Remote Sensing: Principles and Applications
Prof. R. Eswar
Assistant Professor
Department of Civil Engineering and Interdisciplinary Program in Climate Studies
Indian Institute of Technology – Bombay

Lecture – 15
RS data: From Radiance to reflectance - Part 1

Hello everyone, welcome to today's lecture in the course remote sensing principles and applications. In the last class, we have discussed the various ways in which the signal from the terrain feature will be affected and modified by atmosphere and neighbouring pixels. So, we saw how to calculate the radiance that is actually reaching the sensor, and what are the different energy components that will add up to it?

In this lecture, what we are going to see is using this particular radiance, how an image is formed, how an image is represented and how to use that particular data contained in an image and bring it back to surface reflectance. That is, we will be recording radiance using satellite sensors. From that radiance, as users, we will get images out of it. Most of the satellite sensors will provide us like images. Using that image we have to retrieve back the reflectance of the surface in order for us to use it in further applications. How to go about it? And that is what we are going to see in this particular lecture.

First, we will see how an image is formed in the remote sensing system.

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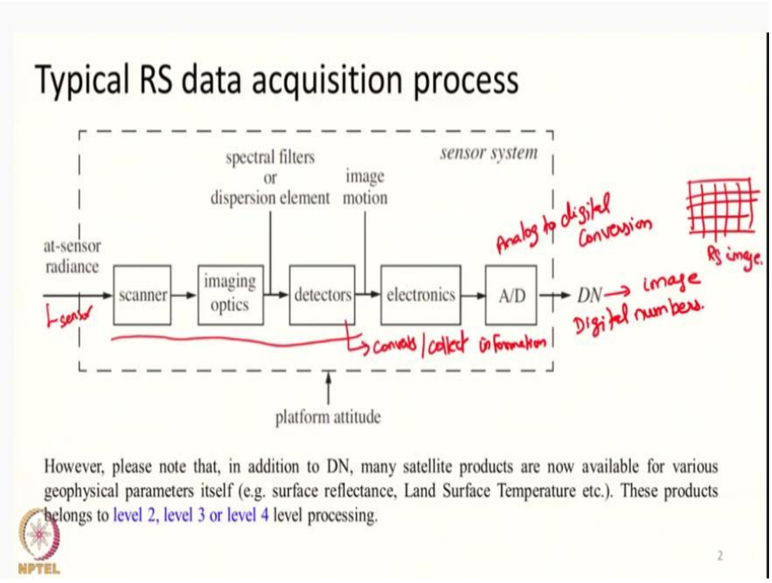

So, this is the radiance that is reaching the sensor. And this radiance that is reaching the sensor is essentially collected by scanning geometry, imaging geometry, detectors and all those things. So, in detail how the image collection process happens, we will see it in later lectures. But now, let us assume whatever the radiance that reaches the sensor is now been collected by imaging scanner and optics and then it will reach the detector. So, this detector essentially converts or I will say collect information. So, detector is the one that collects information from the object of interest. So, whatever is coming in these 2 will be just collected and pass it on to the detectors. The detectors will be able to collect it and record it in a meaningful way. So, the data will be detected, the signal will then be passed on to electronics.

The imaging electronic system will process the collected radiance further as detected by the detector. Then it will undergo a process of analog to digital conversion and will be stored as digital numbers. So, this essentially makes up the image or this essentially forms image. So, a 2 dimensional matrix of DN is a remote sensing image. You can take this in analogy with the normal cameras that we use. In olden days, we used to have cameras in which we will load films rolls. We will take a picture, take the film roll out, develop it in photographic labs and have hardcopy photographs. Nowadays we have digital cameras where the images are stored digitally, which we directly transfer it to computer, process it electronically. And if we want we print it or store it in computer itself as digital photographs. So, remote sensing images essentially are digital images.

The basic difference is, an analog photograph that we used to get earlier from our normal film based cameras are continuous in both spatial and radiometric terms. Whereas the digital image that we collect is actually a sampled and quantized representation of object space. What are these terms? I am telling something as continuous and telling something as sampled and quantized. What are these terms? We will see it in the next slide.

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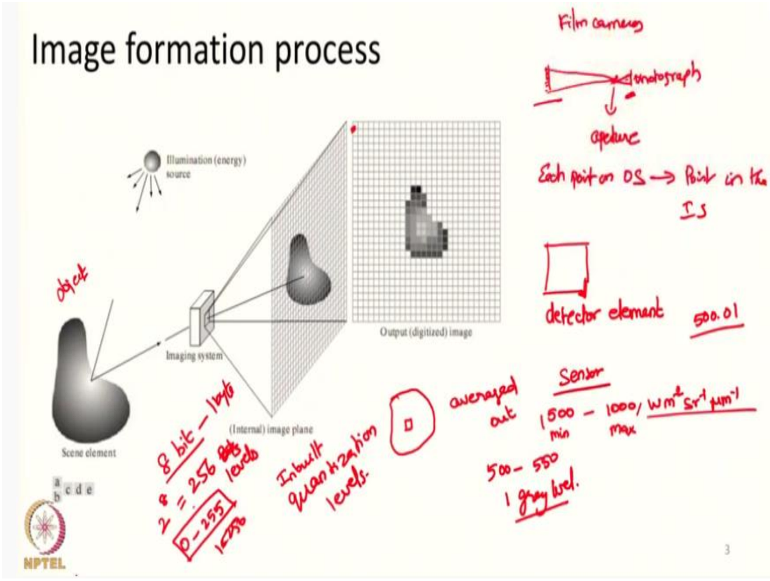

So let us assume this is the actual object of our interest. In olden days if we use a normal film camera, whatever the object is here will be photographed by an imaging system. So this is the aperture lens aperture like our camera will have a lens. It will have a small opening. It is a lens aperture through which signals will pass through. And this is the imaging plane where the film will be kept. So, light source from this particular object will fall through or pass through this optics and will get recorded in the film as an image or photograph. So, each and every point on this object space will have a corresponding point on the image space.

Similarly, whatever be the brightness level recorded here, let us assume an olden day black and white photograph, everything will be recorded in form of different shades of gray. So, each and every shade of gray in the object space will have a corresponding shade of gray in the image space. That is why I said it is spatially and radiometrically continuous.

Each point in the object space will have one corresponding point on the image space. Similarly, each gray level or each level of brightness in the object space will have a corresponding brightness level in the image space in the olden day film cameras. If we look at digital cameras digital imaging system, this is slightly different. How this will be? Each and every point on an object space will not be imaged as the same point in the digital image system.

In digital image system, the sensors will be made up of individual detector elements. So, let us assume this is one detector element. This will essentially see one small area in the object space So, based on the distance at which the detector element is from the object space, this will cover a small area on the object space and whatever energy contained in that particular area will be kind of averaged out and a single value will be seen by the detector. So, olden days energy coming in from each and every point will be recorded in films, it is continuous. Whereas in detector each detector has a finite size most likely should be square in shape and has a finite area. That area say the camera is kept here object space is somewhere here. So, based on the distance between the camera and the object, each detector element will cover a small area on the object space. It is not a point anymore. It is now a small area. Whatever the area is there is covered by the detector element, the energy coming out of that particular area will be averaged out and detected as one single value by detector element. This is one thing. This is what I called as an example for sampling instead of taking everything continuous information, we are now taking like an aerially averaged information. And each and every gray level within the object space will now be lost. So, in the image space, based on the incoming energy levels, we will now have a discrete level of gray levels.

Let us assume a sensor is designed such that it can record radiance in the range of say 500 to 1000 watt/meter^2/steradian/micrometer. So, this is the range of radiance that can be sensed by any particular detector. let us assume some finite 1000 energy units a sensor can record. Each sensor has a own inbuilt quantization levels. So, what is that quantization level? Basically, it will tell us for each pixel or for each detector element for each pixel, what is the number of gray levels that can be represented? Let us say let a image has 8 bit quantization. So, this is like a digital image. Everything works in binary format. So, the memory or the storage for each pixel now will be 2 power 8. That is 256 bytes or 256 levels of gray can be represented by one particular pixel.

So, essentially it will have a value of 0 to 255 or 1 to 256 depends. Most likely it will be 0 to 255. It depends on how the sensor is configured. So, each sensor will be inbuilt. Whatever be the gray level outside the sensor will be programmed with a certain quantized levels discrete levels. So, 8 bit quantization, 10 bit quantization, 12 bit quantization and all. If it is 8 bit it is 2 power 8, 256 different levels of gray. If it is a 10 bit it is 2 power 10, 1024 different levels of gray and so on. So, that is how it will be programmed. So, what essentially will happen. So, whatever be the energy coming in from the object space, a sensor will have a range, a minimum and a maximum limit within which it will sense the energy coming in. Rather than storing everything as it is. Say for example, if an energy of 500.01 is coming, olden day film can store it as it is. Like with the same level that is scaled based on camera properties. Everything will be continuous.

Here in this system, there will be like a bins say 500 to 550 maybe having 1 gray level and so on. That is for a range of gray levels or for a range of incoming energy there will be one particular gray level associated with it. Hence, that is not continuous. Whatever be the energy level coming in within that particular range, the same number will be assigned to that particular pixel. This process is known as quantization.

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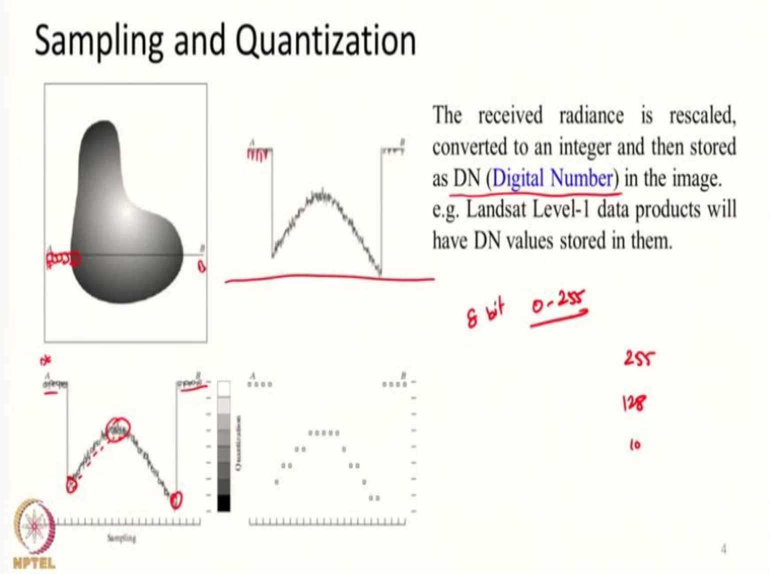

Now, let us say this is the object space. Now the sensor is scanning this particular line. Let us say a sensor is starting from A it is going up to B. It is scanning each and every point along the straight line. So, first thing the detector element will be sensing energy in form of small area. It will be collecting energy. So, the energy collector will be continuous in form of like this. Here everything appears white, it is with very high energy level then comes level of grays like this. Then again white, it is here. So from A to B, the energy is collected. Now it has to be sampled. A continuous stream of energy as sensed will be now sampled at different time intervals. Say that is what represented here in form of dots. That is this stream of continuous energy came in from the ground.

In digital systems, it will not be stored as it is as a continuous wave, but it will be sampled at different points, say at a given time interval. With every time interval delta t, the incoming energy will be sampled and measured. So, now this is measured. Whatever the energy at that particular instant is now measured and one measurement is mean. So, now this measurement will be compared with the gray level.

Say my system has a gray level of 8 bit quantization. That is 0 to 255 will be the values it can save. So, what it will do? Maybe for this particular very bright spots, it may assign 255. For this parts, it may assign something like 128 in between. For these spots, it may assign something like close to say 10. So, for each range of radiance or energy coming in from the object space, 1 DN will be assigned to it. So it is not continuous. Say in the older example 500 to 510 whatever be the energy level coming in within this range 1 DN will be recorded. It is how it will be programmed. So we will lose that continuity. From 500 there can be like infinite energy levels 500, 500.01, 500.02 like this. There can be many different small energy levels can be coming in from object space. Everything will be lost. They will be quantized.

If the energy level is between 500 and 510, record 0. That is how the system will be calibrated. So, that is why I said this kind of conversion in energy terms is known as quantization. The continuous stream of energy whatever is coming in is quantized into discrete bins and saved in digital image. So, that is why a digital image is a sampled and quantized representation of object space. Sampled in the sense we are not seeing each and every point on the ground, we are effectively collecting few samples from the ground. So, we are not seeing all the points on the ground as if olden day film cameras. We are seeing essentially few selective points on the ground, sensing energy only from those points. The energy from those points also will not be stored as it is. They will be converted into some finite discrete gray levels and stored in digital images. So, this is how a digital image is stored.

The number that gets finally stored in an image is what we call a digital number or DN in short. So, when we use some data say from satellite called Landsat, if we download a Level 1 data, it will contain DNs, it is an 8 bit quantized system like olden day Landsat. So, we will have DN values ranging from 0 to 255 in the image. From that number, we have to do further processing, convert it into meaningful radiance, reflectance and whatever. Similarly, if the system has 10 bit quantization, the DN will vary from 0 to 1023 or 1024 different levels. Like that it will be saved. So, essentially a digital image is nothing but a spatially sampled and radiometrically quantized representation of object space.

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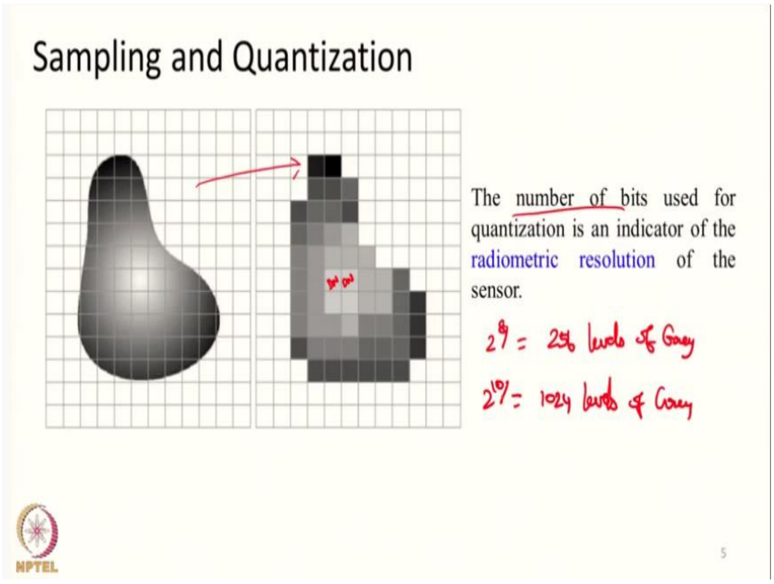

So, this is finally how it will look after the process of sampling and quantization. So, the object space is now converted into a digital image like this. So, each pixel is now has a DN. The number of bits used to quantize is an indicator of the radiometric resolution of the sensor. That is say 2 power 8, 256 levels of gray, 2 power 10, 1024 levels of gray. Say this number 8 or 10 will tell us how many different gray levels will be there in an image.

As the number of gray levels increases, we will be able to see finer variation in gray levels if the sensor is perfect. Like if the sensor is collecting everything accurate, then as the number of gray levels increase, we will be able to see even finer level of energy changes in the object space which tells us how precise we are able to record the incoming energy. So, this is an indicator of what is known as radiometric resolution.

We will see the concepts of resolution in the coming lectures. But this is just as an indicator of how precise we are collecting the data, if you are going from say 10 bit to 8 bit we are reducing the precision of how we are storing the data. If we are going from 8 bit to 6 bit we are further reducing the radiometric precision and so on. Next important thing we are going to see is what is known as radiometric calibration.

What is a radiometric calibration? Why it is needed for remote sensing systems? So, let us simply take an analogy of our normal everyday photography.

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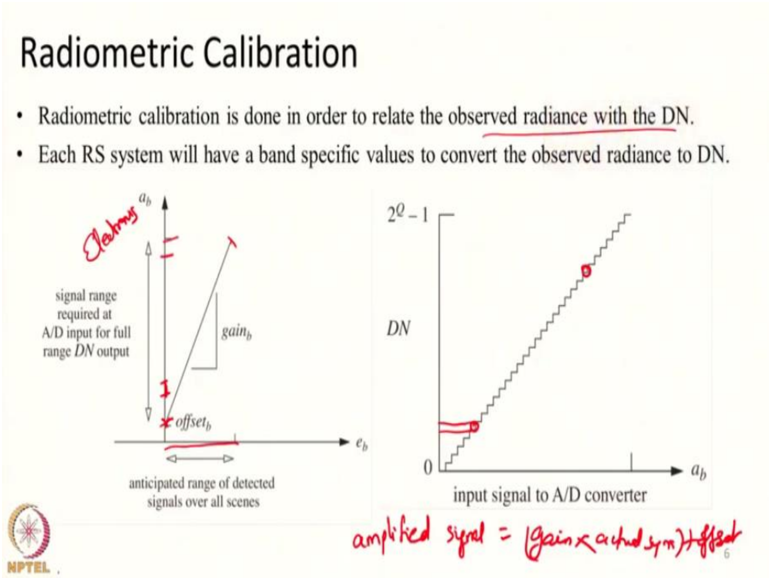

What is the purpose of our normal everyday photography? We take it for storing memories seeing it at later time. When some happy event is occurring or someone is getting wedded, we take pictures out of it as a memory. What it will record? It will record whatever is there in the scene in a sampled and quantized manner. It will have different levels of gray. And if it is like a color image it will store colors. We will see later how color images also produced how it is displayed and all. But now let us assume it will have different levels of brightness and we will be able to see it. Essentially the purpose for which we are taking photograph is to just see and observe what is there. So, we are basically doing what is known as a visual interpretation.

If someone is getting wedded means we are seeing okay the bridegroom is tying the knot. Relatives are standing there. He is so and so. She is so and so. Like this, we will be identifying, will be interpreting the photograph. We will not be interested in knowing, what is the amount of energy that came in from the object space and got stored in the camera. We will be just interested to know who is there. So, we do a basic interpretation. And as long as we are able to see everyone clearly, we will be happy with the photograph.

In remote sensing, this scenario is entirely different. Different in the sense we will also be doing some sort of interpretation, we will be trying to identify what is there. But nowadays, most of the remote sensing based applications are all quantitative applications. So, what is quantitative? They need to know or they need to measure the energy coming in from the surface. They need to work on those numbers, what is the amount of energy that came in. Using that energy I want to calculate something else. So, nowadays most of the applications require a proper measurement of the incoming energy level. So, the radiometry has to be perfectly measured, the incoming radiance has to be measured and stored as it is.

But I said when we get an image; we will not get the radiance. It will not be recorded as like 500.01 radiance units. It will be recorded as say 127, 242 we will get some sort of numbers out of it. What is the relationship between the DN in the image and the radiance that came in from the ground at the point of image acquisition? Relating these 2 is known as radiometric calibration. So, from the DN, I should be able to calculate, what was the radiance that came in at that particular point? Similarly, from the sensors perspective, for a given level of radiance, this must be the DN that should be recorded in the image. The sensor should be doing it perfectly. If this is the radiance, this should be the DN.

From the user perspective, we will get DNs in our hand like an image. We will get only DNs. From the user perspective, if this is the DN, this must be the radiance that should have got recorded in the system. This relationship between DN and radiance and vice versa is established during the process of radiometric calibration. So, that is what is given in this particular slide. So, radiometric calibration is done in order to relate the observed radiance with DN. Each remote sensing system will have a band specific values to convert the observed radiance to DN. That is say this is like the incoming energy from the object space and this is like the anticipated level. So, whenever a sensor is being sent into space, the sensor should be able to observe radiance from this level to this level.

So, based on the applications for which it is sent, the sensor will have a minimum and maximum range of radiance, which it is supposed to detect. And this minimum and maximum will differ based on the application. So, if a sensor is sent to space for sensing oceans, the radiance level will be different. If the sensor is sent to space for observing snow covered regions, the radiance range for the sensor will be different and so on. Based on the applications, scientists and engineers will decide on the sensor to detect incoming energy from this number to this number. They will fix the range. So, that range is given here. So, based on that range, they will not store it as it is. They will do some sort of amplification using the system electronics. So, when they amplify, the amplified signal will be equal to some Gain into actual signal plus offset. This is how it will be. So, this Gain and offset are all like the system's properties how it is recorded.

So, now the amplified signal will be fed into the system's quantizer or the quantization unit, which divides it into different gray levels. That will now split the different energy levels into one one DN level. Say let us take this particular DN level. So whatever is the energy coming in within one particular range of say this, whatever be the energy coming in within this range will have 1 DN. Whatever the energy within this range may have 1 DN. Like this, the quantization will be done and stored in form of digital images.

So this is how the Gain and offset is identified. If this is the incoming energy, after amplification and quantization this will be the DN. This relationship will be fixed even before the sensor is launched. This is known as pre launch calibration. People will be knowing it. If this is the radiance this will be the DN and vice versa. Unless we know this calibration perfectly, it will be impossible for us to do quantitative remote sensing measurements. We will not be knowing the radiance we will be just having DNs from the image. If the radiometric calibration is not proper not being done from the DNs, it will be impossible for us to retrieve the actual energy that was measured again. So, this is really a important step. So, a very generic way of doing radiometric calibration is given in this particular slide.

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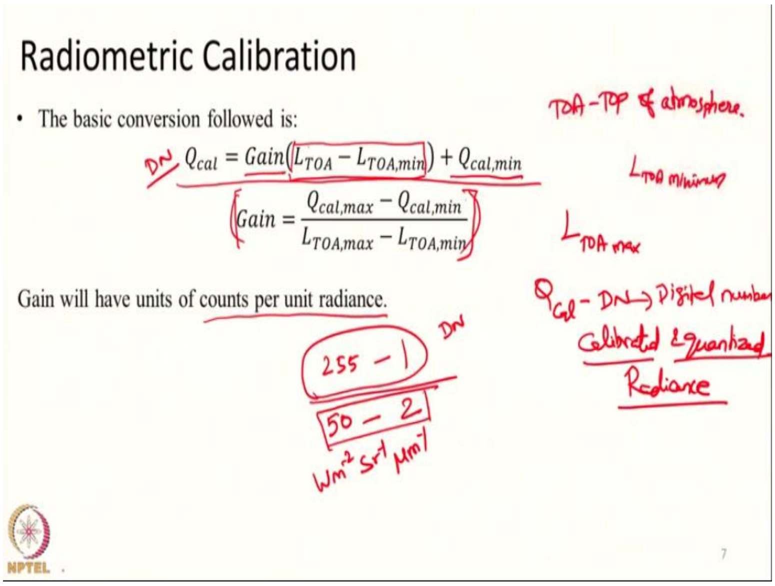

So, how this will be done? Most of the systems in Landsat based satellites, Landsat is like a series of satellites, how this is being done, that is if there is like kind of an energy level. See, this is the range of energy that sensor can record. Radiance TOA that is top of atmosphere, TOA means top of atmosphere and $L_{TOA,min}$ is, what is the minimum that will record. So, any energy less than this, sensor will not record. Similarly, each sensor will also have a $L_{TOA,max}$. Anything above it, sensor will not record. It will be saturated. So, what is the energy that actually came in? And what is the minimum? That particular difference will be multiplied by this Gain factor plus a constant and offset will be added and that will be stored as DN value.

So, here Q_{cal} is nothing but the DN which means calibrated and quantized radiance. So, Q_{cal} is nothing but calibrated and quantized radiance. That is nothing but the DN the digital number now has a physical meaning. A digital number is not a mere number anymore. The digital number was now being recorded based on the calibration done and after which the quantization is done. So, what will be the Gain? What is the DN max minus DN min for that particular sensor? Say, if it is 8 bit sensor, the DN max may be 255 minus if the DN minimum that should be stored is 1 divided by what is the radiance max that can be detected by a sensor, Let us say it is some sort of say 50 units minus what is the minimum?

Let us say it is like some 2 units say in units of watt/meter^2/steradian/micrometer inverse. This is DN levels. So, this will be the Gain. Whatever be the energy level within this particular energy range, they will be equally split into this much gray levels or this much levels of digital numbers. This is the basic way of one way of relating radiance to DN. So, this Gain will have a units of counts/unit radiance.

So, here we are doing some sort of like a linear relationship. Whatever be the radiance range a sensor has to work, divide that range equally into a number of different bins and assign values to it. So, as users, we will be getting DNs. How to get radiance back from this particular DN value is what is given here.

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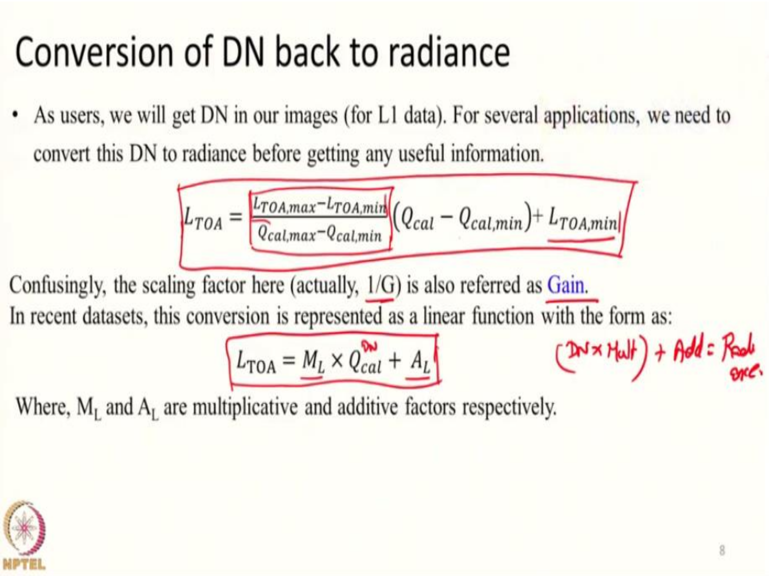

So, this is inverse of Gain parameter, we have seen that in the previous slide, we have seen Gain as $(Q_{cal}–Q_{min})/(L_{max}/L_{min})$. So, here it is inverse of Gain parameter multiplied by what is the DN recorded for that particular pixel minus what is the minimum DN that can be stored in an image and what will be the minimum radiance that will be detected by the sensor. So, if we apply this particular formula or this particular conversion, we will be able to get back radiance from DN. This is possible only if the Gain is set exactly to that particular value. That Gain should be constant for each band. For each band, the Gain will vary because the L_{max} and L_{min} for each band will vary.

Even though the DN_{max}-DN_{min} may be system specific, L_{max}-L_{min} will vary based on which the Gain will vary for each band. The Gain must be fixed or it should be constant throughout. Then only this sort of conversion is possible from radiance to DN, from DN to radiance. So, unfortunately or confusingly, the scaling factor we used here is 1/G that is also known as Gain. People do not call it as inverse of Gain. They still call it as Gain. So, we should be really careful in which context we are using it. Are we using it in the context of radiance to DN conversion or DN to radiance conversion? But still everything is known as Gain. We have to use that particular fraction judiciously. And in recent datasets, the Gain parameter and offset was given like a very simple equation. Say if you look at a Landsat data, for each DN value, they will say one multiplying factor, one additive factor. So, essentially take that DN out multiply it with the multiplying factor plus add the additive factor. We will get the radiance the sensor actually recorded. So, this sort of conversion also in nowadays is possible with recent datasets. People are giving such numbers for us to work with it easily.

So, as a summary to this particular lecture, we have seen the process of how a digital image is prepared and stored. Digital image is nothing but a spatially sampled and radiometrically quantized version of the object space. And we also got introduced to the concept of radiometric calibration. That is essentially relating the radiance recorded by the sensor to the DN that is actually stored in the image. And how to relate them? So, now we will be able to convert radiance to DN or DN to radiance and vice versa. So, in the next lecture, we are going to take this DN and try to do some sort of processing over it so that we will get the surface reflectance back.

Thank you very much.