Remote Sensing Essentials

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Module No # 07
Lecture No # 33
LiDAR Technique and applications

Hello everyone and welcome to a new topic new discussion and which we are going to have all together a new technique which is LiDAR technique and also we will be seeing some applications of LiDAR. Some people call as LiDAR some people as LiDA and this is again ranging technique. So what if we see that definition basically also sometimes it is called 3D laser scanning currently it is little expensive but with the time and instrumentation and other things it might become cheaper also.

So it is not only replacing conventional sensors but also creating new methods with unique properties that could not be achieved before. So there is no other remote sensing technique like LiDAR or your visible or infrared thermal infrared. So this is a basically complimentary to that and ground based LiDAR are very popular. Though we will be seeing some airborne LiDAR example also but that is for 3D laser scanning creating a 3D view of any building or mountain, land slide all those purposes an LiDAR is being used which is tends for basically like (()) (02:00) and ranging.

And this is ranging laser based ranging technique so it is a extremely useful in atmospheric and environmental research as well as in space exploration. And it is also as wide applications in industry defense and military and also in natural disaster which we will be seeing some examples. And it as terrestrial as I mentioned that that ground based LiDAR it is started basically ground based LiDAR so lot of developmental is taken place in terrestrial part of ground based LiDAR. Then of coarse airborne also and some mobile applications that means on a vehicle there are installed and scanning is done.

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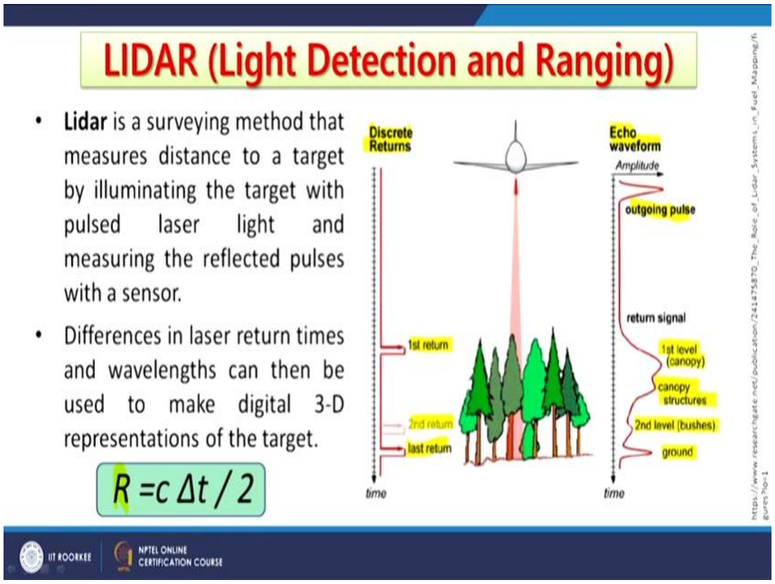

So in the LiDAR like here what we are seeing here that it is this is the Echo waveform and when it is sent this is outgoing pulse here. And when it interacts with the say different vegetation then you get a different you know waves which are created like first level cannot be second and then second level and then finally touches the ground and this is how the returns which the this detector receives after getting here.

So with of caurse it is time remains function here so the first return which is the top of the trees and then the second return is the middle where the canopy structure is about to finish only the trunks are there. And last return when it is at the ground level and as you can realize that this time also that when this situation that it can detect top of the canopy and above the ground also then it becomes very useful to get rid of even your vegetation from your terrain and only get the terrain surface.

So this is how the LiDAR surveying method a basically measures the distance to the target by illuminating the target with the pulse laser light and measuring the reflected pulse with the sensor. So in that way it is more close to your LiDAR technique and the differences in laser return times and wave length can then be used to make digital 3D representation of the target as we are seeing here that there will be changes when it interacts with the ground features. So the range reaches which is giving here is equal to C delta t / 2 because half of the time will or change in the time by 2 is taken and C is of coarse constant.

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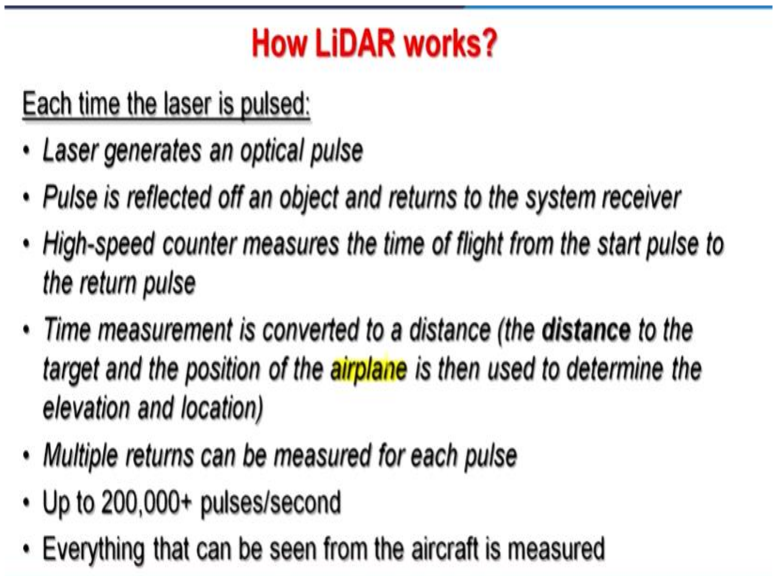

So each time the laser is pulsed the laser generate an optical pulse that is the light that is why it is lighted deduction you know so this is the optical pulse is then reflected off you know jet and return to the system receiver and then high speed counter measures the time of flight from the start pulse to the return pulse and by this the time measurement is converted to distance and that is why it is called the ranging technique and the distance to the target and the position of the airplane is then used to determine the elevation and location.

It may not be airplane if it is terrestrial LiDAR which is very common then that surface an instead of you know rather than grounded aircraft it can be the instrument itself and a surface that may be mountain slope or any other feature. And multiple returns can be measured for each pulse because multiple returns depending on what objects then example I have shown you that top of the tree in the middle and then from the ground also you can have the returns.

So up to 200,000 plus pulse per second are possible with LiDAR and everything that can be seen from the aircraft is measured or ground based LiDAR which are fitted on a tripod can also be used.

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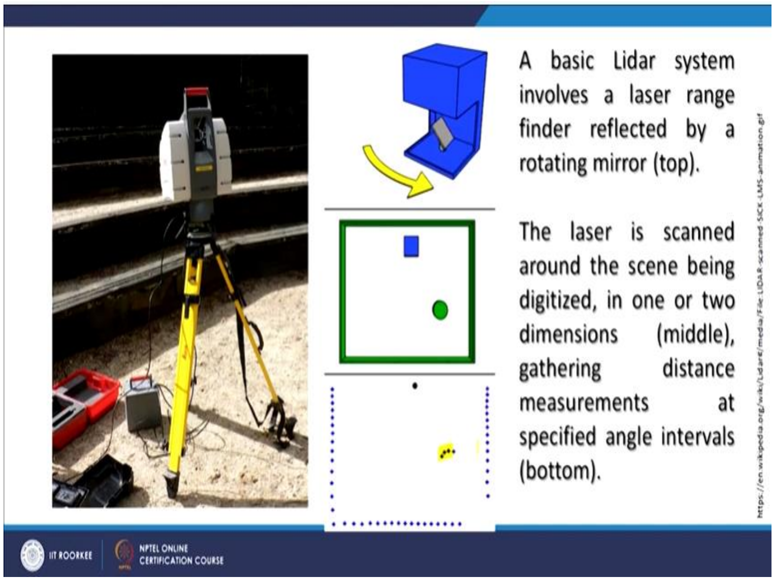

This is the example which is being seen and a 3D scanning is being done through this animation that 3 this is on a tripod and if you put in front of a mountain slope or a light landslide in a few minutes time it can you know scan the every part at a very high resolution. Even if there it is covered with vegetation and through the processing which we will be seeing that this can vegetation affect of vegetation can be removed because it records not only the top of the vegetation but the ground surface as well.

As you are seeing here that every object whenever it is interacting it is getting recorded and this is what you are seeing here also. So different pulses are getting recorded a basically a LiDAR system involves a laser range finder which is reflected by a rotating mirror is you are seeing here and it is being done the top to the blue part and then the laser is scanned around the scene which is being digitized and in 1 or 2 dimensions and basically middle gathering distance measurements at specified angle intervals.

So the user is specified angles are chosen and then you can define that how much area it will I would be scanning. In this example it is going for 360 degree but need not to be 360 degree it can be only and say 30 degree or 40 degree, 90 degree so it will cover only that much area whatever the objects which are present it will scan and create a 3D.

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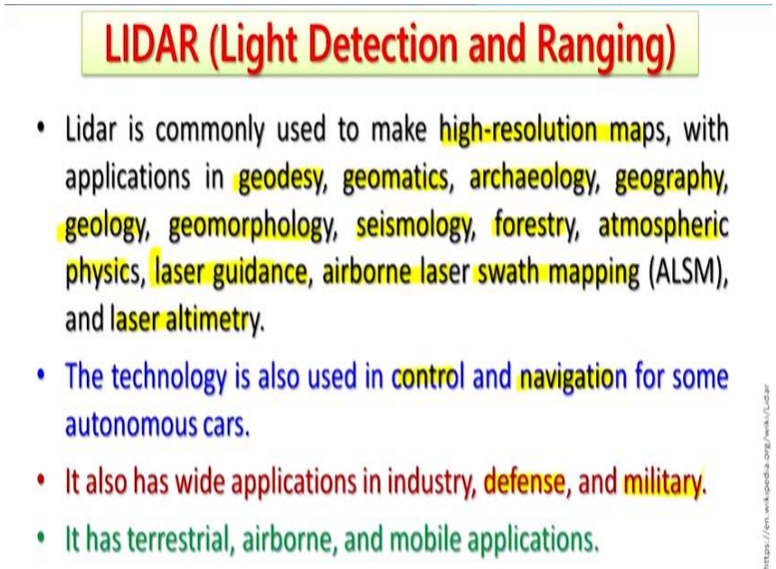

Now LiDAR is a commonly used to make high resolution maps because it can provide you know millimeter resolution data and that is why it can create a high resolution images high resolution maps which has got applications in geodesy any movement if suppose a land slide or a slopping slope of a mountain as mean you know have been scanned on one day and after say 1 year again that is scanned then whatever the changes on that slope as occurred can be deducted.

So it is used for the geodesy that is the movement of the part of the earth or slope and of coarse in the geomatics also it is used in archeology people are using extensively now a days the LiDAR may be for you know they are some minor deformations this may not be visible and to normalize or may not be visible in other remote sensing techniques but if is successive LiDAR maps are created or 3D models are created of monuments historical monuments archeological monument then probably we can detect the change is or the deformation might be taking place.

Now I understand like for Tajmahal they this LiDAR technique is being used so that we can exactly know what are the deformation though they might be very minute may be some millimeter deformation taking place. But because of archeology very important monument such service are done or must be done and then also in geography in geology example I have given about landslides or in mining also it is being used in extensively landforms modifications and deformation which might be taken place again LiDAR is used in a seismology also it is used ground reformation which takes place which is induced by an earth quake or some other reasons.

Then in forestry also because the advantage with LiDAR is that you can deduct different types of vegetation also or remove vegetation from that terrain. So in forestry also it is being used and then in a atmospheric physics laser guidance is very common like an this say English when this tunnel in France England created at through a English channel and the guidance was done through this LiDAR technique so that whatever is drilling which is taken place excavation is done it is all perfect.

So there are lot of tunnels which are created for different purposes for transport or may be for hydro carbon projects and they are laser guidance is required in LiDAR technique is used and of coarse airborne LiDAR is also for swath mapping and laser altimetry is also done. So that one can get the elevation mapping also through LiDAR so various applications many move this is not the exhaustive list many more will coming also in near future.

And the technology is used in control and navigation for some autonomous cars and that is again a lot of development is taken place and that driverless cars for which again for navigation and control and this laser technique or LiDAR technique is used and it is also wider application in industry defense and military and sometimes we do not know much about these two domain. But none the less overall were in the civilian (()) (13:38) are things are being done almost there also plus more things are being done. It is a terrestrial airborne and mobile applications which we have already discussed.

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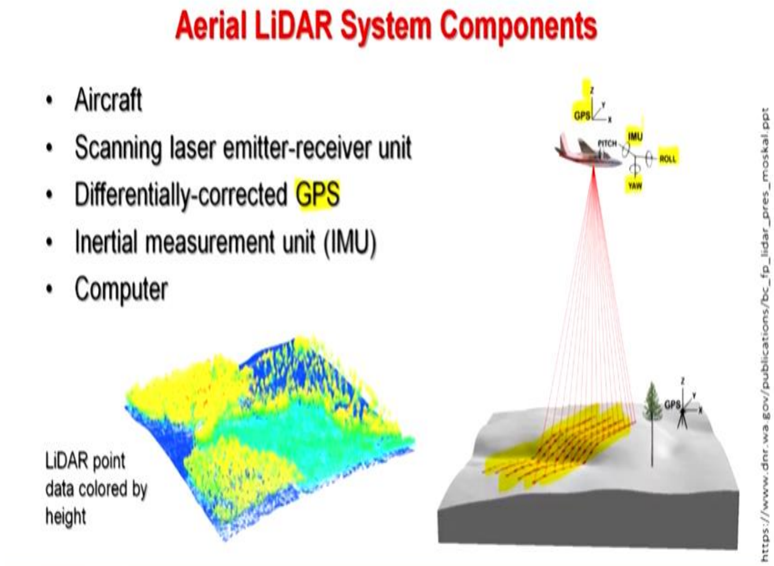

Now when we go for aerial we will be seeing also example this ground based terrestrial radar but here what we are seeing airborne radar through this figure what we can see that the line by line is scanning is been done like this and once it completes then a point data is created or that is giving different heights also so it has been colored based on the height so top of your trees which might be there for its cover you are seeing a red color then yellow then then green of coarse ground surface is in blue.

So in that way and all these things have to be corrected there if you recall the geometric distortions in satellite images. So in as in geometric distortion as we discussed about roll we also discussed yaw and pitch and many more many distortions which occurred due to the movement of an aircraft and variation in the air density. And all these have to be corrected before we employ this data for even for creative digital elevation model.

So all these are also shown here ROLL, YAW, PITCH and many things now a days are controlled through GNSS so those are also our 3D LiDAR equipment's are always having a GNSS receivers by which we can also have controls over lot of things. So in aircraft then if it is aerial LiDAR then you are having a aircraft you are having a scanning laser emitter receiver unit because both the things will be done by that unit and then differently corrected GPS or in this we can say GNSS which is highly accurate and then you are having inertial measurement unit that is IMU.

So that same time it is recording the movement of aircraft ROLL, YAW, PITCH all those things are also being recorded. So later on that information or those information can be used to correct our data and this point clocks basically. And then of coarse for recording purposes and recording other data sets a computer is also there so there are basically 5 components of aerial LiDAR system starting from aircraft for the recording up to the recording system.

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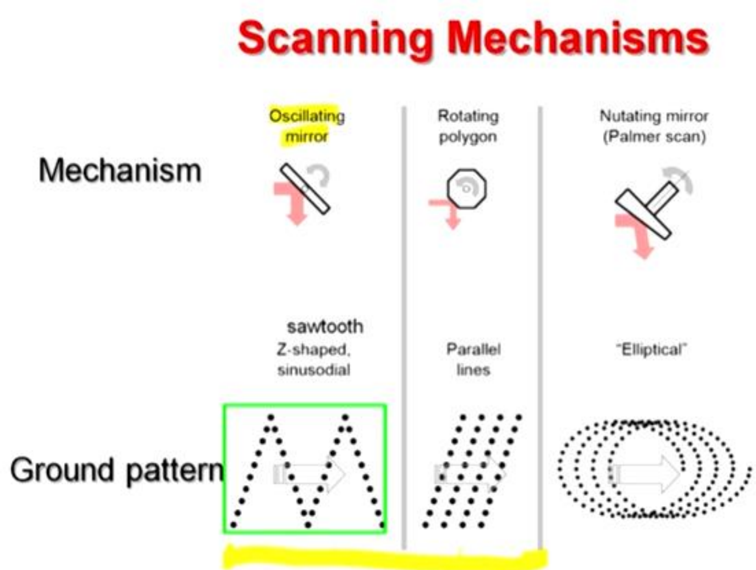

Now the scanning mechanism as also shown through earlier in a ground based LiDAR or terrestrial LiDAR that you are having a oscillating mirror and their also you have seen and then you are having sawtooth Z shaped sinusodial data as you can also see here that this insinusodial data is here. And then you are having rotating polygon like this and then parallel lines are so created and their might be another way of doing is rotating mirror and Palmer scan and Elliptical arrow also and done so most common one either the oscillating mirror or rotating polygon by which we can create a parallel lines of a those points which are later used to create surface or any other thing.

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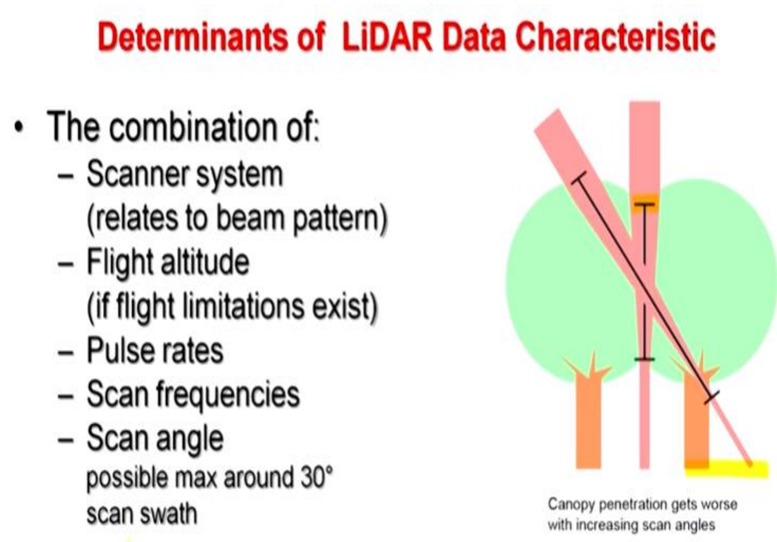

Now how this the you know determines of LiDAR data characteristics basically so here because not only it records the top of the canopy but also it records in between and then of coarse the ground surface is also there that is the biggest advantage with this kind of remote sensing technique where the canopy height can also be determined and because of the penetration which sometimes may come in a dense forest condition may become difficult but otherwise which is possible.

So when you get this data which is a combination of a scanner system and which will relate to the beam pattern what kind of beam laser beam is being used and then flight altitude the height of the aircraft in case of airborne and their might be some limitation also. Then pulse rate at what rate laser pulse are being emitted by a sensor and then scan frequency how you know how frequently that mirror or polygon mirror is being used that will decide the frequency as well what is the angle here two angles like in this example are shown vertically downward that is (()) (19:28) view kind of thing and then of (()) (19:31) also.

And then possible maximum around 30 degree it is possible but same time because one as to remember that aircraft is moving when it stands the pulse it has to collect also. So everything as to be synchronizing manner that the return beam is also collected by the receiver it is not just emitting and going it is collection also. And the scan swath and how much area is to be covered which will depend on this possible maximum around 30 degree scan swath.

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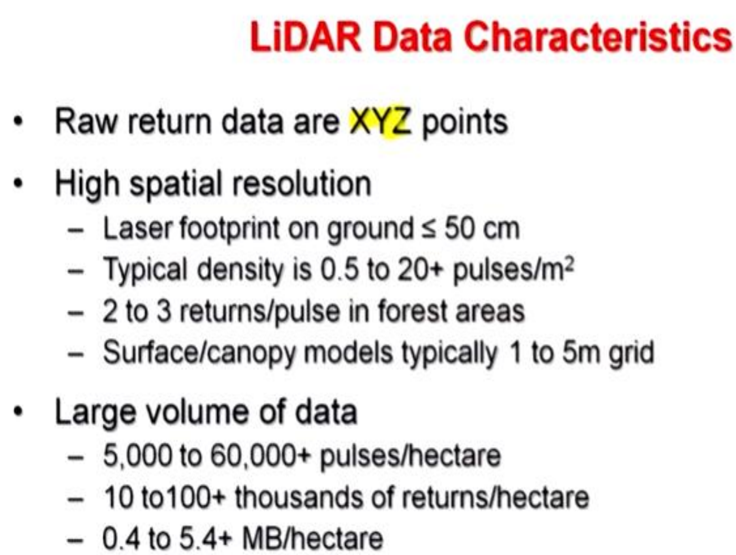

And now when we get the return that row data return is having X, Y and Z points and these are at high spatial resolutions and laser foot prints on the ground may be of even less than 50 centimeter and that is why I spatial resolutions is possible. Typical density of this pulses can be 0.5 to 20+ pulses per square meter that is why we can achieve a very spatial resolution data and 2 to 3 return pulses in forest area and that is possible because of it depends on the density of the forest.

Surface canopy models typically 1 to 5 meter grid is possible and that is the biggest advantage is have been mentioning about that it can also detect the top of the canopy as well as the ground surface and then one can say as the negative with the LiDAR is that large volume of data. It creates hell of data lot of data to process and because of lot of other things are to be considered the moment of aircraft and angle and pulse rate frequency everything.

So the processing is really challenging in case of LiDAR but now a days there are commercial software's equipment's and all kinds of things are available by which is it is become possible to create digital elevation models or you know study land slide movement or monument with the terrestrial LiDAR and airborne LiDAR. So 5000 to 60000+ pulses per hectare that kind of volume of data we are talking 10 to 100+ thousands of return per hectare the return is going to be of coarse less than transmit or you emit.

And then you know 0.4 to 5.4+ megabyte per hectare data that kind of data we are talking. Of coarse these things will depend on the frequency and resolution which one has chosen and the scan view the swath and other things. And in a return density which is the data which is the real you know the recordings by the receiver is that in the foot prints size decreases with increasing post spacing and in importantly the last return from a discrete return system is not always and the ground.

So this is sort of one limitation that whatever the last return may not be always the ground surface it may be from even the base of canopy or may be on crump sum other surface as well. So LiDAR system sensor system very number of returns from a surface one example is shown here.

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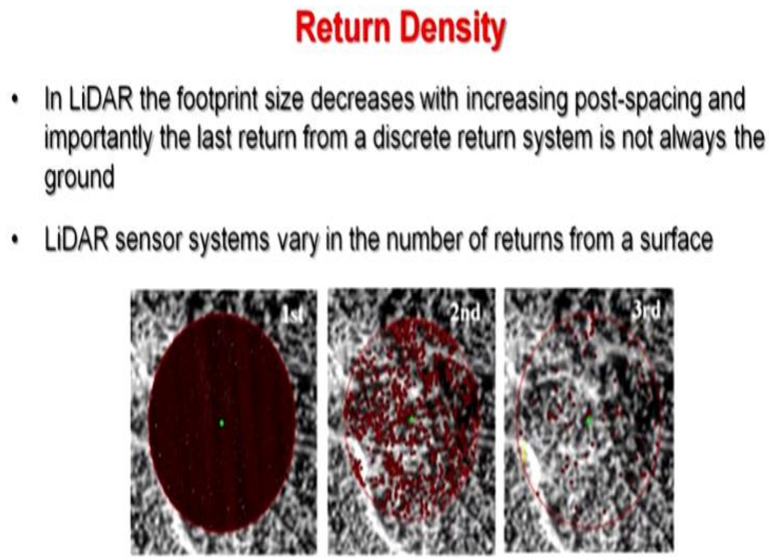

That here this is the first return which is coming then you are having in second return you are having many you know point data is there and then in the third you are getting this very few here. So likewise you get the data in that

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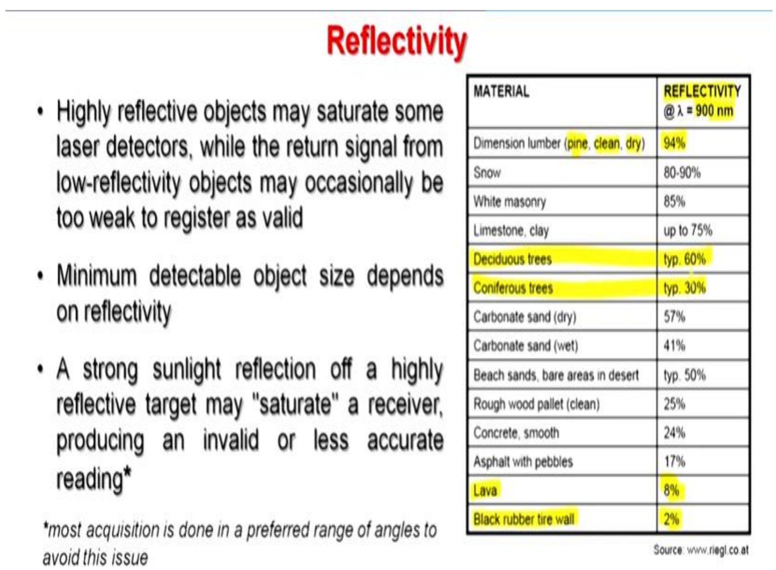

MATERIAL	REFLECTIVITY @ λ = 900 nm
Dimension lumber (pine, clean, dry)	94%
Snow	80-90%
White masonry	85%
Limestone, clay	up to 75%
Deciduous trees	typ. 60%
Coniferous trees	typ. 30%
Carbonate sand (dry)	57%
Carbonate sand (wet)	41%
Beach sands, bare areas in desert	typ. 50%
Rough wood pallet (clean)	25%
Concrete, smooth	24%
Asphalt with pebbles	17%
Lava	8%
Black rubber tire wall	2%

Now there is another thing which has to be considered is the reflectivity because of ultimately the pulses which are sent towards the ground or towards the slope or any building has to be returned will depend on the reflectivity. So this highly reflective objects may saturate some laser detectors while the return signals from row reflectivity objects may occasionally be to be to register as valid signals. So that kind of different materials are shown here and their reflectivity at the rate of Lambda which is generally used 900 nanometer wave length at 99 nanometer.

And what you use see that you know if you are having pine or tree or you are having clean or dry surface 94% reflectivity is there if you are having black rubber tire wall then the reflectivity is 2% if you having Volcano lava may be 8% and the deciduous trees will have a different reflectivity. Coniferous trees will have a completely different reflectivity so based on the reflectivity also one can use a 2 deduct different objects also.

So minimum deductive will objects size and depends on reflectivity and also the resolutions has been selected. So strong sunlight reflection of a highly reflective target may saturate a receiver and may produce an invalid or less accurate reading for the recorder. So that may create and most acquisition is done in preferred range of angles to avoid this issues so that the sun lighter direct reflection does not come and during the these kind of data acquisition service.

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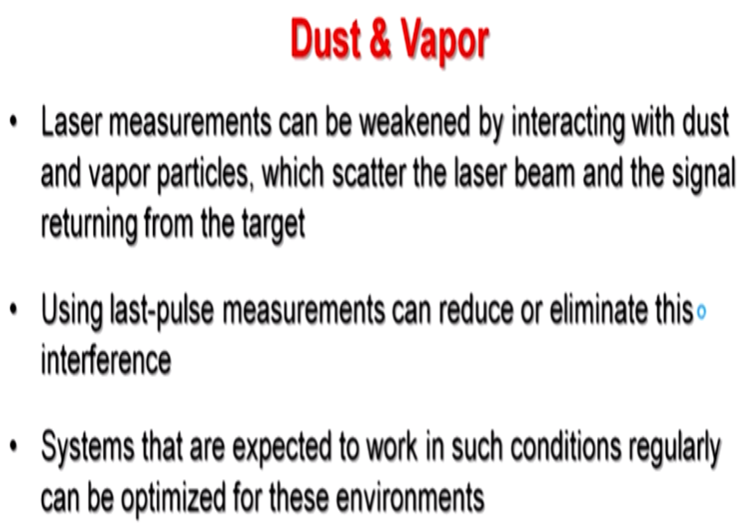

And there are some other distortions like in normal remote sensing like a dust and vapors can also being some distortions and spatially this may be may create problems in airborne LiDAR or even in terrestrial LiDAR is there being used in mining or in a tunnel or other excavation. So because of high density so these laser measurement can be facted weak and wide interacting with dust and vapor particles and because of its scattering of a laser beam and the signal returning from the target.

So 2 ways it will affect because when emitter is a emitting the laser beam at during that time it can become weak to reach to that selecting surface and when return being comes to the receiver or again it has to pass through the same dust and vapors can create a weak signals. So using this last pulse measurements which can reduce or eliminates this interferences some corrections techniques are there by which this scatter affects of dust and vapors can be minimized.

And it is expected to work in such conditions regularly which can be optimized for these environment. So if a systems are have to be used regularly in internal which is full dust or may be water vapors then these things can be optimized depending on the environmental conditions there.

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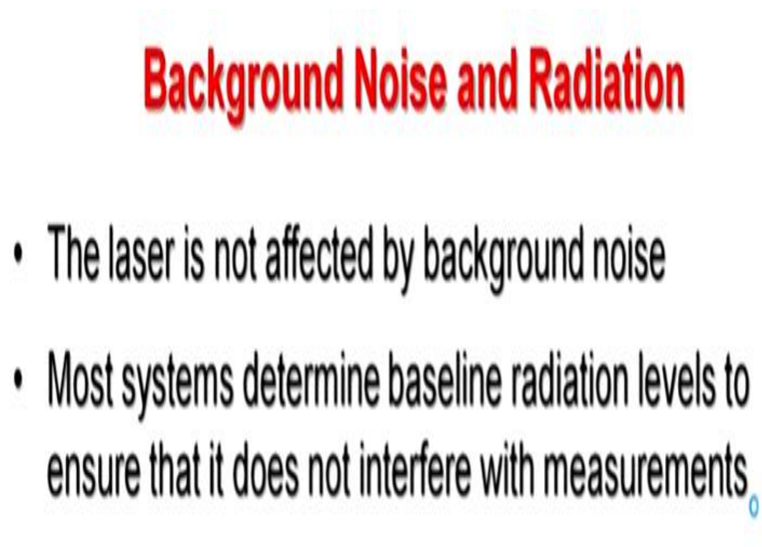

There might be some background noise and radiation which may again affect your laser. So though generally laser is not affected by background noise but more system it determines baseline radiation levels to ensure that it does not interfere with the measurements.

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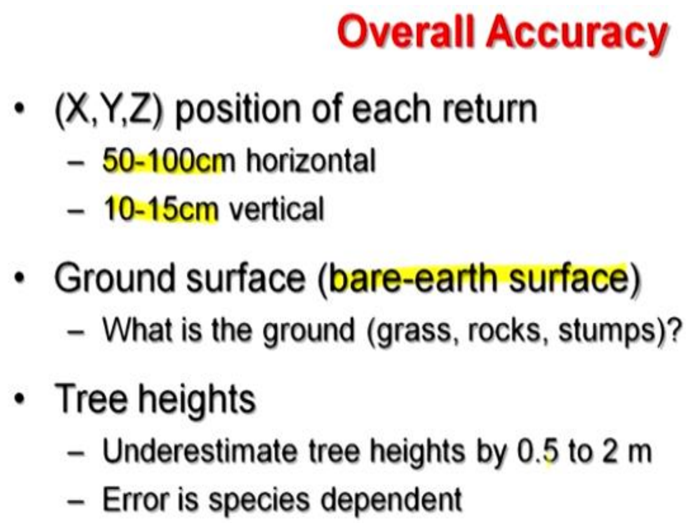

Now accuracy over all accuracy that is X, Y, Z position of each return and of coarse these are very you know general terms this 2 accuracies horizontal and vertical are given and these are improving. So one may find a better systems better results by these accuracies but what a accuracy you get in return is 50 to 100 centimeter in horizontal and 10 to 15 centimeter in vertical. So suppose somebody as gone for digital elevation model then 1 meter spatial resolution digital elevation model can be created and that digital elevation model will have accuracy of 10 to 15 centimeter which is anyways very high compared to what we get through normal remote sensing techniques.

So in that way it is definitely of coarse there are a limitation and the cost effectively should also be seen when we compare these 2 completely different techniques. This is 1 advantage which I have been mentioning repeatedly that the bare-earth surface it is possible that the airborne LiDAR that we can have a digital elevation model without any objects without any trees or other things so that is the bare-earth surface can be created without these things tree heights can also be determined with the very good accuracy of 0.5 to 2 meters.

And of coarse due to different types of trees that species dependents where air is basically is species dependents if it is coniferous trees it is different reflectivity, different accuracy if it is deciduous trees it is different reflectivity, different accuracies.

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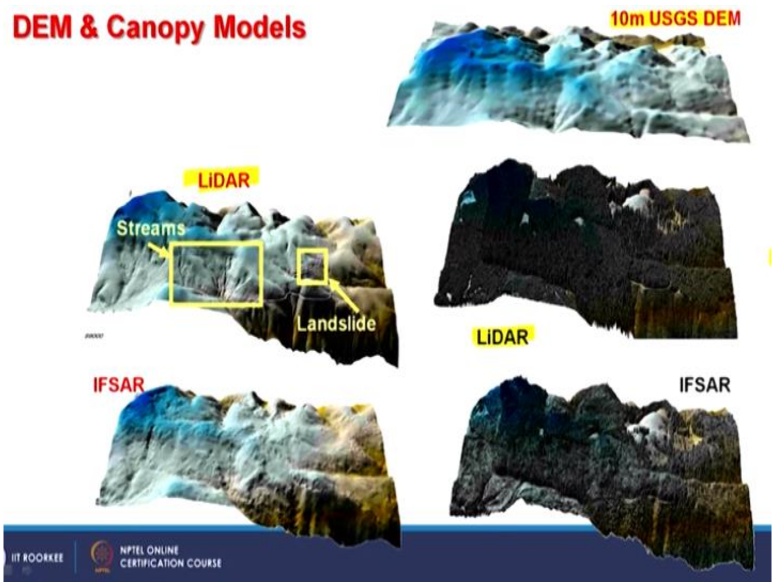

Now few examples of a digital elevations models are shown here based on LiDAR and with comparison with the INSAR or IFSAR. Like if I start with the top right that is 10 meter USGS digital elevation model though this digital elevation model is not available at global scale but this figure we can still use of part of US. And what we are seeing for the LiDAR what we are seeing that this is also having the vegetation covered which you can see in the this right middle figure.

And then if involve the IFSAR then this kind of digital elevation model one gets that is based on the LiDAR technique interferometry technique. And the LiDAR can create a surface or bare ground surface so here this is the input image and then you are seeing here the DEM so which is on let side you are having digital elevation models also this 10 meter on the top also. But then these 2 this one and this one are the canopy models of the same area.

As you can see in case of LiDAR based digital elevation model a many ground features or land forms can be identified very easily like here the stream individually streams can be identified which is not possible in this example by using IFSAR or of coarse not with 10 meter spatial resolution USGS DEM. And if you are having Canopy cover of coarse everything is hidden beneath the trees that cannot be either deducted.

And now what you are seeing also the land slide in LiDAR deduction of landslide which is again not possible in IFSAR and DEM or 10 meter USGS DEM and of coarse you are having Canopy models you do not see any such landslides LiDAR. So the advantage with LiDAR as you can realize is a very clear that these are the things which otherwise one would miss in other techniques is possible to deduct using LiDAR.

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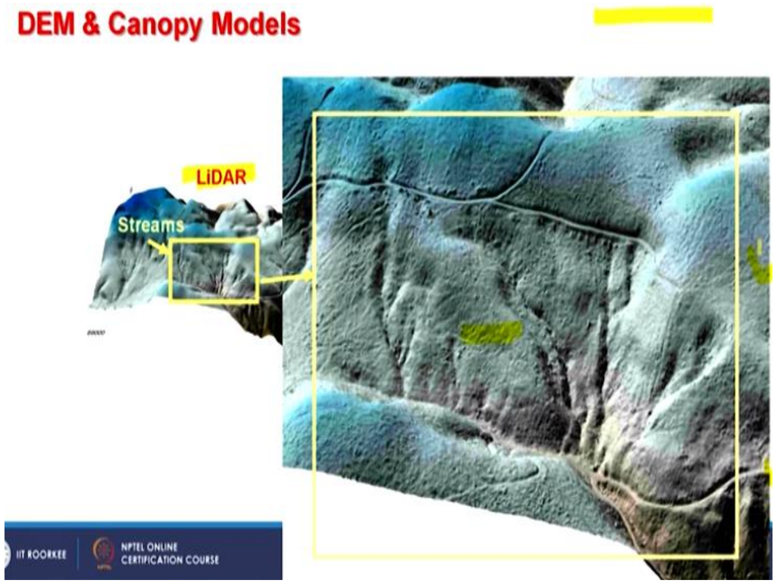

And this is blow up of those things that individual streams can be identified here.

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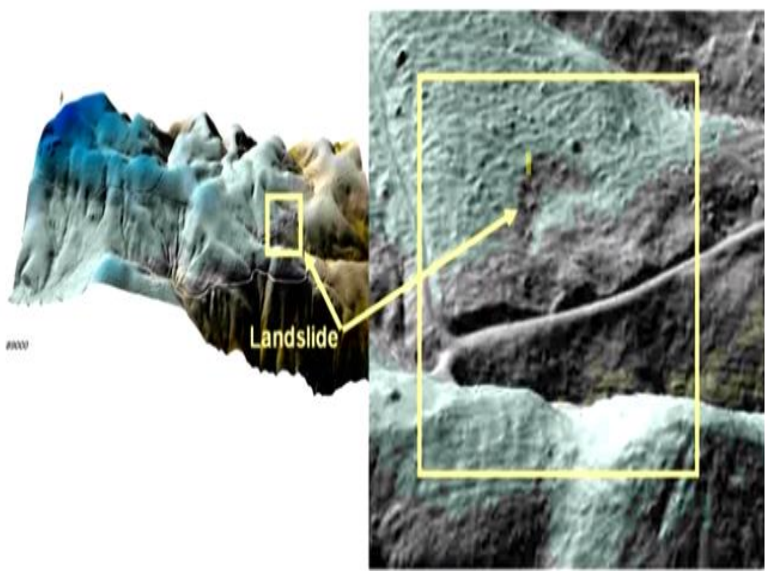

And same with the landslides that very clearly one can see a land slide when you blow up a that part of a digital elevation model that is in 3D prospective. So careful study of such surfaces can give the idea as such a slope movement well so it has got really very good application.

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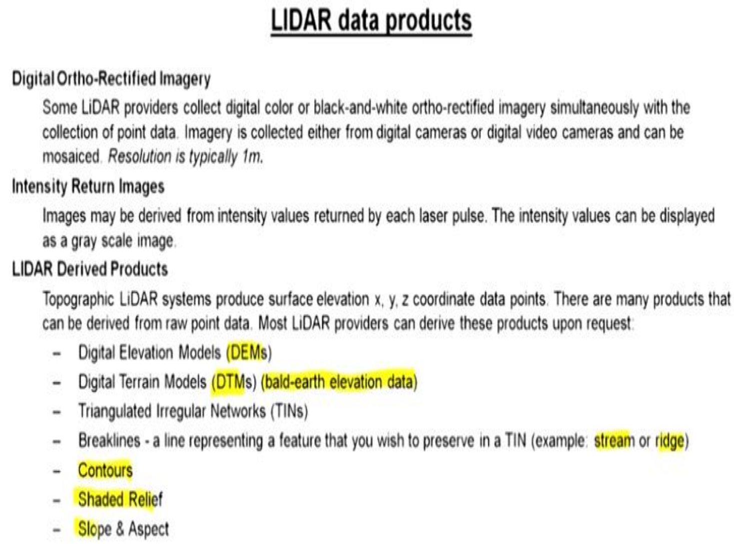

Now what are the LiDAR products which are available may can be made available though one global skills such things are not there like digital ortho rectified imagery are there some LiDAR also provide digital color black and white ortho rectified imagery simultaneously with the this point clouds and then of coarse intensity return images are also created by the LiDAR derived products are many.

One example you have already seen the digital elevation models is once you are having the data you can drive a digital elevation model at a very high spatial resolution and relatively very high with the very high accuracy. Digital terrain models this is a the digital elevation models which are created using your conventional remote sensing or LiDAR remote sensing and those are having whatever on the surface of the earth on the ground whatever I have (()) (35:14) the elevation values are having that part included. But here this bald or where ground elevation model is possible as you have seen earlier in the example.

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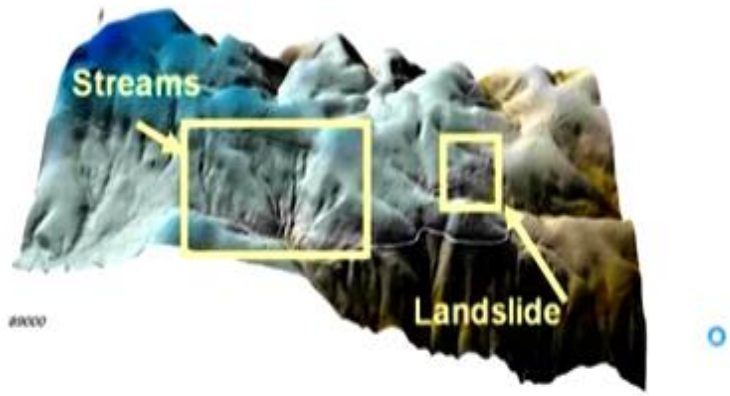

That here what you are seeing that without canopy a bare ground digital elevation model can be created. And then of coarse TIN which is again a representation of a surface continuous surface can also be created because originally LiDAR collect the data in point form. And using these points one can do the interpolation and one can use this points to create it TIN as well Triangulated Irregular Models which we have discussed in our earlier lectures.

And brake lines also which are line representing feature that one was one wish to preserve in TIN may be stream or a ridge or a (()) (36:21) line in those things can also be deducted quite easily can be derived from LiDAR products or LiDAR data. Of coarse once it is still elevation model or DTM digital terrain model can be created so contours can also be derived out of that. And once you are having this digital elevation model or DTM you can also drive your shaded relief model or (()) (36:49).

And there are lot of derivatives of digital elevation models which are discussed in GIS lectures or coarse and very you know early outputs of digital elevation model or first outputs of DEMS or DTMS or slope and aspect. So here also one can derive those as well.

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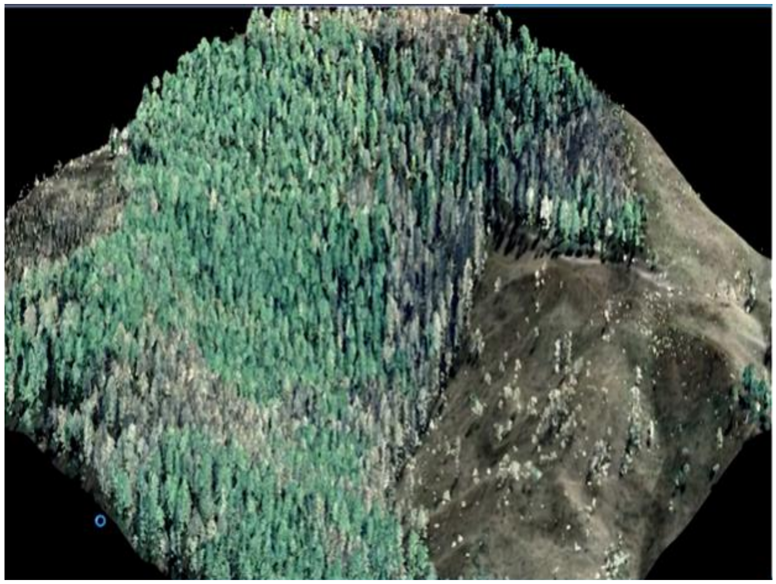

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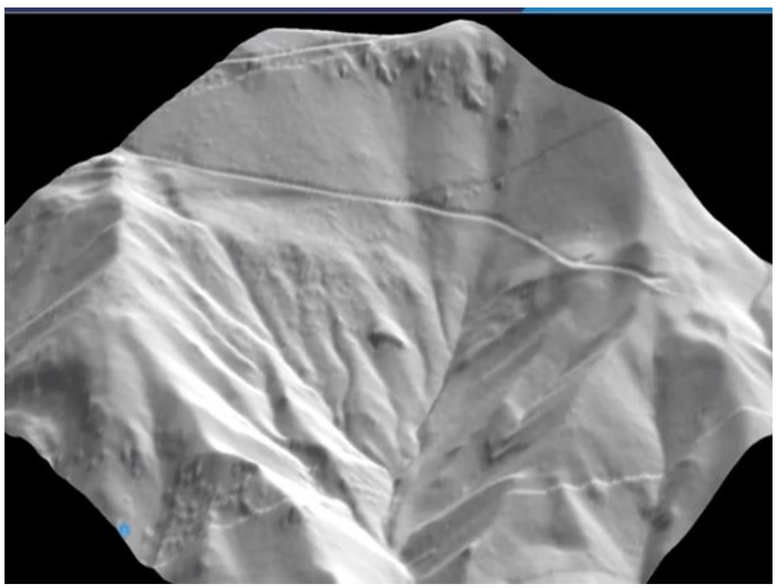

Now one example here with canopy which you are seeing a you know after laser survey this has been created and since the data is the because it records not only the top of the canopy but middle and the bare ground also. Whatever is get the lead return or the last return and using that you can remove the vegetation completely. So here with vegetation or with canopy that terrain is with canopy and once that is removed then you get it so this you can call as the DEM or real terrain condition and this is a completely digital terrain model without any canopy or without any other features.

So completely involved or bare ground surface and of coarse this has been this is a shredded relief model and (()) (38:18) so near 3D prospective. But if one is studying doing some water sand management or any kind of work one would love to have a tile surface without any objects like vegetation or buildings or any other and this is how it is possible implying LiDAR technique. Now indirectly we have already discussed the sources of errors in LiDAR data but for completeness we will be going one by one about the sources of errors in LiDAR data.

You know the similar things are also in a normal remote sensing so many sources of errors are also common here and none the less during acquisition it is possible any wrong selection of swath or angle or anything that may results into the errors in your data sets.

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Processing may again create some errors like strip adjustments are there because after all if it is airborne then it has the object are the sensor is moving. If it is terrestrial then it takes the angle maximum may be 30 degree and may be during if I have to cover very large area which cannot be covered in 30 degree then there might be some adjustments mosaicking and other things may create some errors.

So selecting ground control points GCP's again the error might be there for because of requirement of geo-referencing and the thinning or making generalization in the data may also create a some errors may bring some errors in our data. Interpolations of coarse with because the data is been collected as point data so many times the choosing a wrong interpolation techniques are any interpolation technique may bring some kind of errors in the data in the results.

And of coarse at later stages of analysis and visualization and their might be some errors are there. Errors might be due to scan acquisition scan angle is a shown here that because the if it is slope in surface then the angle may create different kind of appearance of objects and that may create some errors in the data.

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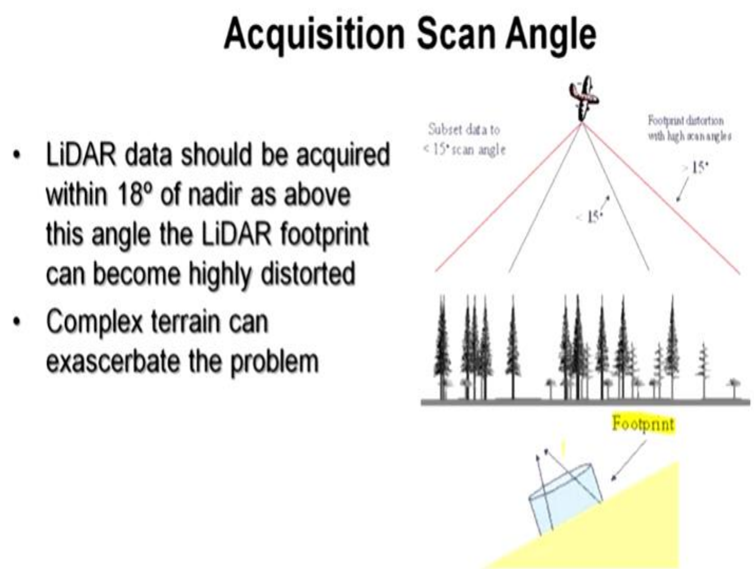

So LiDAR data should be acquired within 18degree of nadir and we cannot go beyond this angle because the LiDAR foot print become highly distorted as shown here in this example here. And as this angle is more the large error will erupt in our data set. Complex terrain can exaggerate the problem this problem can become bigger in terrain like Himalaya which is highly rugged and dilating terrain where things can become very difficult.

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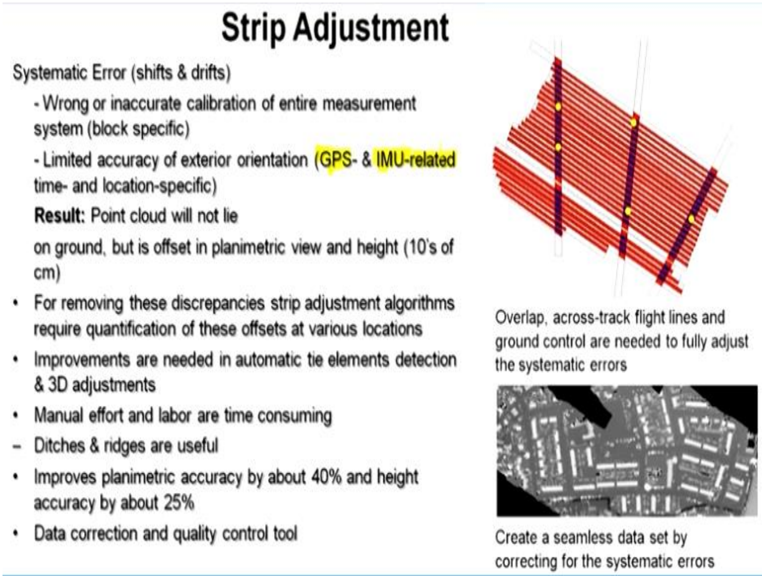

When we get the data this is strip adjustments can also be there in that (()) (41:54) some errors so there are systematic errors again systematic errors can be corrected easily but there are some non-systematic errors and which is very difficult. Also if we are using GNSS and that is not giving good accuracy and then that can create problems by doing the processing or preprocessing the LiDAR data this moment aircraft related movement can all aircraft related movements cannot be fully corrected.

So they may leave some errors in our results also but as you know that point cloud will not lie so one ground but it is upset in planning metric view and height and that can create problem. And there are ways to some extent that these errors can be removed that discrepancies strip adjustment algorithms require basically quantification of these offset at various locations. So lot of if one go for very accurate output or results then lot of other data sets are also requirement and those data sets are to be recorded during the acquisition of originals survey that one as to remember.

So improvement are basically needed as we go for automatic tie or ground control points deduction and 3D adjustments manual effort and labor are time consuming if we are having none systematic errors then this problems will come. Ditches and ridges are useful and which can help us to remove some of the errors and improves planimetric accuracy by 40% and height accuracy by 25%. So these can be created 2 limited errors but 100% errors cannot be removed all the time and data correction and quality control tools are there and which can be employed.

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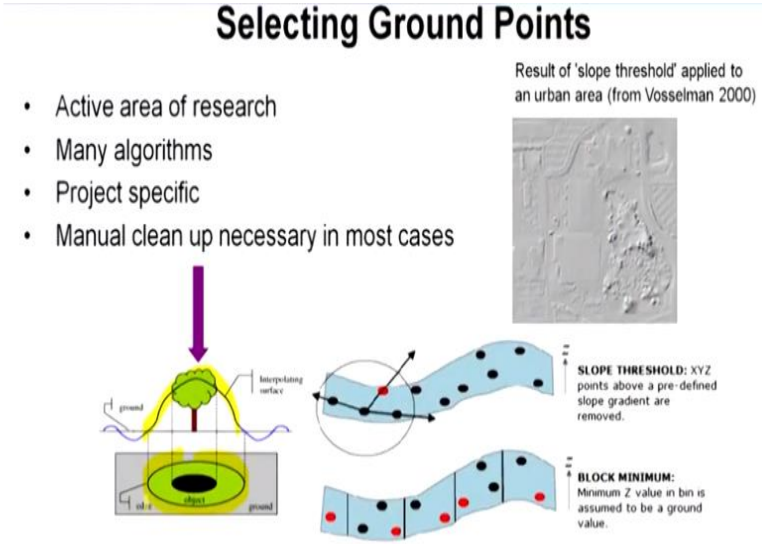

Now selecting ground points like here say mixed kind of data collection is there so whether you would select this much area like here or only this much area. So that is basically will go ultimately in your results so the slope threshold apply to the urban areas as in this example and depending on the requirements. So active area of research how to make LiDAR technique more accurate more reliable and you know less expensive cost effective. Many algorithm are being developed to improve on this and there are many times project specific things are being developed and of coarse manual cleanup also necessary in many cases to remove the errors.

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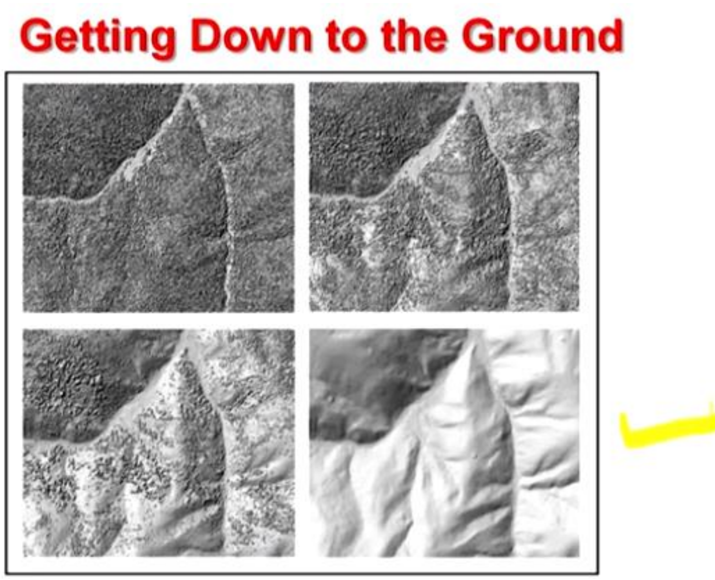

Now one of the examples here is that you having a completely forested part one can get rid of certain objects and finally completely bare ground digital elevation model can be created of that area.

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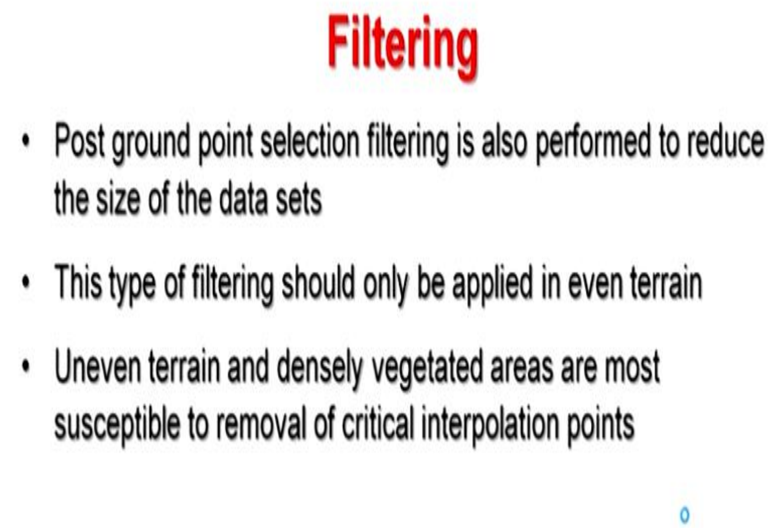

There are some other processing techniques like in our normal digital image processing techniques filtering here also filtering but different kind that once this ground point selection is done the filtering is performed to reduce the size of data sets and this type of filtering should only be applied in even terrain. But if terrain is high ruggered then such filtering is should be applied because in highly rugged terrain each and every point is important to preserve the ruggedness of a terrain.

But if it is a flat terrain then there might be redundancy in the point data and therefore some kind of filtering technique applied to reduce the size of the data. Uneven terrain and densely vegetated areas are more susceptible to remove more critical interpolation points and their one should note really apply the filtering.

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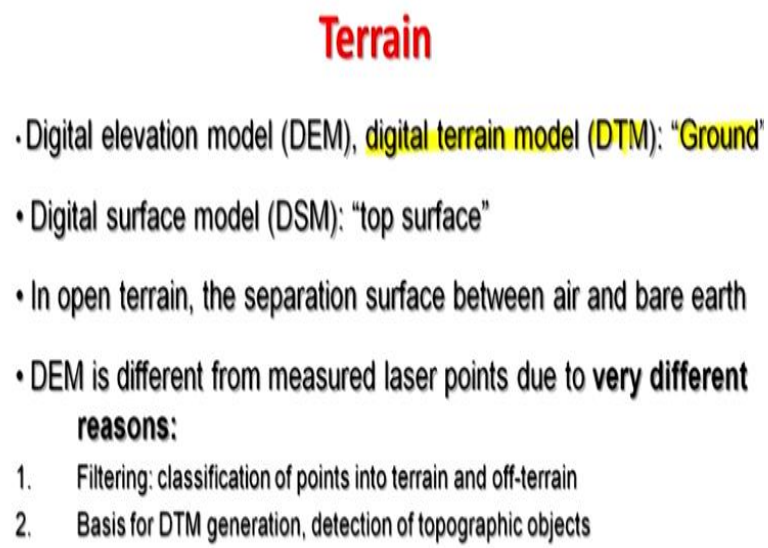

Now digital elevation models and digital terrain models where the ground is so here when say digital terrain models the ground part is here otherwise in digital elevation models as discussed it is also having canopy cover. There is another term which is used also in GIS which is called digital surface model that is the top surface that is above the canopy and digital terrain model is below the canopy.

So when we want to do some series things on using ground surface or terrain model then this DTM is the most useful and reliable then digital elevation model or DSM. Using LiDAR based airborne service it is possible to create all three that is DM, DTM and DSM whereas DTM and that is digital terrain model that is the bare ground surface is the most important in many applications.

In open terrain where you do not have lot of ruggedness the separation between the surface between the air and bare earth is good and then DM is different from major laser point and due to very different reasons. Filtering classifications of point into terrain and off-terrain and then basis of DTM generation that is detection of topographic objects.

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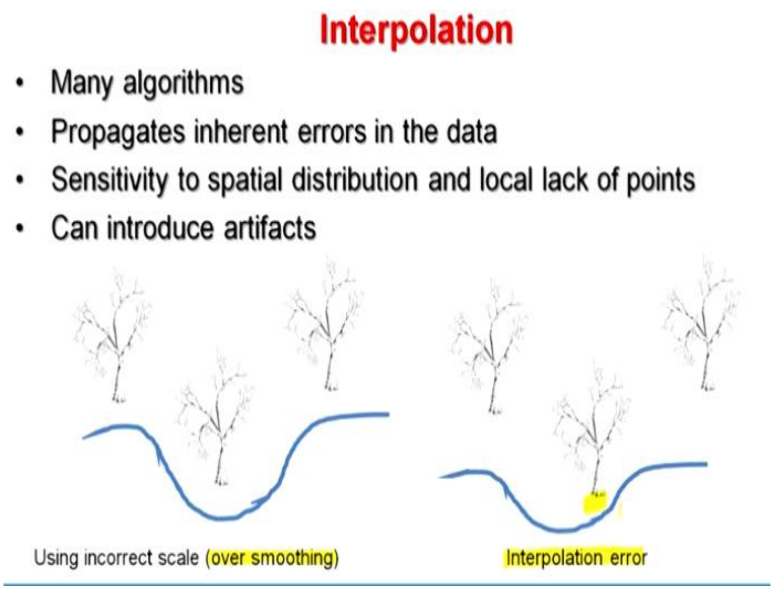

Like here there might be that using incorrect scale and over smoothing has been done for the terrain and here the interpolation error which has shifted this tree instead of here it has here so lot of errors many algorithms are there which propagates inherent errors in the data that is always true that propagates in processing also and sensitivity to spatial distribution and local lack of points ground control points is (()) (49:20) not there might be errors something like this which you are seeing here. And can introduce some artifacts also and in during the interpolation.

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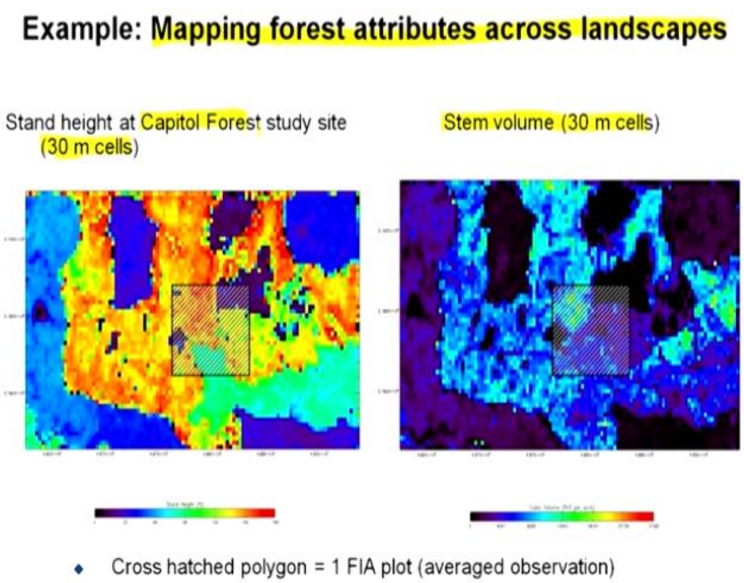

Here is one example of mapping forest attributes across landscape here stand height at a capital forest side is 30 meter per cell and what you are seeing this stem volume is 30 meter cell here. So this 1 plot which is marked here will give a different results across different land scape. But here what we are seeing that mapping forest attributes across land scape so one area has been so here the forest capital forest and this is the stem volume how much volume that can also be calculated using LiDAR technique.

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Other Considerations

- LiDAR derived DEM are not often hydro-corrected so as to ensure a continuous downward flow of water (no Digital Line Graph (DLG) hypsographic and hydrographic data)
- Water creates a natural void in LiDAR data and manual addition of breadlines is necessary
- This type of processing is feasible with LiDAR data but it adds cost

There are some other more few more points which we need to discuss related with LiDAR that digital elevation model which we drive using LiDAR are not often hydro-corrected as to ensure the continuous downward flow of the water. In a digital elevation models which are created using different techniques in normal remote sensing. Sometimes they are having these issues are not as big as incase of LiDAR that hydro-correctness of a downward because digital elevation models are used for surface hydrologic modeling and in which it is assumed that whatever even a single drop of terrain even it occurs it will flow to an outlet.

So that means the surface which is being created based on LiDAR should have that characteristics that it should have should be hydro logically corrected that means the water should flow downward at that to the outlet. So these things are important while using digital terrain models so digital elevation models which have been created through LiDAR technique. Now because if water is present on a surface then water creates a natural void in LiDAR because of the absorption of LiDAR beam and manual addition of breadlines is necessary that use manual correction sometimes may require in your data set.

And this type of processing is possible with LiDAR but definitely it is time consuming may require come techniques and it will add some cost to it.

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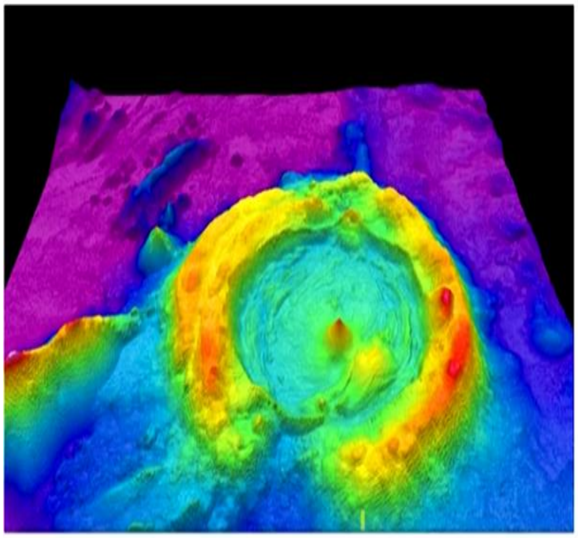

Airborne Lidar Bathymetric Technology-High-resolution multibeam lidar map showing spectacularly faulted and deformed seafloor geology, in shaded relief and coloured by depth.

Now few examples are here airborne LiDAR Bathymetric is here high resolution which is Bathymetric technology very high resolution multi beam LiDAR map showing spectrally faulted and deformed seafloor which you can see here and of coarse it is a colored shaded relief model it has been shown in that form. So definitely the surface is which are created by the LiDAR's are highly useful because of high spatial resolution high vertical accuracy whether it is for surface or for under the water as here the Bethymetric example is shown here.

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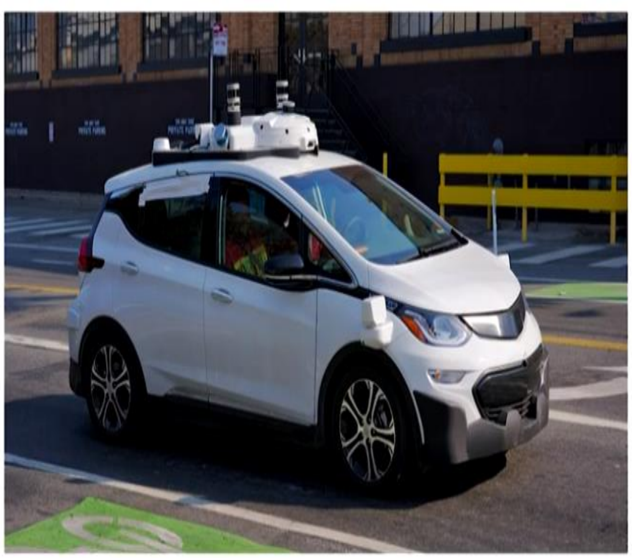

Cruise Automation self driving car with five Velodyne LiDAR units on the roof.

I was mentioning about an very small mansion was there in the beginning while discussing about the applications of LiDAR is in case of autonomous cars or this is that example is here that the cruise automation or driver less cars in which LiDAR technique is being used extensively and lot of research brought over is taking place that how to make a vehicles completely driverless in trying all kinds of techniques not only LiDAR but GNSS techniques GIS techniques and many communication techniques and so that the first of coarse the essential condition here is that no accident should happen and they should not be harm (()) (54:36) to any human on the road or texture or to the car.

With those conditions such autonomous vehicles are being developed which is fine examples of a integrated technologies including as I mention LiDAR including GIS including communication and of coarse GNSS technologies this is one of the example may Google has also developed this is an other example from that one. And now we will just going through a quick comparison between traditional photogrammetry versus LiDAR because LiDAR is a laser based so therefore it is possible to do in day and night time whereas traditional photogrammetry is done only in day time.

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Traditional Photogrammetry vs. LiDAR

LiDAR	Photogrammetric
Day or night data acquisition	Day time collection only
Direct acquisition of 3D collection	Complicated and sometimes unreliable procedures
Vertical accuracy is better than planimetric*	Planimetric accuracy is better than vertical*
Point cloud difficult to derive semantic information; however, intensity values can be used to produce a visually rich image like product (example of an intensity image)	Rich in semantic information

And direct acquisition of 3D collection is possible with LiDAR but in case of photogrammetric it is complicated and sometimes unreliable also because of lack of procedures and other things. Of coarse vertical accuracy in case of LiDAR is very good spatially then better than the planimetric accuracy and vertical accuracy incase of photogrammetric also be a good one of the examples of satellite based photogrammetry is using stereo pair data and creating digital elevation model.

There that is the satellite based but the ground based photogrammetry techniques are there aerial photogrammetric techniques are also there. And in case of LiDAR this is plan point clouds which is difficult to drive semantic information however intensity values can be used to produce visually rich image like product example of intensity image can be create using LiDAR. But a photogrammetry is definitely rich in semantic information.

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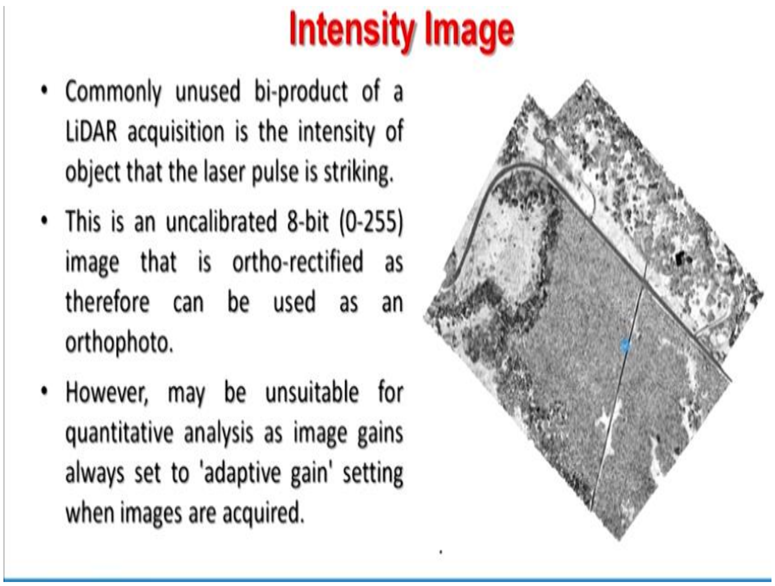

Now intensity image example is shown here that LiDAR intensity can be used here like in your LiDAR remote sensing also intensity images can be used. So this is a generally unused byproducts of LiDAR acquisition is the intensity of the object and that the pulse is striking and this is un-calibrated the example here is 8 bits image though it is ortho rectified and can be used at ortho photo for any other applications.

However it may be unsuitable for any kind of quantitative analysis because as image gains always set as adopted gain settings when images are acquired. So these are having some limited applications there.

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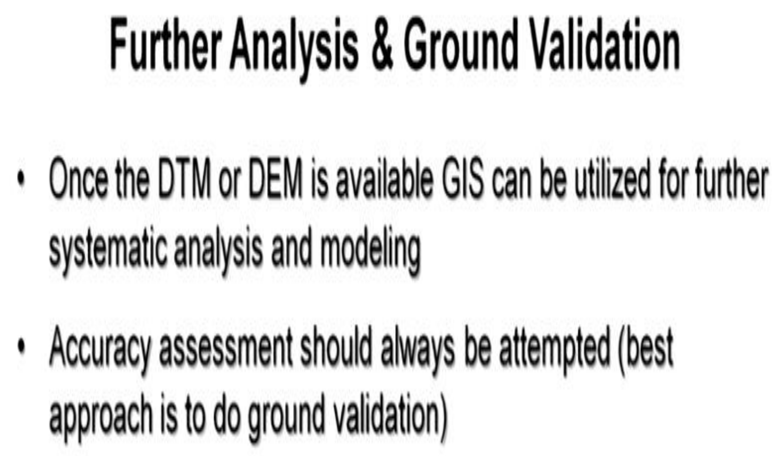

Now there are further analysis which can be done using a LiDAR based products once the DEM or DTM are available then one can employ this in GIS for further analysis systematic and other modeling’s systematic analysis and modeling. Accuracy assessment is always challenging in every technique so in LiDAR that should always be attempted one accuracy assessment which we have discussed while discussing in the supervise classification also.

So everywhere that has to be done so that the best way like in supervise classification ground trothing or ground validation so here also ground validation will require. So this brings to the end of this discussion about LiDAR applications limitations and error part and how this can be minimized and main is mention that LiDAR provides a bare ground surface which is very useful in many application and that too at a very high spatial resolution and very high vertical accuracy however the cost is one thing and availability is another limitations may be else limitation in certain projects. So this brings to end of this discussion thank you very much.