction, that is possible. And then the shadow effect will be severe in the far range**.** That is if there is a slope in the near range there are chances that the back slope will get illuminated, shadows may not be there but in far range shadow effect will be very severe. This is like opposite to this foreshortening effect, foreshortening effect will be very severe in the near range will decrease in the far range. Shadow is exactly opposite, shadows will be occurring to a less extent in the near range it will be occurring to a larger extent in the far range, so these are some characteristics of radar images.

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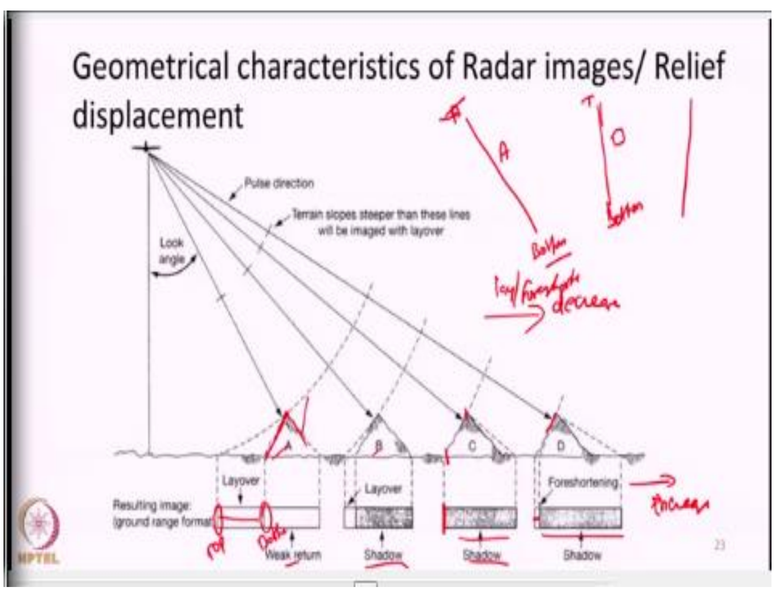

So, this particular slide tells us an interesting picture of an example. All these hills A, B, C, D are almost identical. And they are positioned in different positions in the range direction. A is very near to the antenna B, C, D are little farther from the antenna. So, here at point A there is a layover effect, that is extreme case of foreshortening. A will be imaged first then the bottom will be imaged. When you slightly move away in the range direction and come to this hill B, this effect will become slightly reduced.

Say the top rather than appearing very steep, it may appear slightly lesser steep as if both of them are in almost like straight line. So, this is for hill A, this is hill B, a slightly reduced effect of layover. At point C the layover effect is further reduced, so the top and bottom will appear as if they are at one single exact point, that is the slanted distance of top and bottom are one and the same. Then in the far range some foreshortening occurs, foreshortening is like layover is translating into foreshortening. So, your extreme effect is translating into something, if layover has not occurred here, if the slope is much shallow here itself then there will be layover here and the layover effect may vanish in the far range**,** so that is the concept.

So, the layover effect is slowly decreasing as we move away in the range direction. Whereas look at the shadow, this backward slope, here there is some sort of return for the radar signal, there is some weak return. Whereas from this mountain B, the shadows will be dominating and the length of the shadow is keep on increasing as we move away in the range direction**.**

So, the layover or foreshortening effects will move together, so the effect will decrease in the range direction for layover or foreshortening. Whereas the length of the shadow will increase as we move away from the nadir point, as we move away in the range direction. So, these are essentially the geometrical characteristics of radar image.

And these geometrical characteristics will be clearly visible in image acquired by aircraft systems. Because normally in aircraft systems due to the shallower flying height the look angle will vary a lot. The aircraft has to cover a large area, there will be a large variation in the look angle and there will be a drastic change in the image acquired, so these effects layover or foreshortening will be clearly seen.

When we move to satellite systems, the look angle will not be varying to a large extent because of the very large flying heights involved, due to which the effects may be slightly reduced. So, whenever we work with aircraft based radar images, we have to really take this into account. So, that is why in radar image processing, there are certain open source tools available to process SAR images.

For example SNAP toolbox by ESA and Copernicus team will have an inbuilt terrain correction feature using a digital elevation model in order to correct the effects of terrain due to the layover and foreshortening effects. So, terrain correction has to be performed in radar images, whenever the images are acquired over land surfaces having very large variation in surface topography.

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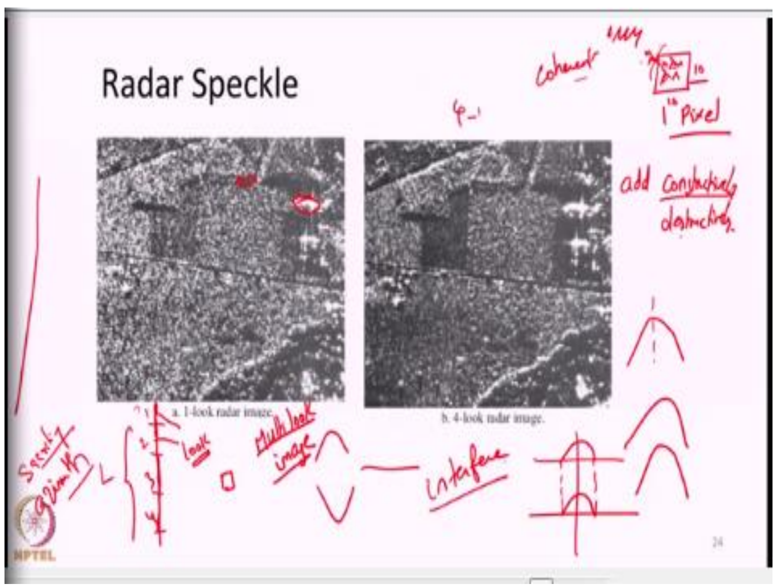

The next important feature of SAR image is radar speckle. Previously I told that the phase information is also getting stored and it is being used to process the data to produce one image and in order to improve the azimuth resolution. Let us take one pixel in the radar image. There can be many different features present, even though if you assume this is 10 meter by 10 meter, but still within this 10 meter by 10 meter that can be different, different features present within this pixel. So, when radar interacts with these objects, based on the object characteristics, the backscatter signals will have differing phases, like phase relationship can be the same or it can be different based on the features present. All these things will be processed together by the radar system to produce this one particular pixel. So, when all these are combined together along with the phase information, the phase of each of this return signal may add up constructively or they may add up destructively. If the different reflected microwave signals add up then essentially they will produce a very bright patch in the image for that particular pixel. So this is constructive interference or adding up of waves. Whereas if 2 waves are out of phase with each other, they will cancel out and they will produce a very dark patch. So, the waves within each resolution element of radar pixel can add up during radar data processing and they can add up in either constructive manner or in destructive manner leading to bright and dark spots in radar image. We call this as radar speckle, especially certain images acquired over urban areas may have speckle effect to a large extent. So, on a colloquial note we call this as a salt and pepper pattern, bright, dark, randomly appearing bright and dark patches. Image with this kind of characteristics will not be helpful for us. They may not be pleasant to look, we will be having random patterns or random patches of bright and dark patches which may not look good. So, the speckle has to be kind of reduced.

It is a characteristic of synthetic aperture radar. Because in synthetic aperture radar the phase information is also recorded and used in data processing thereby enabling the addition of 2 different waves or superimposition of 2 different waves**,** so this is due to radar data processing. So, this speckle effect has to be reduced. So, there are plenty of ways in which this radar speckle can be reduced, we are not going to discuss everything in detail. But one of the simple ways that people use in radar processing is multi look. In synthetic aperture radar processing, the same object will be appearing in the radar system for a long distance much longer than the physical length of the antenna. So, all the distance for which the object is visible will be combined together in order to synthesize a very long antenna length.

So, let us say one particular object is visible for several kilometers of distance. They will be broken up, all the things will not be combined together, so they will be broken up into small, small patches say 3 or 4 different patches. Each patch will be processed separately and then they will be added together, we call this as multi look. So, let us say this is the entire length for which an object is being imaged by the radar system. Instead of taking this entire length L, let us say this is broken to small, small chains**.** This is 1, 2, 3, 4, for this 4 it is broken to small, small chains and they will be processed separately. So, conceptually speaking the phase information is just added for a small amount of distance covered rather than adding up all the phase for this entire length.

So, each of these things are called as one look, so all these looks will be added together to produce a multi look image. So, essentially a multi look means rather than synthesizing a very long antenna, the antenna length will be broken during data processing itself in order to reduce this speckle effect. So, here essentially we are sacrificing the azimuth resolution, because as the antenna length decreases azimuth resolution will become coarser and coarser.

We are sacrificing the azimuth resolution in order to reduce the speckle effect. So, radar speckle is a salt and pepper pattern that is appearing in synthetic aperture radar images which will produce a random pattern of bright and dull spots. And in order to reduce this effect, system itself will do multi look processing. Apart from this we can use some sort of image processing filters to reduce this effect further.

So, in this lecture as a summary, we have discussed about the image characteristics or relief displacement features of radar images. And also we have discussed about the radar speckle which is a characteristics of image acquired by synthetic aperture radar system. With this we end this lecture.

Thank you very much.