Remote Sensing: Principles and Applications
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Lecture-58
LIDAR-Part-3

Hello, everyone, welcome to the next lecture in the course remote sensing principles and applications. In the last two lectures, we discussed about LIDAR and its operations from terrestrial platform, aerial platform, which can be extended to space-borne platform also. Then we discussed about discrete way from LIDAR and full waveform LIDAR.

Discrete return can store maybe 1, 2, 3 some discrete number of returns, it would not store the entire waveform or the signal that is coming back after getting backscattered from the ground elements, whereas a full waveform LIDAR will be able to store the maximum amount of information that comes back from the ground. Hence, for certain applications, especially dealing with vegetation monitoring the full wave from LIDAR is often used, because of its ability to capture most of the features present underneath the canopy.

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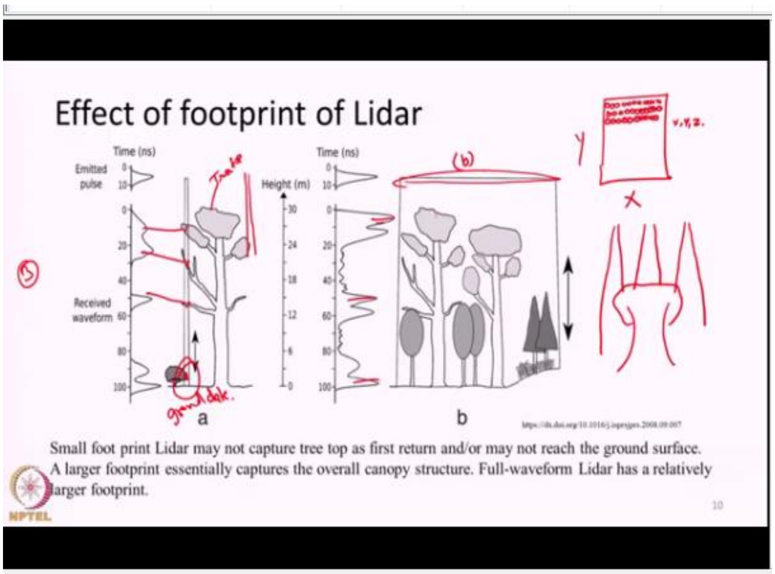

The next important concept that we are going to see is the effect of footprint of LIDAR. A footprint is the projection of the laser beam onto the ground and how much ground area the laser beam covers. So, essentially, the returns within each footprint will be going back towards the target and at least some of them will be saved. So, each footprint provides us a valuable information about the features present on the terrain. So, in order to properly capture the terrain, we need to have a large number of footprints. Each footprint will be giving us one x, y and multiple z values associated with it. So, if you have a large number of footprints, we may get proper information about the topography.

The footprint sizes may be in the order of 1 meter or 2 meter. So, even if there is a large tree it will be captured properly within that 1 meter footprint. The single tree will be captured in multiple footprints, which may help us to capture the terrain properly, that is what naturally we will think. That is also true in most of the cases for topographic surveying purposes. People naturally go for small footprint LIDAR in order to have a small footprint plus a dense point cloud LIDAR especially for topographic applications. But sometimes, it may give us some false information. Say if you are collecting data over a forest, this kind of small footprint LIDAR may actually miss the tree tops.

Let us say for example, the small footprint LIDAR is seeing here and the next footprint is seeing here. So, what exactly are we capturing? First thing we are missing the tree top. Second thing is this small footprint is going to capture this leaf, this stem, another stem and so on. So, maybe some return from here. Let us say this is a discrete return LIDAR system, it is going to store first 3 returns, if that is the case, this will be stored, this will be stored and this will be stored. Actually the ground data is going to be missed. So, because of the small footprint we are actually missing the tree top and also being discrete return we are also missing the ground. So, all these things being a discrete system or having a small footprint is going to change the way in which we are going to collect information about the ground.

But let us think in another form; let us say we have a large footprint system say in the order of 10s of meters say 20 meter system, 20 meter footprint. If that is the case, then the entire tree may be covered properly or even a group of trees may be covered. The example is given in this figure B. So, the group of trees is covered and we will be getting information from the tree top because the entire thing is covered in one footprint. So, having like a larger footprint will essentially capture the overall canopy structure, it may not miss the tree tops. So, for certain applications it is beneficial to have a large footprint LIDAR.

But if you want to perform a highly accurate and precise topographic surveying then we may actually go for small footprint, but for certain applications, large footprint also may give us good results. And also having a discrete and full waveform return is further going to influence the information we are going to collect. So, the effect of footprint may actually give us or removes some information that we want to get.

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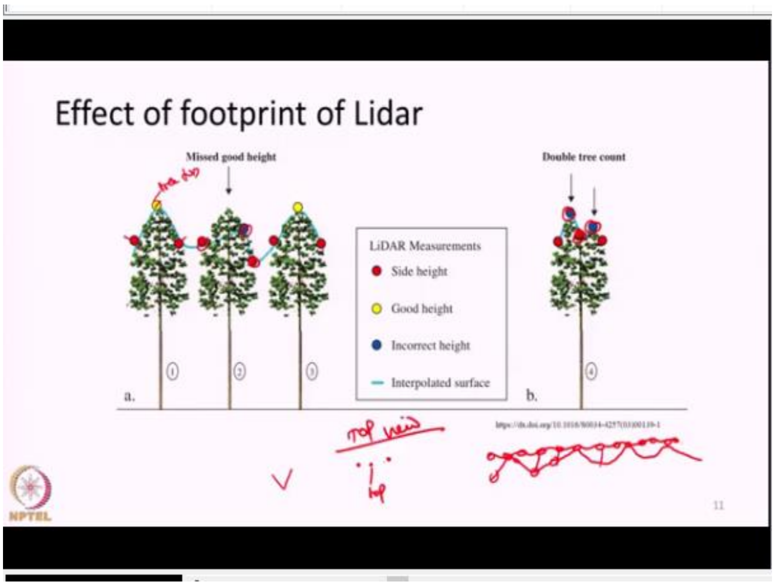

Say another example for the footprint of LIDAR has given in this slide. Let us say we have many small footprints. So, for this particular tree essentially if we want to capture the entire tree then we may need to get this information like the tree top and maybe 1 or 2 side elements. So, if you look from the top you may have 3 returns. But a small footprint LIDAR system may actually miss the top of the tree, may take measurements here or for certain large trees it may take multiple measurements over the same tree.

So, either we may miss the tree tops which may actually force us or give us a sense that the elevation of the tree canopy is slightly reduced. So, actually this is the points connecting all the tree tops let us assume, this particular line what I have drawn here, but let us say our LIDAR system is missing at least 50, 60% of tree tops. Then it may give us some line like this. Say the interpolated points may be lying here, that is some of the tree tops we are actually missing without even collecting the data which may give us the topography that the canopy structure is highly undulating with lot of large trees and small trees interspersed with among each other.

So, if you have a large footprint LIDAR, then essentially we are going to get a collective information, that is one advantage of having a large footprint data for certain applications. And also large trees we may count like more than 1 return. So, even we can count the number of trees over certain areas, using LIDAR. We may have a wrong count of the trees in such circumstances.

So, the footprint of the LIDAR and the returns coming in from that particular footprint is effectively going to influence the way we are going to observe the terrain. So, in a discrete LIDAR system, we can separate all the first return separately, second return separately, last return separately and so on. So, essentially, for a discrete return system, with a small footprint, all the first returns may not come from the tree top or building top, it can be captured on either sides or similarly, large footprint system is not necessarily bad.

So, based on our needs and applications, we need to decide which laser system we have to use a discrete form or a full waveform LIDAR. So, essentially, we have to choose based on the applications for which we are going to use LIDAR system. In addition to giving information about elevation, LIDAR will also store the intensity or the power that is returning back from the ground surface. So, whatever reflected from the canopy, the power will be recorded back by the sensor and that is again useful to get more information about the terrain. In the initial lecture, I told you that we use green wavelength or NIR wavelength for the lasers in LIDAR system 532 nanometers or 1064 nanometers. If that is the case, then let us talk in terms of NIR based LIDAR system, we all know that in NIR wavelengths vegetation will have a very high reflectance.

Similarly, even soil surfaces has typically higher reflectance, water bodies have lower reflectance and so on. But this kind of relationship between optical remote sensing and LIDAR sensing is not really direct. If there is some vegetation present on the ground, in LIDAR intensity image it will appear very bright. Normally in the NIR band image, our normal image it will appear very bright because of high reflectance, but in LIDAR intensity, it may not be the case.

Say in the figure a we have is the LIDAR last return elevation. So, it is giving information about elevation of different points. So, it is interpolated to give you a surface because naturally earth is a surface, not a collection of points. So, essentially we interpolate the points to produce a surface.

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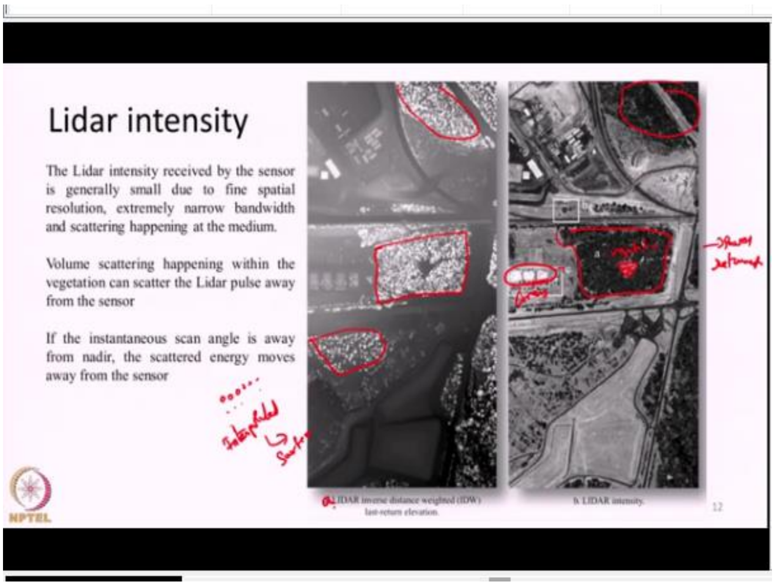

We can identify trees here. So, these are some high elevation points. This is the intensity you can think of in terms of the power returned. So, from return power we can sense there is vegetation. But the trees will have a very high reflectance in NIR portion and is actually appearing dark than in between barren surface or open surface. Naturally, we expect vegetation to have very bright reflectance than soil surface, but here trees has lesser reflectance. Why is this happening? Why trees appear actually dark? Tree should naturally appear bright in NIR images. It has a very high reflectance, but we also need to look at the nature of reflection or nature of scattering happening in the terrain element. Like in the earlier classes we discussed that reflection can be happening from the surface scattering or it can happen from within the volume, within the terrain feature which we call as volume scattering basically.

So, if you have a large tree, there will be plenty of gaps in between so, the LIDAR pulse may penetrate into it and multiple scattering will happen from different, different portions of canopy. Naturally, it is not only the top portion that reflects everything, sunlight will always penetrate especially NIR penetrates through the leaves to certain extent and we also know this additive reflectance property because of the penetration.

LIDAR is a backscattering observing system. If the sensor is here then the signal should come towards a straight direction for our sensor to record it. Then volume scattering happens within the canopy, the reflected signal need not go in the direction of incoming beam, it can also go in all other directions because it may become more diffused in nature.

When volume scattering happens it will become diffused and a large fraction of energy will be scattered in all other directions and only a small portion will go back in the same direction from which the energy came. So, it is not like specular reflection, it is like backscattering, energy came in and energy went back in the same direction. So, the backscattering is essentially a small component whereas energy is now actually being scattered into several directions surrounding it. So, that is the reason vegetation appears dark. If you have a normal NIR sensor, which means all the information going in certain direction within the IFOV, then it will be able to capture some amount of larger signal coming in from the vegetation. Grass is naturally not producing lot of volume reflection, most of it happening within the surface. So, essentially what is coming towards the zenith is going back.

So, that is the difference between a normal optical remote sensing system and the LIDAR system. There is no one to one correspondence between them, we cannot interpret the LIDAR intensity images. Similarly, what we do with the normal images, we need to exercise some caution, the patterns may differ, but essentially LIDAR intensity provides us additional information rather than just looking at x, y, z points. It will help us to know what is there on the surface to a very good extent, but still we need to exercise some caution while interpreting such images.

There are few LIDAR systems that are operating from space based platforms. In early 2003, there was a satellite called ICESat with a LIDAR instrument called GLAS which was in orbit up to 2009, for measuring the topography of poles, ice sheets and glazier. That is why it is called as ICESat. Its major application is to collect topographic information especially about the glaciers, ice sheets and also about world's forest. This is the first space based or satellite based LIDAR system. Now, we have two LIDAR systems, one is ICEsat-2 with an advanced laser altimeter system called Atlas advanced topographic laser altimeter system which is developed version of the GLAS.

The ICESat-2 satellite has an orbit of around 500 kilometers orbital altitude with laser footprint size of 17 meters and orbit return period of 91 days. The orbital inclination is 92 degrees and it is in a near polar orbit again. It uses a green wavelength 532 nanometers, because that is the characteristic wavelength used for studying ice.

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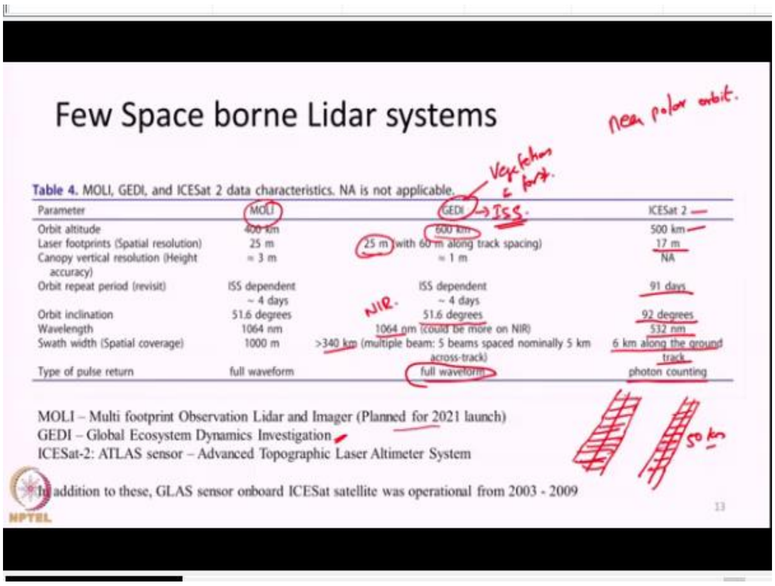

So, it has a swath width of 6 kilometer along the ground track and the type of pulse return is called photon counting, it is slightly different from the discrete and full waveform. They use what is known as a photon counting technique. So, this is one of the operational satellite based LIDAR system that is available. So, this will produce a repeat interval of 91 days. So, on an average once every 3 months it will collect the topographic information over the same spot on the ground.

But why do we have such a very large number of repeats cycle? Actually ICESat-2 is not scanner system ICESat-2 produces multiple beams and each beam will have its own footprint. So, within this each beam the elevation will be stored and because of the very small swath width it has to go large number of orbits in order to give a global coverage. But let us say now swath width is just 50 kilometers. So, what essentially happens? rather than collecting one full 185 kilometers we are now collecting only 50 kilometers So, you have to make at least 3 orbits in order to have a good coverage even for the same portion. So, the number of orbits the satellites should make before it covers the entire globe increases.

In the discussions about the platform's I told you almost all near polar satellites and sun synchronous orbits will have a repeating cycle, once every 16 days, once every 24 days. Say after making 233 orbits, Landsat satellite will return to the same position again towards the first orbit when it started. So, just like orbital cycle, ICESat system before it makes complete one full cycle it will undergo more than 1300 orbits because of its very narrow swath. The number of orbits it should make in order to cover the entire globe is extremely large, it should undergo 1300 plus orbits in order to cover the entire globe. And hence the revisit time is very large, because of its very narrow swath width. So, the swath width and orbital characteristics will define the repeat cycle and also the repeat cycle and swath width will further affect the temporal resolution. So, all these things are interconnected. That is why ICESat-2 has like a very long gap between its repeat cycles almost 3 months once.

There is another sensor called GEDI, GEDI, which is global ecosystem dynamics investigation. This is not a satellite; this sensor is there in the international space station which is now housing more number of remote sensing sensors. GEDI is one of the sensors, there is another sensor called ECOSTRESS. There are multiple remote sensing sensors are now being housed in the International Space Station. It is not orbiting in terms of around 500 to 600 kilometers in elliptical orbit and it will not produce a global coverage. ISS has an inclination of about 51.6 degrees that means it will not cover the entire large part of globe. It will be mostly confined within 50 degrees. So, that is one of the things we need to remember. So GEDI sensor essentially covers forest, vegetation in tropics and temperate regions.

This is one of the demonstration system to prove that LIDAR based remote sensing is really helpful for monitoring the global biomass, carbon cycle and so on. Using this height information, we will be able to model the biomass and also get information about the carbon cycle happening within the forest ecosystem. All these things are really vital information in order to understand the earth's climate, even like the earth system as a whole.

So, the GEDI sensor uses an NIR wavelength, swath width of 340 kilometers. Again it is not a scanning system, it will have multiple beams in the across track direction and cover it. So, space based system, they are not scanning based systems, they have individual beams, 4 beams, 6 beams and all. Simultaneously it will be covering the ground. And this was a full waveform LIDAR, for vegetation monitoring. And the laser footprint has a size of roughly 25 meters. These are the 2 LIDAR based sensors that are there in orbit.

So, after this GEDI one more sensor called MOLI, multi footprint observational LIDAR and imager is planned to be launched, again to be placed in International Space Station. So, this is kind of a second demonstration tool, GEDI will be taken off and MOLI will replace. And it is planned to be launched in the year 2021.

Again, it is a full waveform LIDAR, observing in any NIR wavelength 1064 nanometers with swath width of 1000 meters and so on, again in ISS. So, these are some of the examples of space based LIDAR systems, which provides data. ISAT-2 data and GEDI data are publicly available, we can download them and use them. So, before we conclude, we will just see few applications of LIDAR briefly.

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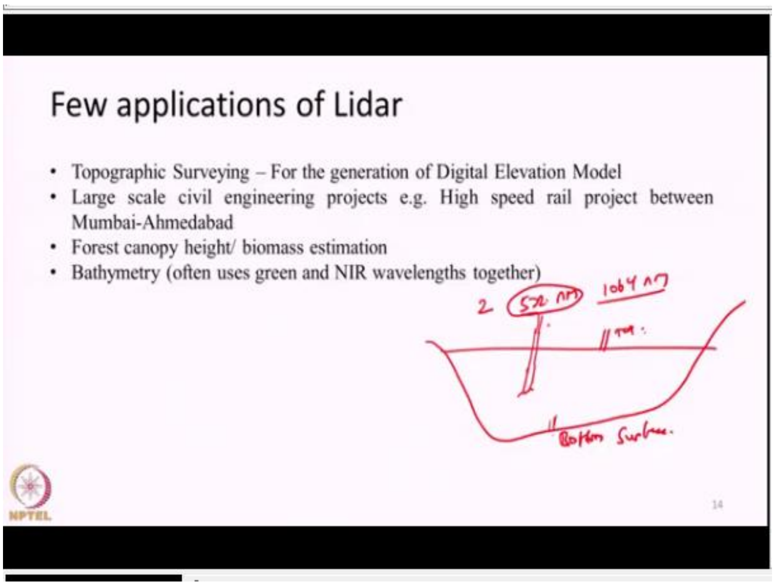

The first major application for which LIDAR was used is topographic surveying in order to obtain x, y, z of the various features on the earth's surface. Whenever we want a high precise or highly accurate digital elevation model, three dimensional representation of the terrain then LIDAR is one of the go to technologies. It will provide really quick, accurate and precise digital elevation model. And actually scientists from different organizations led by like IIT Bombay created the flood mapping or like the flood forecasting system for Chennai city in which, the DEM was collected from LIDAR system. Because for flood modelling or flood forecasting applications we need a highly accurate and a dense DEM.

So, the LIDAR system was used to collect the DEM information for that particular project. And also for various large scale civil engineering projects like the high speed railway project between Mumbai and Ahmedabad LIDAR system was used. It is also used to carry out the survey along the path, because the survey has to be completed in a few months within the entire stretch. And if it is a ground based service, it is going to take us years to cover that 600 kilometer stretch. So, people used LIDAR system in the large scale application of LIDAR system for engineering purposes. And also LIDAR based elevation information is useful for monitoring and modeling global ice sheets glaciers like ICESat satellite. Normally people will not launch a satellite if some data is not extremely helpful for a certain application. Launching a satellite is extremely costly. So, from that itself, we can infer how important elevation information is for cryospheric applications.

And also especially forest ecosystem based applications, we use LIDAR system for understanding forest canopy, height, estimating biomass. And one more application is bathymetry, like in order to map the topography of lakes or water bodies, below the water, how the topography is. So, how the topography of this bottom surface lies, LIDAR has been used to map in certain bathymetric studies, most of the bathymetric LIDAR systems will use both the wavelengths 532 nanometers and 1064 nanometers. So, we all know that NIR wavelength has extremely low penetration in water bodies. So, whatever the returns we get in NIR wavelength will most likely would have returned from the top of the water surface and green has certain penetration capacity into the water bodies.

So, the last return might have originated from some features present in the water or sometimes even at the bottom of the bed topography. So, the difference between the returns of green band and NIR band will give us information about the bathymetry of that particular water body. So, this is another application for which LIDAR system is used. So, essentially, LIDAR is one of really advanced technology or I will say it is a combination of different technologies combined together which helps us to get information about the earth and features on the earth with a much rapid turn around time. So, with this we end this particular lecture and also this particular topic.

So, essentially we have covered almost most of the principles that a new coming students want to know about remote sensing like optical remote sensing, like visible NIR wavelengths, how it will interact with earth's surface features. thermal infrared remote sensing, their physical basis, passive microwave, active microwave and all the basic principles, we have discussed about at least to some detail. So, from the next lecture onwards, we will slowly move on to application part or the analysis part. We will just briefly get introduced to various data products. Then we will see few analyses and also few applications in the last few lectures of this particular course, with this we end this lecture.

Thank you very much.