Remote Sensing: Principles and Applications
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Lecture - 12
Interaction of EMR with Terrain Features – Part 2

Hello everyone, welcome to this lecture on the topic interaction of electromagnetic radiation with terrain features. In the last lecture, we discussed about how a surface can be classified based on how they reflect. That is specular, diffuse, near specular, near diffuse and so on. So, how to characterize, whether a surface is specular or not? That is what we are going to see in this particular lecture. How to tell whether a surface will behave specularly or on a diffuse fashion?
Essentially, that depends on surface roughness. In last class, I told you whenever a surface is rough, that is whenever there are some elements present like sand grain, stones, and surface is not even and it is having ridges, small faults, pits and everything, that surface will appear rough to our eyes. That is what we call basically as surface roughness. So, based on surface roughness, each surface may appear smooth or rough based on how much is the deviation.

So, what is the criteria to classify a surface into smooth or rough? And that particular criteria we are going to see in this particular lecture. The criteria is known as Rayleigh criteria.

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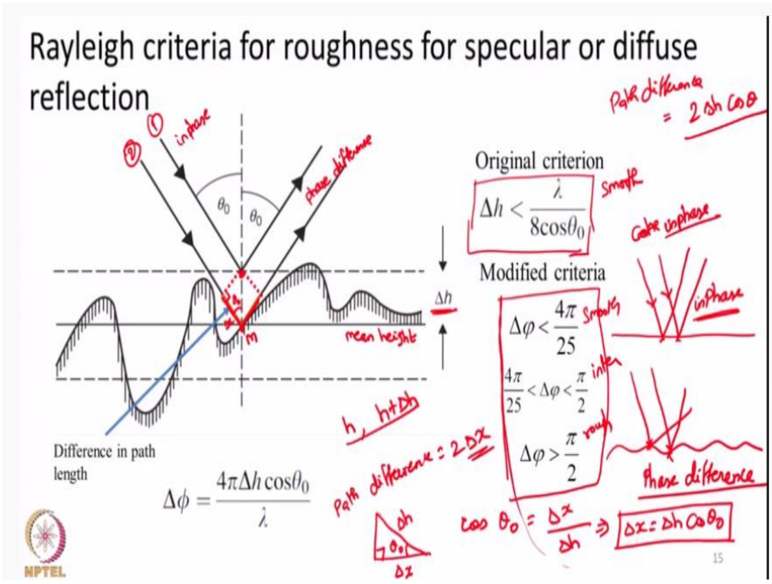

So, based on Rayleigh criteria, we will classify a surface as smooth or rough. What Rayleigh criteria is? We will see now. Let us say there is a smooth surface. Assume 2 beam of parallel radiation which are in phase coming and falling on it. If the surface is really smooth, what will happen? Both the beams will be reflected and they will obey Snell's Law. And the phase difference or in phase nature will be still maintained even after reflection. Because they travelled parallely, they got reflected almost at the same instant. The surface is really smooth, not much of difference would have occurred. They would have still continued parallely without any change in phase.

Let us say there was a rough surface. Assume 2 beam of parallel radiation which are in phase coming and falling on it. Just because of the presence of this roughness, now, they will be reflected in different direction. This may go off like this. This may go off like this, first thing. And since for each one, the distance they travelled is slightly different, this particular wave stopped here itself. This wave travel a little farther to reach this down point. So, the distance they travelled varied. Hence, the parallelism will be changed. And when they are now reflected, there will be some sort of phase difference got introduced after reflection.

That is if a surface is not extremely smooth, then there will be some sort of phase difference introduced between the waves, here within the first 2 rays, between rays 1 and 2. Even though when they came in phase, after reflection there will be a small phase difference between them. So, the Rayleigh criteria was based on this particular phase difference. What Rayleigh said is, if the phase difference between different waves reflecting at different points on the particular terrain feature is less than $\pi/2$, then that particular surface can be classified as smooth. On the other hand, if the phase difference between the 2 waves is more than $\pi/2$, he classified the surface as rough. So, how this thing came up? The term $\pi/2$ was actually like a thumb rule. He said $\pi/2$. And most of the people used it that is fine but, how to calculate the phase difference? For calculating the phase difference, we will do a small derivation. So, there is a rough surface given here. So, this particular line is the mean height line. That is if you take average of heights in the surface, this is like the mean height.

So, there are 2 different points we are taking. Let us say one is here on some surface here. Let us say there is one more reflection happening at this particular height. And this should be actually marked on the terrain, but this is marked here just because for clarity. So, let us say reflection is occurring at height of mean height and another reflection is occurring from surface slightly above this at the height of Δh above mean height. So, there are 2 points on terrain, one at a height of h and the other at $h+\Delta h$. 2 waves are coming one is getting reflected from the point with height h, one is getting reflected from the point at height $h+\Delta h$. Let us assume both of them are in phase.

So, now, this is reflected from this point going like this. This is reflected from this point still going like this. But still there will be some phase difference introduced between them.

Why this phase difference is getting introduced? This phase difference is getting introduced because of this additional path that this wave travelled to reach this point. When I discussed about coherence, I told you like as long as 2 waves are exactly parallel they will be maintaining the phase relationship. But when the path difference changes, when the path length changes, when they become non parallel, they will lose their phase relationship. The phase relationship will change. They will lose their coherency. Same thing is applied here. Due to the difference in path length between 2 radiation there comes a small phase difference between them.

How to calculate the path difference between the 2 points? Say, there are 2 points and two waves are coming. Let us name this wave as wave 1, this as wave 2. The wave 2 has travelled this much distance more than wave 1. Wave 1 got reflected from here to here. Whereas, wave 2 has travelled an additional path, a path difference is there when it travelled. So, how to calculate it? If you take this as a straight line, this is also θ_0, this is 90 degree. From this point, I have drawn a perpendicular to this surface. So, this is 90 degree. So, we are interested in this particular Δx.

So, the phase difference the path difference we need is $2\Delta x$. That is Δ x in this side, Δ x this side. First, we need to calculate, what is Δx? So, just look at the small triangle here. This is θ_0. This is the 90 degree line. This is the Δx we need. And this hypotenuse here is the Δh, the height difference between them. So,

$$\cos\theta_0 = \frac{\Delta x}{\Delta h}$$

$$\Delta x = \Delta h \cos\theta_0$$

So, this is the half of the path difference. So, the path difference is $\Delta h \cos\theta_0$. So, we need $2\Delta x$. Because this is Δx, this is Δx. So, multiply this by 2. We will be getting the total path difference is equal to $2\ \Delta h \cos\theta$. So, now, we know that for a wave to complete one full cycle 0 to 1 (full cycle λ). It has a phase of 2π. Here the path difference between 2 waves is $2\ \Delta h \cos\theta$. So, that is also a distance. So, what will be the path difference that would have come for this particular distance? That is what we are going to calculate as a next step.

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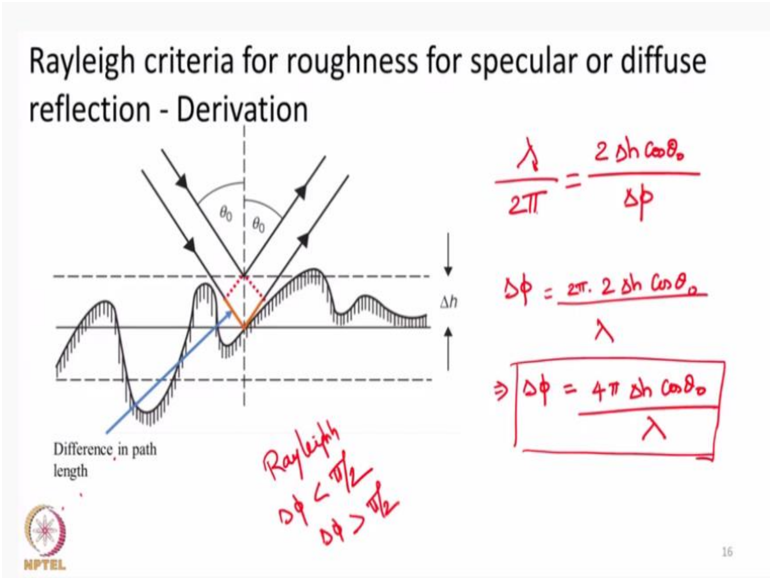

That is for a wave with wavelength λ or distance for full wavelength λ, the phase is 2π. For now, our distance is 2 Δh cos θ, it is actually a distance. What is the phase? We do not know, because this is the phase difference between 2 waves. So, we need to calculate this. So, rearrange this,

$$\Delta\phi = \frac{2\pi\ 2\ \Delta h \cos\theta_0}{\lambda}$$

$$\Delta\phi = \frac{4\pi\ \ \Delta h \cos\theta_0}{\lambda}$$

So, what we did here, I am just telling it again for simplicity sake. That is a wave of wavelength λ will have a phase of 2π over the center wavelength. For us, we are going to calculate the phase difference for a wave which has travelled this much distance 2 Δh cos θ. So, the small phase difference Δϕ is (4π Δ h cos θ_0)/λ.

So, what Rayleigh said is, if this Δϕ is less than π/2, that particular surface is smooth. Or, if this Δϕ is more than π/2, that particular surface is rough. That is what is given in this particular slide. So, what essentially will happen? If you imply that condition for this equation that is Δϕ less than π/2 or more than π/2. we can calculate Δh here.

So, if the Δ h is less than λ/8cos θ_0, that particular surface is smooth. If the Δh is more than λ/8cosθ_0, that particular surface is rough. That is the original Rayleigh criterion developed by Lord Rayleigh. But later on people decided a surface need not be only smooth or rough and that can be in between nature. So, then people decided to modify the Rayleigh criteria based on smooth surface, intermediate surface, rough surface.

So now, the conditions are given here for the 3 surfaces. If the phase difference $\Delta\phi$ is less than $4\pi/2\pi$, the surface is smooth. If it is between $4\pi/25$ to $\pi/2$, that surface is intermediate, or if the $\Delta\phi$ is greater than $\pi/2$, that surface is rough. So, this is the modified Rayleigh criteria to characterize whether a surface is smooth or rough.

One thing here to note is the calculation of Δh that is how much height a point is above the mean height of the surface. If there is a lot of roughness elements in the terrain we can fix a mean height and we can fix how much the height of other points varies with respect to that mean basically. That is what is Δh. And that Δh depends on the wavelength and the angle of incidence with which EMR is coming and falling on the surface.

So, a same surface can appear rough to one particular wavelength, but appears smooth to another wavelength. Like I said, example of a sandy beach with coarse sand grains, when we look at it, our eyes will see only visible wavelength. At visible wavelength 0.4 to 0.7 micrometers the dimensions of big sand grains is much coarser. So, the Rayleigh criterion for roughness will be satisfied and that particular surface will appear rough.

So, that is why coarse sandy beaches we appear to our eyes rough. On the other hand, if you take an image of the same beach at microwave wavelengths, maybe like say 30 centimeter wavelength and so on. That particular beach will appear smooth, because of wavelength dependency on surface roughness. So, same roughness same surface may appear smooth at one wavelength or may appear rough at other wavelength. This you have to remember.

So, surface roughness is not fixed, it depends on the wavelength and also it depends on the angle of incidence, whether the angle is coming straight from the zenith like θ is 0 or whether like θ is coming at larger angle and so on. These particular surface roughness characteristics will vary. This we should remember when we work with Rayleigh criterion.

So, one more important feature about EMR interaction with surface is, in wavelength less than 3 micrometers, we will be interested to study the concept of or study the reflectance properties of objects, how objects will reflect back. Each object has a characteristic reflectance curve. What exactly a reflectance curve is? A reflectance curve is say, if you are able to measure reflectance of an object on different wavelengths and plot it in form of a graph that is known as a spectral reflectance curve. Example for this is given in this particular slide.

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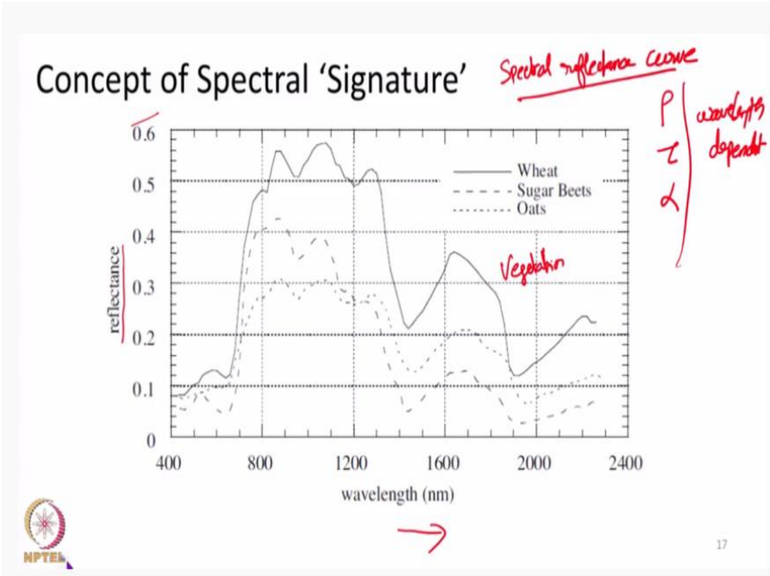

Say here we have plotted reflectance. As I said, reflectance will vary between 0 to 1. Here in this case, we are stopping at 0.6. This is with respect to wavelength. So, all the 3 properties of objects, reflectance, transmittance, absorptance, all are wavelength dependent. They vary with wavelength. Hence, here I am plotting how objects will reflect our different wavelengths. So, this particular curve that I got is known as a spectral reflectance curve. And if we get this spectral reflectance curve for various features on the earth's surface, like vegetation, water, sand, urban materials, ice, snow, whatever, we will be able to see that different class of features has a characteristic shape of curve. Like this, the curve given in this particular slide is actually for vegetation. So, vegetation curve will have this characteristic shape. It will have a small peak, a valley, a large peak, there will be lot of small valleys in between.

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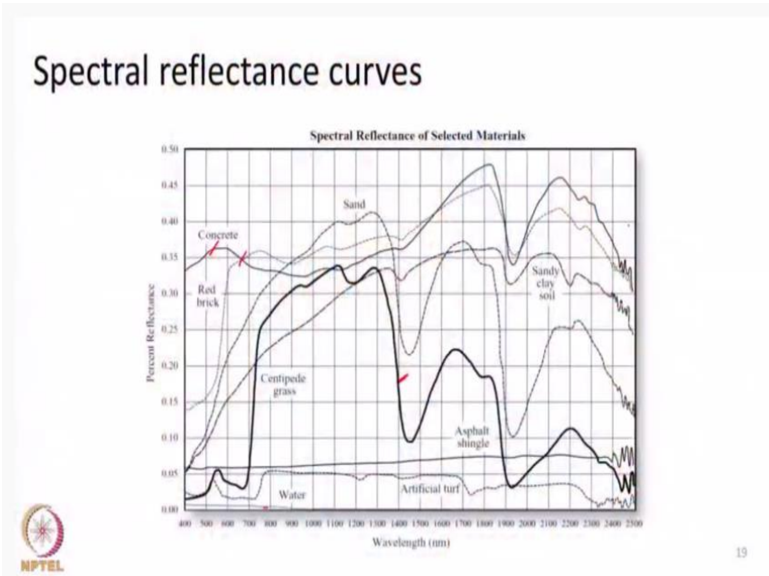

See here in this particular slide, the spectral reflectance curve of different features is given. So, this small dotted line is for water, this is for grass again a vegetation. So, this is for concrete. This is for red brick. So, different features has completely different spectral reflectance curve and they are almost unique for each feature. Say, when we do remote sensing actually we will have lot of other interference. We will see later. But, if all the interferences are removed, if you are only capturing the reflectance of objects in a closed laboratory, means perfectly controlled conditions, then each different class of objects will have a characteristic reflectance curve. Using this characteristic reflectance curve, we will be able to identify that particular object from remote sensing images. And that is why we call these particular curves also as spectral signatures.

Like each one of us will have a unique signature. By looking at the signature, people in bank will identify you. This is like Eswar, the sign is matching with him. Fine, I can pay him whatever money he asked for. Similarly, each one of us has a unique signature. Same thing, each object has its own unique spectral reflectance pattern. And hence we call this spectral reflectance curve also as spectral signatures.

Using the spectral signatures, we will be able to classify all objects, most of the objects at least from remote sensing images. So, in this particular lecture, what we discussed is, we discussed the Rayleigh criterion of roughness. What is the criteria to classify a surface as smooth or rough? And based on the Rayleigh criteria, we also noted that the criteria is dependent on wavelength, a same surface can appear rough or smooth based on the wavelength involved.

And also we got introduced to the concept of what is known as a spectral reflectance curve and what is spectral signature? In later classes, we will understand, what happens to these particular curves? What are the problems we will face when we try to do remote sensing to classify objects using this curves. With this, we end the lecture.
Thank you very much.