Forests and Their Management
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Module - 05
Forest Surveying
Lecture – 15
LiDAR

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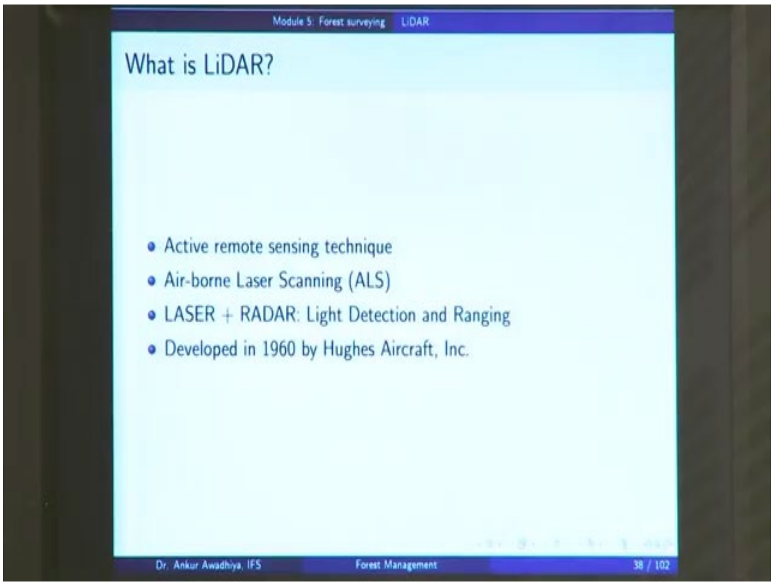

[FL]. Today, we will have a look at LiDAR, which is another method of doing Forest Surveying. Now, LiDAR is a combination of these two words “LASER” and “RADAR” and the full form is ‘Light Detection and Ranging.’ It is an active remote sensing technique. Now, what is an active remote sensing technique? as we saw in one of the previous lectures.

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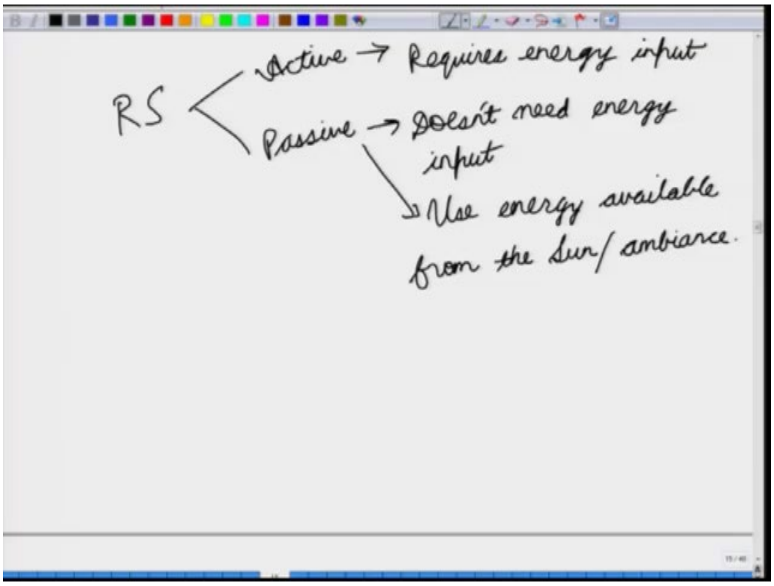

When we talk about remote sensing, it is sensing from a distance; sensing something remotely, getting information about something from a distance without a physical contact with that object. Now, the remote sensing can be active or it can be passive. Now, active remote sensing is something that requires energy, whereas passive remote sensing is something that. So, this requires energy input and this one does not does not need energy input.

Now, why does not passive remote sensing need energy input? Because in most cases, you use energy that is available from the sun; or the energy that is available in the ambience. So, for instance, if you just take a camera and you are using that camera without a flash, so, in that case, you are making use of the energy that is available in this room and when you use a camera in this manner, then you are doing a passive remote sensing.

But, if you are using your camera in a very dark environment, say in a night and you are using a flash to illuminate the surroundings, then it is an active remote sensing. Now, in the case of LiDAR, it is an active remote sensing technique which means that it is it requires energy that needs to be given to the instruments to make it work.

So, you need to illuminate your surface using energy, because of which this is an active remote sensing technique; it is also known as ALS or Air borne Laser Scanning. So, with this term you can make an idea about what LiDAR is? It is air borne. So, you are using an aircraft or maybe a drone, but the platform is air borne. It is not on the ground; it is not in the space - it is air borne. And, it is laser scanning. So, you are using a laser to scan your object. So, it is also known as ALS. It was developed in the 1960's by Hughes Aircraft Incorporated. Now, why does it use laser? Or, first of all what actually is LiDAR, what how does it work?.

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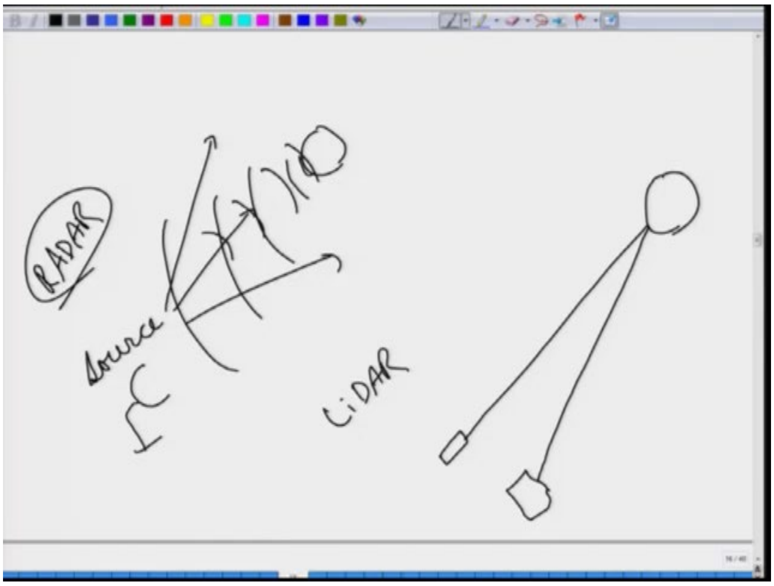

So, most of you would be knowing how a RADAR works. So, in the case of a RADAR, you have a source and the source is giving out radio waves. And, if there is an object that comes here, so, these radio waves they go to the objects then they interact with the object and then they get reflected, and this reflection is then sense use sensed using an antenna.

So, this is a RADAR, which is the radio detection and ranging. In the case of LiDAR, which is light detection and ranging, it is very similar. So, what you are doing here is that you have a source that is giving out a laser beam, and this laser beam when it interacts with the object, it reflects back. And, when it when it reflects back, you are using a sensor to detect the this laser pulse.

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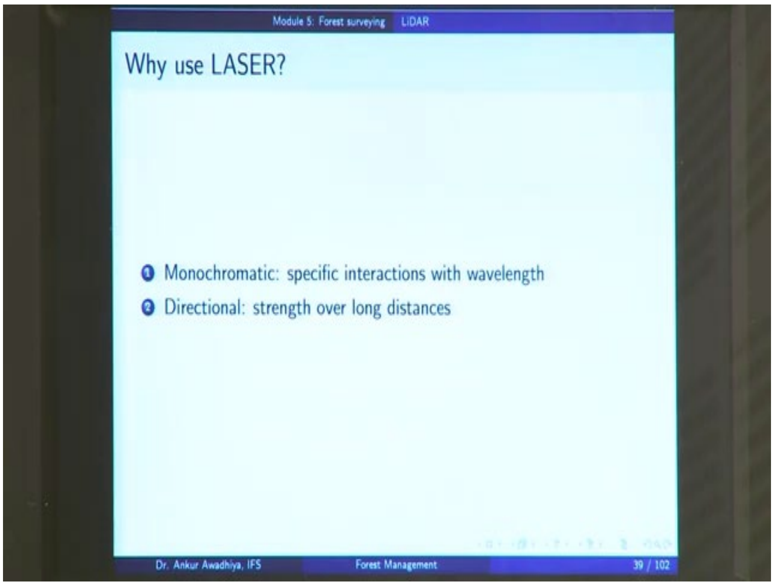

Now, why do we use a laser pulse? Why do we have to go for a laser pulse and not the normal light? Because, of two reasons. One it is monochromatic, and so, you can note down specific interactions with different wavelengths. So, for instance, if you have an object that is red in colour, so, in that case, if you use a red coloured laser, then all the light will come back.

If you are using a green laser, then the light will get absorbed. So, just by using different wavelengths, you can understand the colour of the object. Now, colour is a very general term, but you can make use of different wavelengths of light to know the interaction of that particular wavelength with the object, and so, if you are you are using different wavelength, so, one after the other in that case you will have a much better spectral resolution of the final data.

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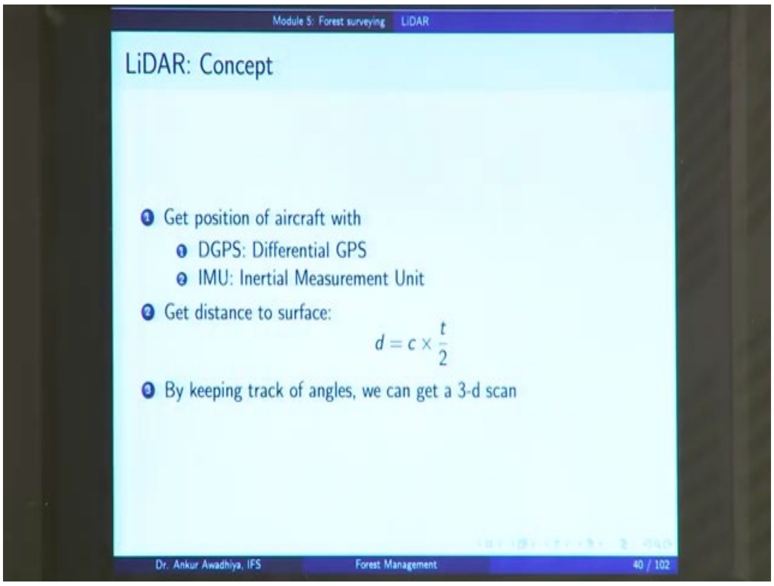

Then laser is also directional and so it maintains its strength over long distances, which is unlike our normal sources of light, in which case, the strength will go down with the distance. Next, how does the LiDAR work? How what is the concept of a LiDAR?

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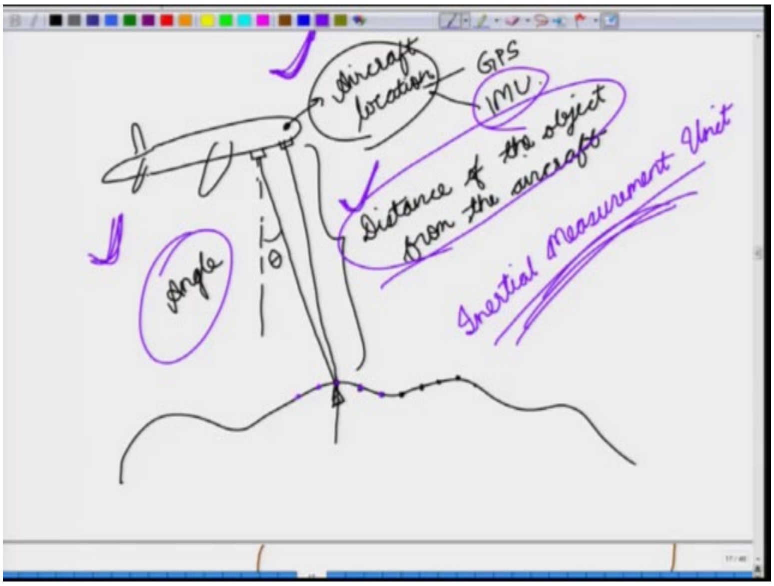

So, in the case of LiDAR, what you are doing is that, you have an aircraft which is going above your, sorry here you have an aircraft, here you have the ground level and this aircraft has a laser which it is pointing downwards. The light is interacting with the surface and then it is getting reflected back, and then it is detected using a detector. Now, to know the locations of all these different points on the surface, you require two kinds of data; one is the exact position of the aircraft when this laser beam was shot, and when this laser beam came back.

So, you need to know the location of the aircraft; and secondly, you need to know the distance of the object from the aircraft, and third you need to find out the angle. So, if this is say the vertical, then what is this angle. So, you need to find out the angle. So, if you know the position of the aircraft; if you know how much time does it take for the laser beam to go to the object and come back, so, with this time you can figure out the distance, and if you know the angle at which this laser was shot, so, in that case, you will be able to determine the location of this point. And, similarly when you do this again and again, so, you will know the locations of all the points on the surface. So, this is the general concept of the LiDAR.

Now, the first thing to know is the aircraft location. Now, to know the aircraft location we make use of two things; one is a GPS and the second is an IMU.

Now, GPS refers to the 'Global Positioning System.' It is a constellation of several satellites that are moving around the earth, and these satellites are giving out signals which your equipment can read and figure out the distance of the equipment from several satellites.

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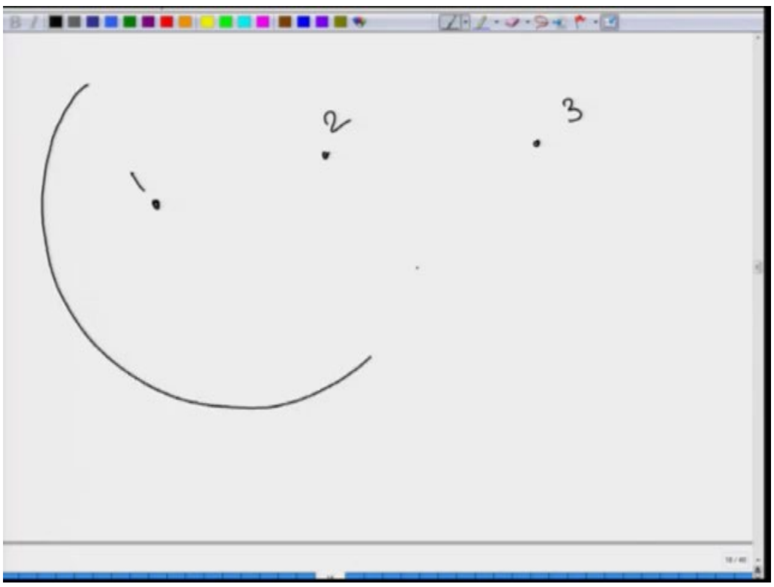

So, what we are saying here is that you have one satellite, you have the second satellite, you have this third satellite, and so on. Now, if you know the distance from the first satellite you can construct us a sphere or.

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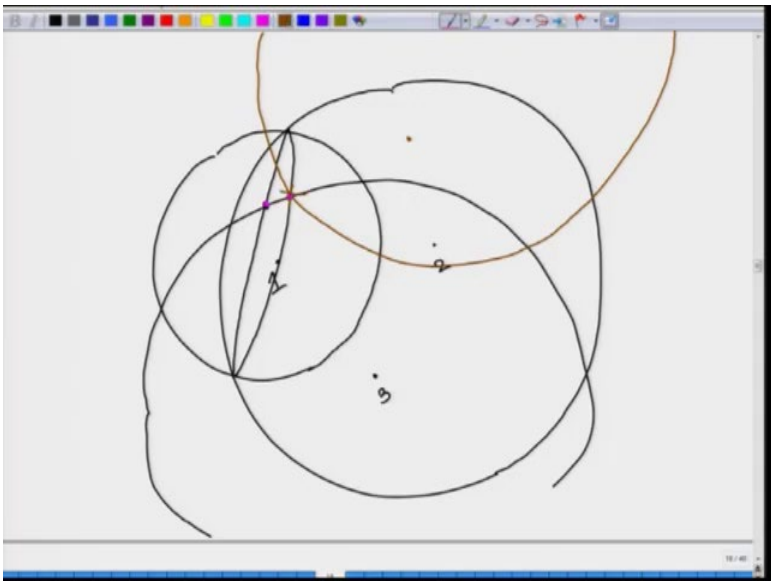

Let us say that this is the first satellite this is the second satellite, let us say that this is the third satellite. Now, if you know the distance from the first satellite, you can construct a sphere, and your location is somewhere on this is sphere; it is on the surface of the sphere that is being made with the first satellite in the centre. Similarly, for the second satellite, you can construct another sphere; now both of these spheres are meeting in a circle.

So, there is this circle and now you can say that your location is somewhere on this circle. Now, with the third satellite, you can construct another sphere, and in this case, you will know that you are at one of these locations, so, you are at either at this location or at this location.

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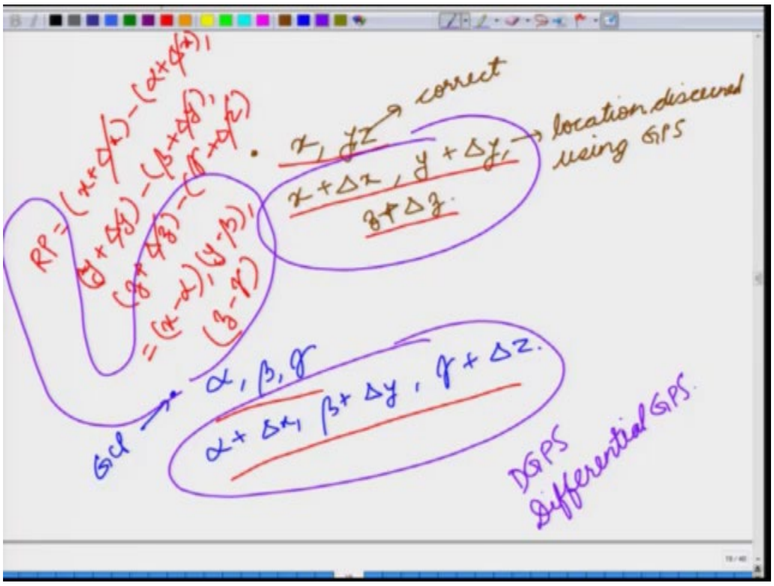

Now, one of these locations will fall on earth. If you are; if you are taking measurements from the earth, and then earth also makes another sphere, or else if you are taking measurements in the sky in the three dimension, and then probably you will have to make use of a fourth satellite. So, you have this fourth satellite and you are at this distance from the fourth satellite, this is the fourth sphere.

So, now because this is your eye on either of these points and this second point is also falling on this sphere. So, you will exactly get your own location. So, GPS is a system through which you can figure out your location in three dimensions by making use of a constellation of satellites.

Now, when we take any measurement there are bound to be certain errors. Now, suppose you are at this location the location is (x,y), but then because there is certain error. So, let us say that your position is coming as $(x + \Delta x)$ and $(y + \Delta y)$. So, this is the correct location, and this is the location discerned using GPS, or let us say call it in three dimensions (x,y,z) - $(x + \Delta x)$, $(y + \Delta y)$, and $(z + \Delta z)$.

So, this is your location that was discerned using the GPS, but then to reduce the error what you can do is that you can take another location, and suppose here your coordinates were α, β, γ. And. when you are using your GPS because the error is coming to be the same in both, so, you here you have $(\alpha + \Delta x)$, $(\beta + \Delta y)$ and $(\gamma + \Delta z)$.

Because, you are having certain errors which are common in both of these locations, but then if you want to find out the relative position of your brown object from this ground control point. So, this is something that we call as a ground control point. So, this is a point whose location you know exactly.

Now, if you want to find out the relative position of the brown point with respect to the GCP, then you will have the relative position is given by $(x + \Delta x) - (\alpha + \Delta x)$, $(y + \Delta y) - (\beta + \Delta x)$ and $(z + \Delta z) - (\gamma + \Delta z)$. Now, in this case, delta x delta x delta y delta y delta z delta z get cancelled out. So, now you have that the relative position is given by $(x-\alpha)$, $(y-\beta)$ and $(z-\gamma)$.

Now, in this case, because you are just taking these two readings and you are actually at the location x y z, but you are measuring $(x + \Delta x)$, $(y + \Delta y)$, and $(z + \Delta z)$, and similarly in these locations, but then when you want to find out the relative position the relative position, if you find it out using your measured readings, then that will be the same as your actual relative position, and this is a process that is known as a DGPS or a Differential Global Positioning System.

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So, what is a differential GPS? In the case of a differential GPS, you have a ground point? So, the ground point is lying here; you have an aircraft that is moving above it; you find out a measurement; you take the GPS reading here; you take the GPS reading here, and using both of these GPS readings even though because even though if they are having the error then to if you subtract these readings, you will get the exact relative position of the aircraft with respect to your ground control point. So, this is how you figure out the location of the aircraft.

Now, the second thing that you make use of is an IMU. Now, IMU refers to an 'Inertial Measurement Unit.' Now, typically this is a chip; it is a system on a chip, in which case you are able to find out if it is lying flat, or if it is tilting on any of these axis, what is the speed of this object? What are the accelerations that you are getting in different direction this is something, that you measure using the IMU.

Now, with the GPS and the IMU, you know the position and the orientation of the aircraft the acceleration of the aircraft. And, using both of these information, you are exactly able to pinpoint the aircraft. So, this is the first thing that we wanted to find out the aircraft location.

Now, the second thing is the angle now angle is easy to measure. Because you are having an IMU, and if you are putting your laser device at a particular angle. so, you know this angle and you also know the angle of the aircraft using the IMU. So now, you exactly know the angle that is being subtended with respect to the vertical by the laser. So, you exactly know this angle.

Now, the third thing that you need to know is the distance of the object from the aircraft.

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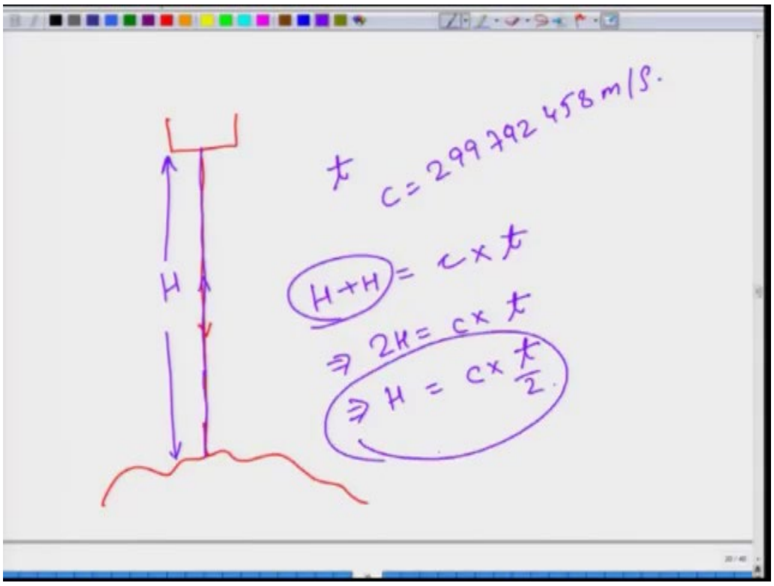

Now, how do you find out the distance of the object? Now, in the case of LiDAR, here we are having a sensor; the source of the laser. Here, you have the surface. Now, the laser is coming here and then it is getting reflected back, so, let us show it by another colour. So, it is getting reflected back like this, and what the instrument, now measures is the time, it takes for there a from the start of the laser beam till the time it comes back.

Now, if suppose the time is t and the distance that the laser has covered is x, so, in this case, what we have is that the laser is covering; let us say that the height of this point is H. Now, the laser is moving from the aircraft to the ground and it is travelling a distance of H, then it is moving from the ground towards the aircraft and it just again travelling a distance of H.

So, the total distance that was covered is H moving downwards plus H moving upwards. Now, this distance is equal to speed. Now, speed of light is given as c and c is equal to 299 792 458 meter per second. Now, this distance is equal to c into the time that it takes; which means that 2 H is equal to c x t, which means that H is given as c x t by 2 where c is the speed of light.

And, t is the time that the laser pulse takes from the moment it is emitted to the time it has come back. Now, using this you can figure out the height of the object or the exact height of the aircraft with respect to the object. So, now, you know all these three things; you know the aircraft location, you know the angle that has being subtracted, and you know the distance of the object from the aircraft, and using all three of these you can figure out the locations of each and every of these points.

And when you do that, you have a very good representation or a very good three-dimensional representation of the surface that you are interested in. So, basically the concept of LiDAR is that you get the position of the aircraft with differential GPS an inertial measurement unit, you get distance to the surface by d is equal to c into t by 2, and by keeping track of the angles we get a 3-d scan.

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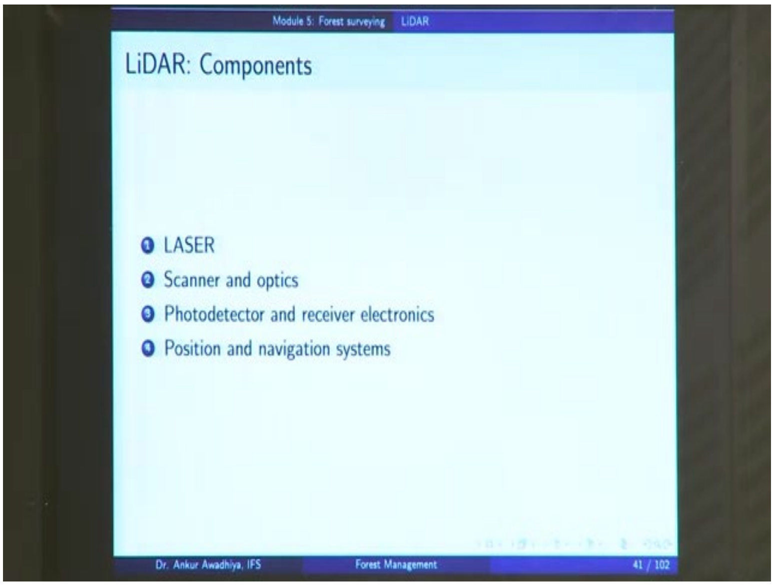

Now, LiDAR comprises of several components. The first and the most important one is laser, then you have a scanner and the optics, then you have photodetector and receiver electronics, and positional and navigational systems.

So, essentially the first component is laser. So, you need to decide which wavelength of laser you are going to use. Then, you have the scanner and the optics that is used to position this laser on to the ground, then when the laser comes back; you detect it using a photodetector. And, you use the receiver electronics to convert it into a signal; and then, you have positional and navigational systems to exactly know the location and the orientation of the aircraft. So, with all of these components, you add them together and you have an idea of how the surface appears.

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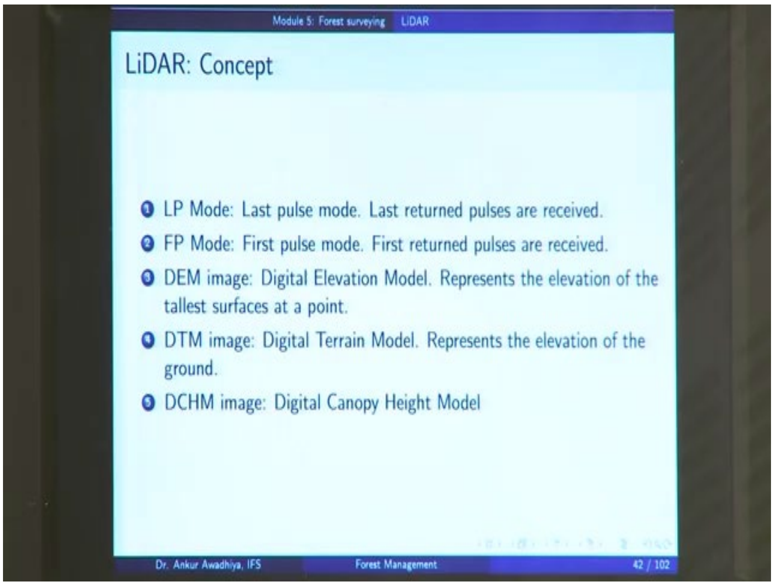

Now, a laser can be used in LP mode or FP mode. Now, in the case of LP mode, you are looking at the last pulse mode, in which case, the last of the returned pulses are received. And, in the FP mode or the first pulse mode, the first of the returned pulses are received. Now what is that?

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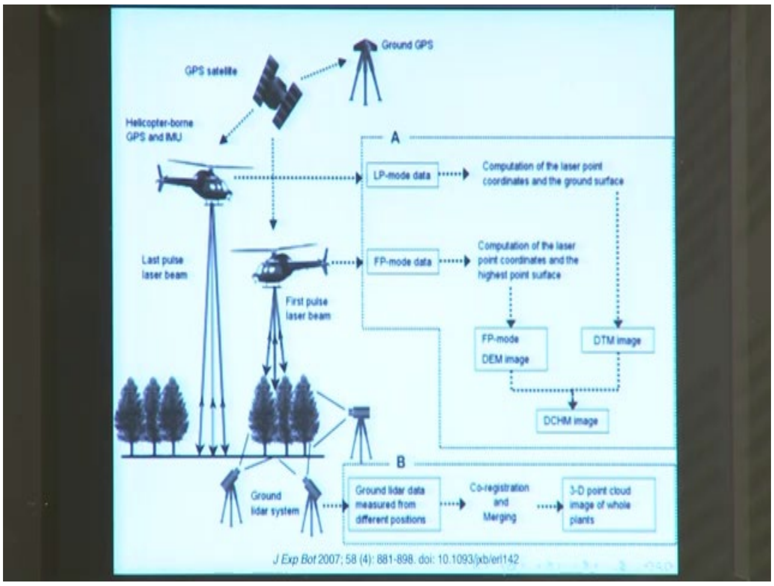

Now, suppose here you have your aircraft, and it is and you have the canopy and you also have the ground. Now, when you are shooting a beam of laser, then the first laser would interact with the top of this canopy, and come back. So, that is the pulse with that

that is the first pulse method, but then, you will also have some laser that will go down and then it will come back so, that is the last pulse method.

Now here you are using a helicopter as the aircraft. So, you have a helicopter-borne GPS and IMU, it is taking data from the GPS satellite and it is comparing at with the ground GPS, to know its differential position with respect to the ground GPS. So, we exactly know the location of the aircraft. Now, in the last pulse laser beam method, you are measuring the you are measuring this surface; the ground surface. In the first pulse laser beam, you are measuring the top surface. Now, in this case, you can construct two different sorts of surfaces.

One is the DEM image; DEM is the 'Digital Elevation Model' - DEM; it represents the elevation of the tallest surfaces at a point.

So, in this case, what you are doing is that, you are measuring this surface and when you construct the whole surface; it will give you the DEM. Next, we have the DTM or 'the Digital Terrain Model,' which represents the elevation of the ground. So, in this case, you are measuring where is your ground surface. And, using both of these, you can subtract the DTM from the DEM, and you will get the 'Digital Canopy Height Model' or the DCHM.

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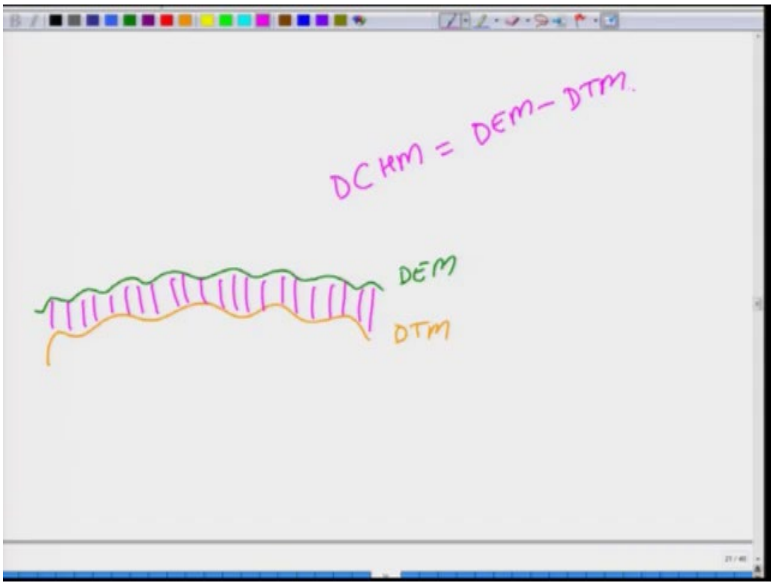

What we are saying here is that, you have a ground and then you are getting a canopy. So, the these are the two surfaces that you are generating. So, you have the digital elevation model, which is giving you the tops of the canopies. You have the digital terrain model, which is giving you the shape of the earth below it.

And if you subtract both of if you subtract DTM from DEM, you will get this location which will give you the heights of the canopy at different positions. So, this is giving you the digital canopy height model, this is equal to DEM minus DTM.

So, using the LP mode, you get a computation of the laser point coordinates on the ground surface; you get the DTM. With the FP mode you get configuration of you get a computation of the laser point coordinates. And at the highest point surface; so, from this you get a DEM image. You subtract both of these, and you get a DCHM - Digital Canopy Height Model. Now, let us look at the scanning mechanisms that are available.

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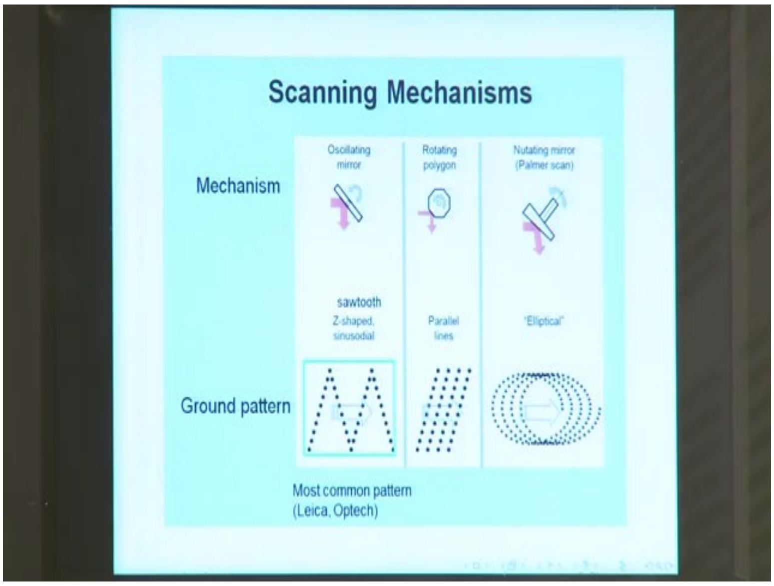

So, in the case of your LiDAR, you are having the laser beam; you have a detector. Now, this laser beam is supposed to scan the hole of the surface. Now, how does this scanning work? Now this, for to do this scanning, you have these three common mechanisms. The first one is an oscillating mirror. So, in this case, you have a laser beam that is going like this and you have a mirror that is oscillating. Now, when you have this mirror that is oscillating, the reflected pulse is going to move like this. So, this is the ground pattern that you get. So, essentially your aircraft is moving like this, and you are getting a pattern that is like this. So, you get a sawtooth pattern or a Z shaped pattern, when you are using an oscillating mirror.

Secondly, you can make use of a rotating polygon; now, in the case of the rotating polygon, this surface which is interacting with the laser; it will lead to the reflection of the laser. And then, it will then the next surface comes, then the next surface comes; in this case, you will be getting parallel lines. So, from the first surface, you get this line; then from the next surface, this one; then this one, then this one, and it goes like this. And, in the case of nutating mirror or a palmer scan; in this case, you have this mirror and it is nutating in this direction. And so, you are getting an elliptical shape so, it goes like this.

So, you have these three common scanning mechanisms. So, we said that, in the case of a LiDAR, you have the laser - the first thing was the laser, the second was the scanner and the optics. So, now, we have a look at this scanner and the optics, that are creating different patterns on the ground to scan the whole of the surface. Now, once it has interacted with the surface, then the laser beam comes back and it is detected using the photo detector and the receiver electronics.

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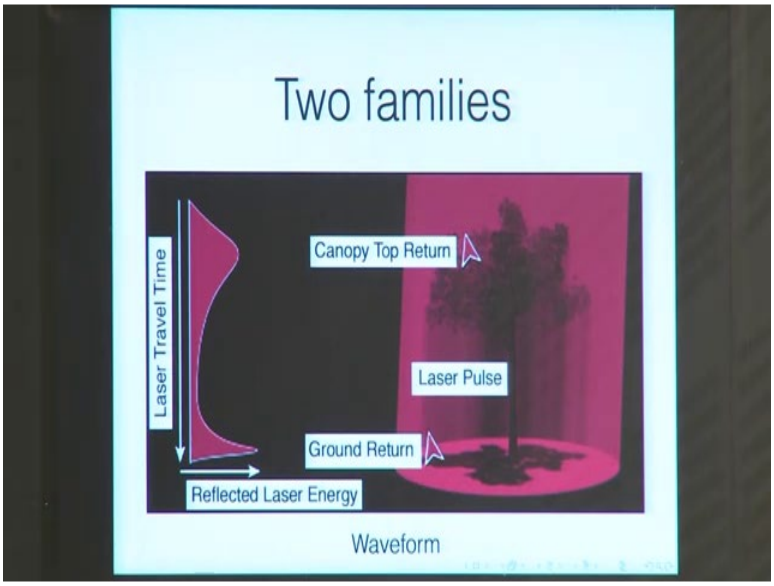

Now, in this case, we have two different families of measurements. The first one is known as a waveform measurement, in which case, if you have the laser travel time, and you are measuring the reflected laser energy. So, what you are seeing here is that this is a tree, and then the more the laser travel time, the more downwards you are going. So, this laser travel time is corresponding to the distance of the aircraft from the tree. So, from the topmost portion of the tree, the distance is less and the distance of the ground level is greater.

Now, in this case, what you are seeing is that, here you have the canopy and so, more of the light is reflecting back. Here you have the ground level, so again, you have you see a peak and in between there is less amount of reflection.

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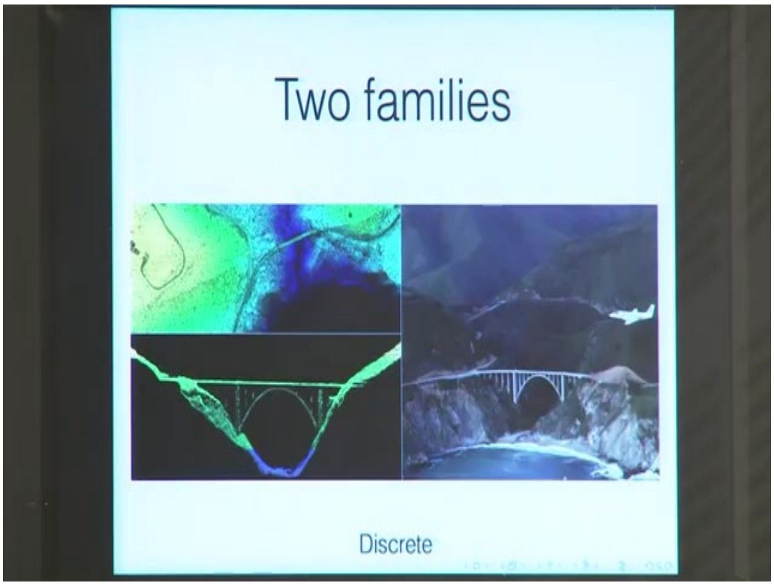

So, you can measure and get a waveform, or you can get discrete measurements, in which case, you are getting omega. So, this is a bridge and you are getting the measurement and at each and every of these points, and so, you get this cloud like pattern of the points.

So, these are the two different families of measurements that are made use of.

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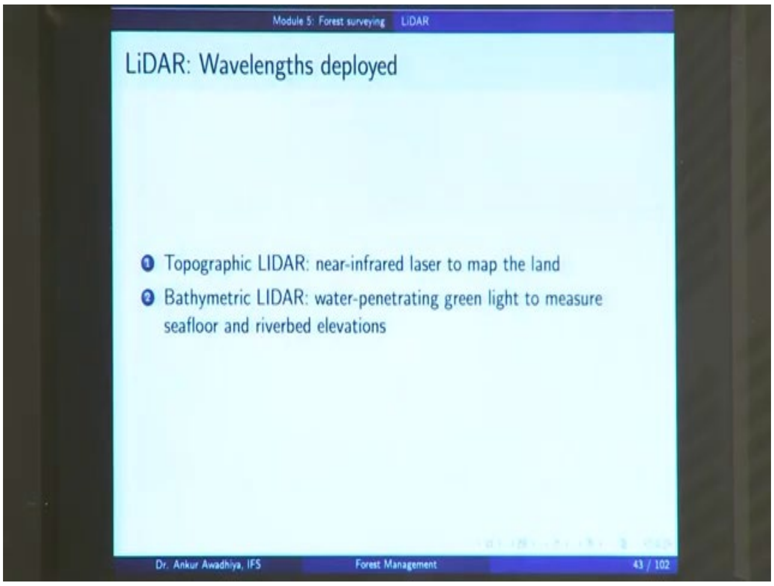

Now, in the case of LiDAR, you can deploy different wavelengths for different purposes. So, you can go for a topographic LIDAR, in which case, you make use of a near infrared laser to map the land. So, this is used for land topographic LIDAR.

And, in the case of a bathymetric LIDAR, you make use of a green coloured light. So, it is water penetrating green light to measure the seafloor and the riverbed elevations.

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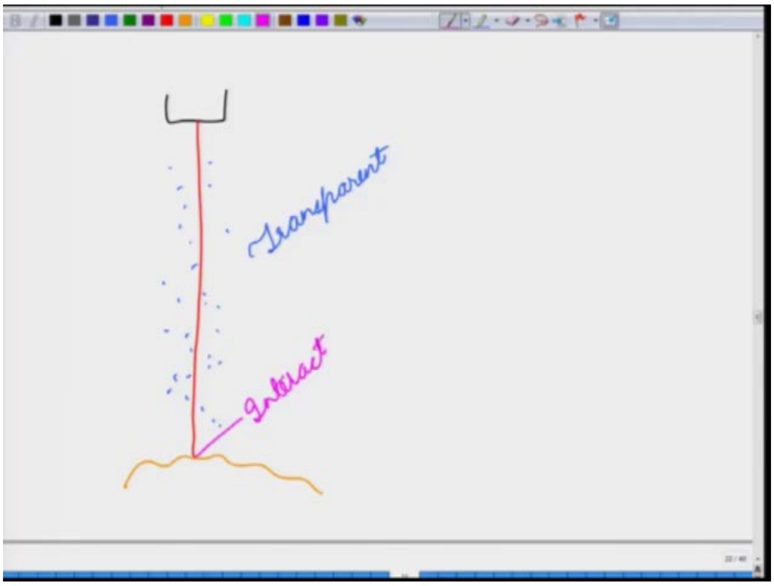

Now, why do you need these different wavelengths is that, when you have your laser and it is interacting with the surface; so, here different things are happening. The first thing is that some amount of the energy is interacting with the medium. Now, suppose the medium is such that or the wavelength of the laser is such that, it interacts with the medium in such a way, that it gets absorbed. So, in that case, your laser beam will not be able to reach the surface. So, you want something or some particular wavelength at which the medium is transparent. So, that is the first requirement.

So, if you for instance if you are making use of the infrared light, and if you shine it on the surface of water, then this infrared red energy will be absorbed by the water. So, in this case, the water will not be said to be transparent to the infrared wavelengths; but towards for a green coloured laser, the water will appear to be transparent.

Now, secondly, your laser should be of such a wavelength that it should be able to interact with the surface. And, in this case, the interaction is that it should interact and it should come back. So, it should be reflected back. So, these are two different criteria through which you decide what wavelength of laser you should be using.

Your wavelength should be such that the medium is transparent for that wavelength, and to the wavelength is such that it is able to interact with the surface of interest and come back as a reflected beam. So, for that purpose, in the case of land, you will make use of topographic LIDAR, with near infrared laser. In the case of water, you will make use of bathymetric LIDAR, with green coloured wavelengths.

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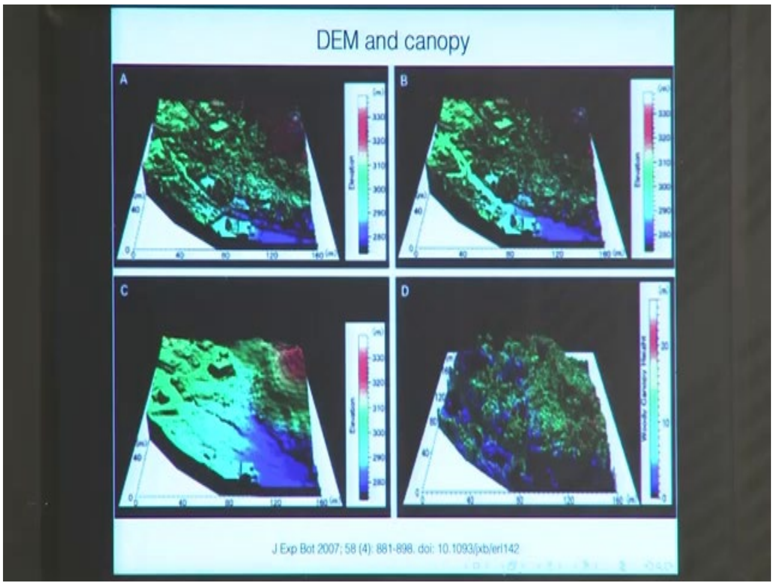

Now, how do we use this LiDAR in forestry? So, one application is to know the digital elevation model and the canopy.

Now, in this case, you can see that where your trees are lying and what is the height of these different trees. So, again as we talked before, you can find out the DEM model; you can find out the DTM, you subtract DTM from the DEM and you get the height of the canopy. So, one very good application is to find out the canopy and the height of different trees, in different areas of the forest. So, this makes for a very good and a very fast survey.

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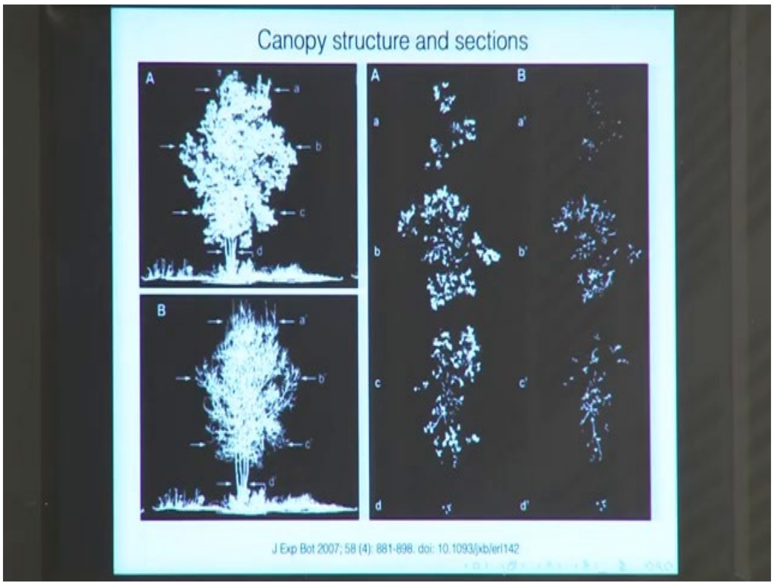

Second, you can study the canopy structure and the sections. Because here if you go for a higher resolution imagery, then because you have and if you go for say a discreet a family of measurements, then you have each and every of these points is getting represented in your 3-D model. And once, you have this representation you can then ask your computer to create a section of these different regions. So, like this A a section would look like this, and this image the A a section is looking like this. The B b section is looking like this.

In this case, you are having very thin leaves. In this case, this is the C c section and then the D d section. So, if you have a three-dimensional representation of your tree in the digital space, then you can use that information to construct any sort of sections, and get in an information about how this section will actually look like, when you are cutting the tree.

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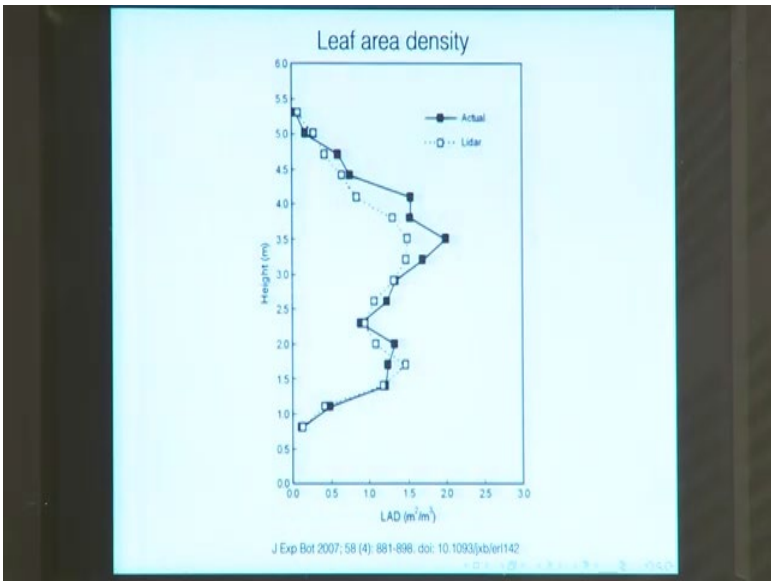

Next, you can figure out the leaf area density. Because more the leaf area density, then this is impacting the amount of energy that is being use by the plants.

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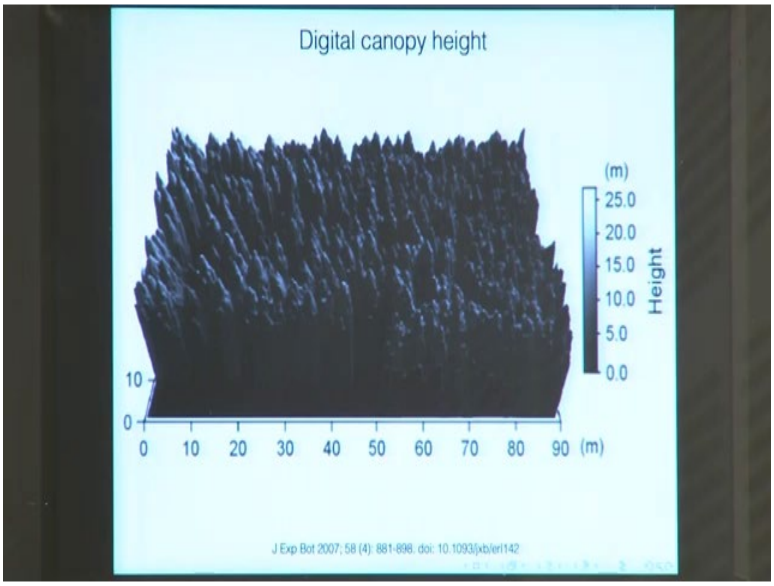

So, you can figure out the leaf area density using LiDAR. You can construct a digital canopy height model as we saw before.

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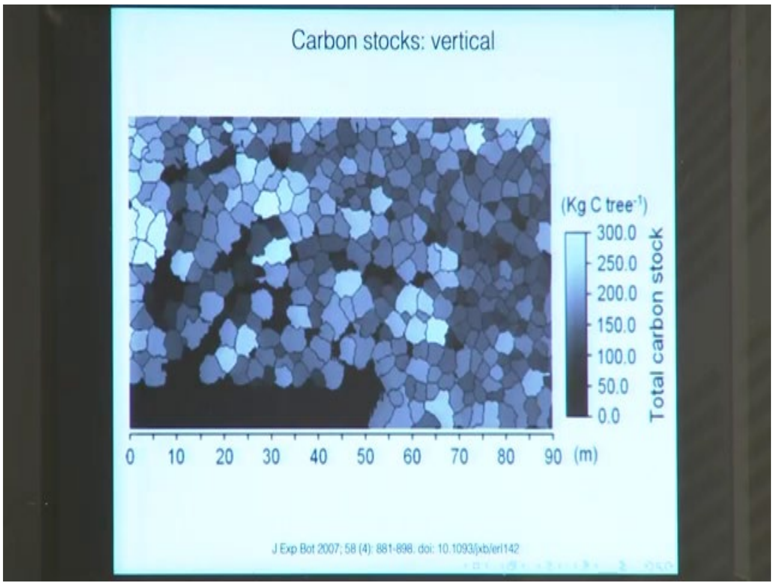

And, this digital canopy height model together with the information of the canopy structure, can be used to figure out the carbon stocks that are present in your forest. Now, carbons now measurement of carbon stocks is essential, because forests are one of our very good tools for climate change mitigation. So, they sequester carbon and deposit it in the form of biomass in their bodies, and you can do a carbon stock measurement by using LiDAR. Now, these sorts of measurements are important because in the case of any management you have this cycle.

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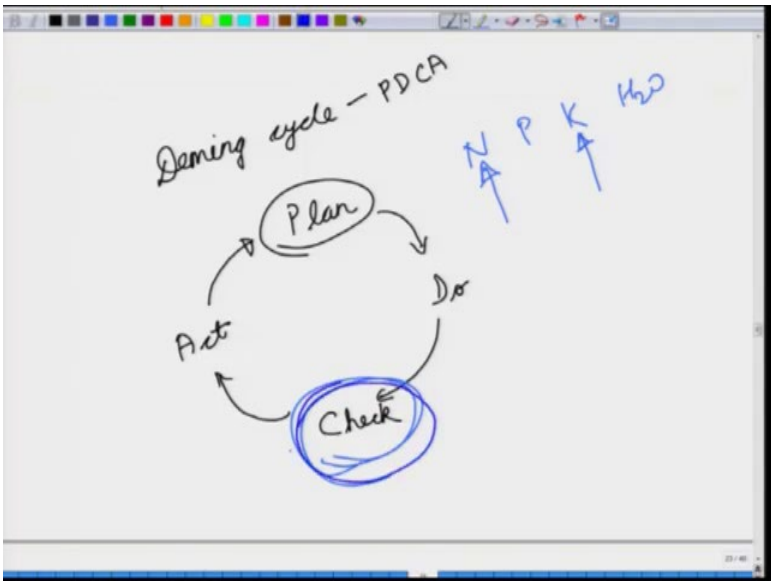

You have the Deming cycle, which is PDCA. So, you first of all you PLAN an operation. So, your planning is, for instance, to increase the amount of carbon that is sequestered by your forests. So, you are doing a silvicultural operation; you are manage you are managing a stand to have the maximum amount of carbon sequestration.

Now, in this case, your plan is to you manage it in such a way that the amount of carbon sequestration increases. So, you have greater amount of stock or your stock builds up faster. So, this is your plan. So, with for this plan, you will come up with certain operations. So, you might say that this in this area the plants are not getting sufficient nutrients. So, let us add certain nutrients to the plants, or let us provide irrigation to these plants. So, this could be a plan. Now, once you have this plan, the next stage is to DO; so, in this stage you are actually implementing the plan.

So, your plan was to give more nutrients. So, in the DO stage, you go there and you put nutrients in the soil. Next stage is to CHECK. Now, you were adding the nutrients, so that your rate or amount of carbon sequestration went up. But now, the question is did it actually go up? So, it is possible that in the soil where you are having a number of nutrients you have nitrogen, phosphorus, potassium, say water and a number of other nutrients, possibly you thought that it is nitrogen deficient. So, you added nitrogen, but it is possible that your soil was having sufficient amounts of nitrogen, and it was actually deficient in potassium. So, if that is the situation, then you will when you are in this check stage, will you will find out that there is no measurable or appreciable change in the amount or the rate of carbon sequestration that was happening.

So, what happened what was happening before is the same as what is happening after you did this intervention. So, probably this is not a nice intervention to do; it is not required. So, when you have this result, then only you will start thinking if nitrogen is not working, probably I should look at some other nutrient; or probably this site is rich in all the nutrients. And, it is already at the most optimum stage, and so there is nothing that can be done.

So, you can only have an idea of what you are doing the impacts in the checking stage. And now, based on the checking stage, the next stage is ACT. So, you act on the information that you are getting from the checking stage, and with this ACT, you again start make to make a PLAN. So, in place of nitrogen, now your new plan is to add potassium.

So, then it will move back to the D stage. So, this is the PDCA cycle. So, you have PLAN, DO, CHECK, and ACT; this is the PDCA cycle. So, whenever we are working with carbon sequestration, one of the very important stages is to check what we are doing and LiDAR provides you a way to check the carbon stocks in a fast manner; in a manner that is not very labour intensive. Because you can very easily make use of drones; these drones will scan the whole area, and it will give you this figure. And, with this figure, you will have an idea of the total amount of carbon stocks that are there in the forests. And, you can do these measurements again and again repeatedly.

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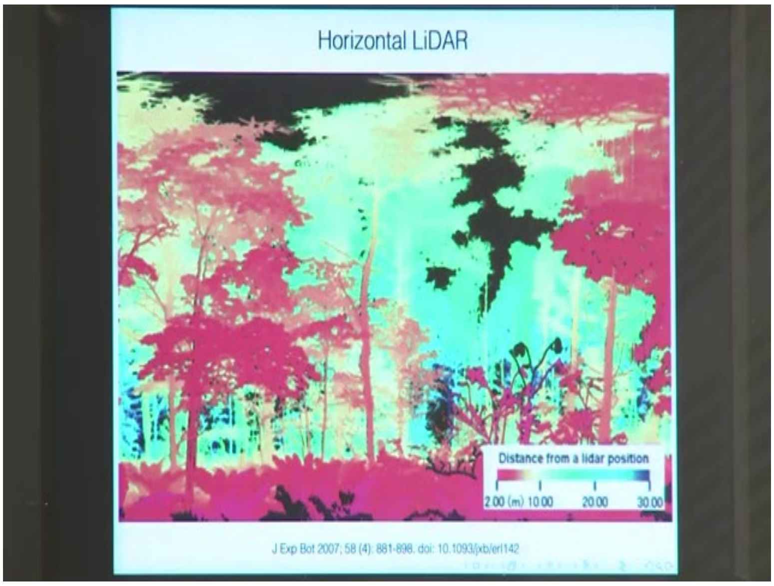

Now, another application is a horizontal LiDAR. So, a horizontal LiDAR is a ground-based LiDAR. So, remember that we said that we said in the beginning that you either go with an air-borne LiDAR, in which case, you are looking at the forest from top-down. Or, you make use of a horizontal laser LiDAR, in which case, your LiDAR equipment is kept on the ground; probably on a stand, and then you are using it to scan the forest from a ground perspective.

So, this is how your forest is looking using the horizontal LiDAR. Now in the case of this horizontal LiDAR, if you go through these operations, you can find out where each and every of these trees are located. Because, you have this information in a three-dimensional space now, in this three-dimensional space, you know the location of every tree; you know the girth of every tree; and so, with by using the horizontal LiDAR, you can figure out the amount of biomass or the carbon that is there in your forest, in a much greater precision, as compared to the vertical LiDAR.

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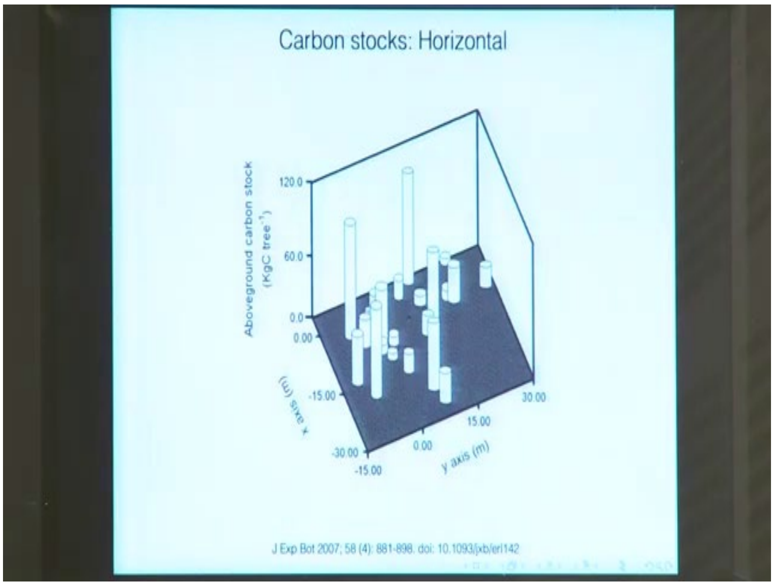

And so, you can convert this sort of an image into the carbon stocks of different trees. So, suppose you only took this photograph. Now, in the photograph, you have a two-dimensional representation. So, you know that there is a tree; and, but you do not know at what distance this tree is lying. But, in the case of a horizontal LiDAR, because this is a three-dimensional structure; so, you know the position of each of these trees or in the three-dimensional space.

So, you know that this tree is located at this position, in the x axis; this position on the y axis, and this is the total amount of common stock that is there at this location.

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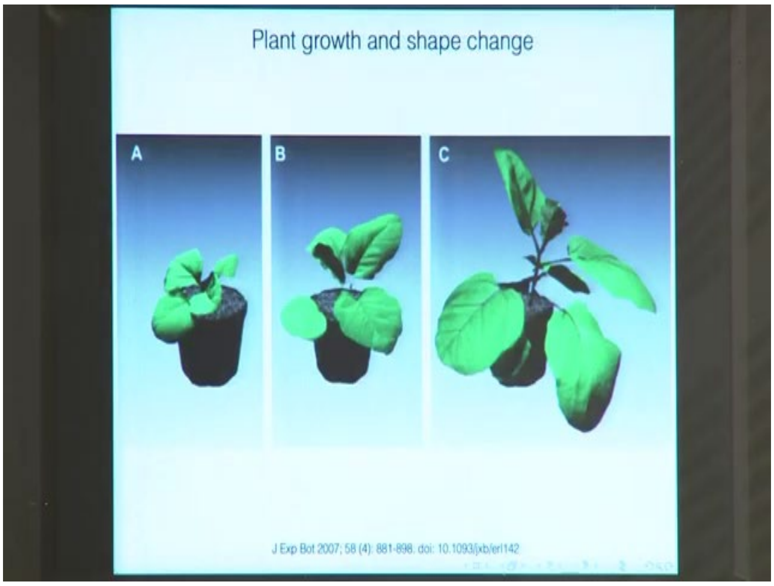

Next, LiDAR is also used to understand the growth of plants, and the changes in the shape of the plants. Because, in this case, you can make use of a LiDAR, and convert your plant in different stages into a three-dimensional object in the digital space. So, once you have that you can now play with the system.

Also, LiDAR is used to understand the growth of the forest.

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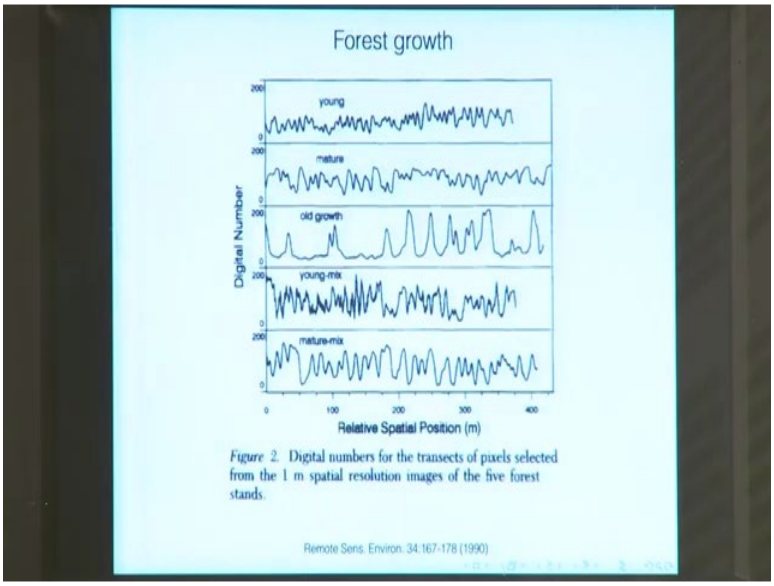

Now, how can you make use of a LiDAR to understand the growth of the forest?

So, in the so, in all of these the y-axis is showing you the digital number, and the x-axis is showing you the position of the trees. Now, in the first case, you are saying that you have these canopies that have a very short height; so, probably these are young plants. In the case of this curve, here you are saying that there is a huge tree, then of then till some distance there are these hardly anything, then you again have these two huge trees, then there is nothing, then you again have a huge tree, then nothing then again a huge tree, and so on.

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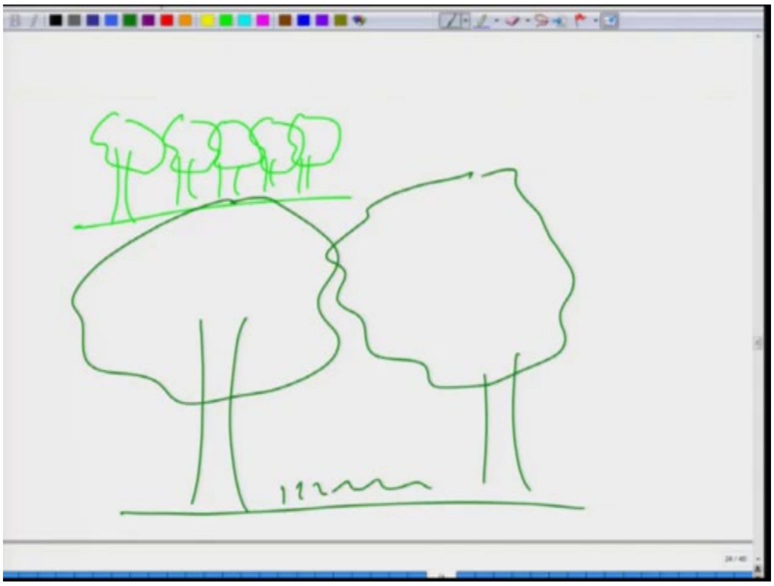

So, what we are seeing here, in the case of LiDAR, is that, in the first case, you were having small trees that were close together. So, it is more or less uniform, in the case of a young crop; but in the case of the old trees, so, you have a huge tree here; then you have a huge tree here; and in between, there is hardly any vegetation or probably some undergrowth So, this is what you are seeing here; one huge tree, another huge tree, another huge tree, another huge tree, another huge tree. Whereas, in the case of these this stand, all your trees are of a shorter height and they are very close together. So, by using a LiDAR, you can have an idea of what stage your stand is in, whether it is a young stage it is in the old stage or it is in a mature stage.

Now, in the case of the mature stage, the number of trees will go down; the height of the trees will be more than that of the young plantation. Then, you can also see whether you have a mix of the forests. So, this is young and a mixture, and this is a mature mixture.

So, most of the trees are mature, but then you are also having some other trees that are of a young stage. So, you can very easily understand the growth characteristics of your stand by making use of the LiDAR data.

So, in this lecture, we started by looking at what a LiDAR is. So, LiDAR is light detection and ranging. So, it is a system in which you are using a laser beam to scan the surface. because you are using a laser beam which requires energy to operate, so this is an active remote sensing system.

So, you have a laser beam on an aircraft and this is scanning the surface, and when the laser beam is going down and then it is interacting with the surface, and then there is a reflection. And, the reflection is measured on the aircraft. So, in that case, we saw that the distance that is travelled by the laser beam is given by (c x t) by 2; where 'c' is the speed of light, and 't' is the time it takes for the laser beam to come back.

Now, if we know the position of the aircraft; if we know the angles that are being subtended; and if we know this distance, then we can very easily compute the surface over which you are doing the measurements.

Now, the position of the aircraft is measured using two things. One is a GPS global positional system, in which case, you make use of satellites to figure out the location of the aircraft. Now, typically you want to have a greater amount of precision, so you go for a differential GPS, in which case, you have the aircraft and you also have a ground control point; and at which another receiver is kept. And, both of these are talking in real time.

Then, the second thing that you use to get the position is the IMU or the Inertial Measurement Unit, which tells you acceleration of the aircraft in different directions; so, and the angle that is that your aircraft is subtending. So basically, if you have this aircraft and if it is moving like this, the laser beam will go up. So, you need to measure the angles very correctly. Now the angles are measured by two things; one is the IMU which is giving you a feed back of the angle that is being subtended by the aircraft, and two is the angle at which you had actually installed the equipment.

Now, in the case of LiDAR, the first thing the first criteria that we need to look into is the laser that we are using. So, the wavelength of the laser would depend on two things -

one is the transparency of the medium to that wavelength, and two is the interaction of the surface of interest with that wavelength.

So, you should be having a wavelength at that is such that it is easily able to pass through the medium and come back, and two; your wavelength should be such that it is able to interact with the surface of interest. Now, typically in the case of ground measurements, we go for a near infrared laser; and typically, in the case of water-based measurements or bathymetric measurements, you go with a green coloured laser.

Now, so the first thing was the laser. The second thing is the scanning and the optics that is used to move the laser beam on the surface, and so, here we saw that you can make use of an oscillating mirror; or you can make use of a polygonal shape mirror; and so on. And, all of these will give you different kinds of patterns on the ground.

Now, once this laser has come to the surface and it is getting reflected; now, you require a receiver and the receiver electronics to know the position to compute the time that has been taken by the laser beam to go there and come back. And, the fourth thing, in the case of laser, is to know the position accurately using differential GPS and the IMU.

Now, laser can be used in two different families of measurements. So, you can have a waveform measurement or you can have a discrete measurement. And, typically you can use your LiDAR in two ways - you can go with the last pulse method or the first pulse method. Now, in the case of the first pulse method, you are measuring the top of the trees. So, you are getting a digital elevation model. In the case of a last pulse method, you are measuring the ground surface, in which case, you get the digital terrain model.

And if you subtract DTM from DEM, you will get the Digital Canopy Height Model or DCHM. Now, in the case of a digital canopy height model, you will know the position and the height, and the canopy size of each and every tree, that is there in your forest. Now, you can make use of these sorts of information to say - know the position and height of different trees; kow the amount of biomass that is there in different trees; know the amount of carbon that has been sequestered in each and every of these trees, or say to get a scan of a tree in any direction. So, once you have this three-dimensional model of a tree, you can ask your computer to find out how each section would look at different locations. Then, your LiDAR is also made use of in see the horizontal mode to get to get your carbon sequestration in much greater precision.

Or, it is also made use of to understand the growth of plants, in which case, you convert different plants in you convert plants at different stages into three dimensional models. Or, it is also made use of to understand whether your stands are young mature old or in a mixed stage. So, LiDAR is a very important tool these days, in the case of forestry, because it makes measurements and specially repeated measurements. It allows for repeated measurements that are very fast and that are done in an economical manner, without expending too much of labour or time.

So, that is all for today thank you for your attention, [FL].