Higher Surveying
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Module - 7
Lecture - 24
LiDAR (LiDARgrammetry)

Hello everyone. Welcome back in the course of Higher Surveying and we are in module 7, LiDAR grammetry. In the last lecture of this module we have learned that what is a laser and how laser can be used in order to collect the topographic information, ok. And then we have seen two forms, one is the wave and another is the pulse.

Wave is the continues emission of the photons like a continuous turning on of a torch, right. Secondly, the pulse is some collection of photons over a short duration, and that is why when pulse is triggered we have some number of photons, which are compressed or which are sent over a very short duration and as a result we can compare this phenomena by turning off the torch and turning on the torch continuously. So, during the turn on time we have thrown some number of photons in very short duration and that is what we call the pulse, ok.

Based on the pulse we have defined a principle called time of flight principle where pulse will be triggered from transmitter, and it will travel through the space it will interact with the object surface and it will be reflected by the object. The reflected pulse will be again received at the receiver, and the time between the triggering and the receiving is called the time of flight. By measuring the time of flight we can measure the distance between the transmitter and the object, or we can measure the distance between transmitter receiver assembly and the object surface. Well this was the time of flight principle.

On the other hand we have the phase base principle that we employ with the waves. In case of phase base principle what we do? We measure the phase difference of the trigger pulse we measure the phase difference of the triggered wave and the received wave. So, that was the principle.

Moreover, in case of pulse since the energy or the power of photons is triggered in very short duration and because of that we have very peak energy or peak power of some photons and because of that we know one thing now that pulse can travel for a long distance because it has high peak power. At the same time wave which has each and every photon of which has small energy, and that is why although the phase based at measurement is more accurate but sees the photons of the wave cannot travel for a long distance. And as a result we say that we will use the wave for a shorter distances and we will use pulse for a longer distances that means, you will use the pulse for the topographic mapping if the distances in order of 500 meter, 700 meter or may be 1000 meter or more. So, that was the idea we have developed in the last lecture.

Moreover, then we have seen that if pulse or a wave is triggered how to measure the power or the energy of the reflected pulse or reflected wave. By that we see that if the reflected pulse energy or power is less than certain threshold we will ignore it or if it is above certain threshold we will accept it, and we will say that yes we have received the reflected pulse from an object surface. So, by measuring the power of the reflected pulse we will say, yes first of all we have received the reflected pulse and then we will say that what is the time difference between the triggered and the reflected pulse. So, using the time of flight you will find out the distance that we have learnt in the last lecture.

So, let us learn that how to acquire the data of the topography or the topographic surface using LiDAR. So, in this lecture we are going to discuss about the LiDAR data acquisition using pulse, mainly pulse, ok.

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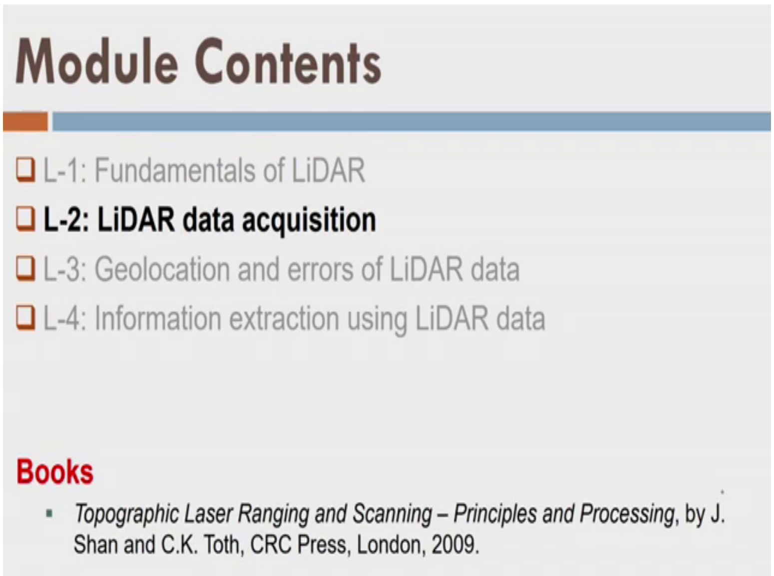

So, this lecture is my lecture 2, and it is LiDAR data acquisition fine, ok. The book is (Refer Time: 05:01) same, fine.

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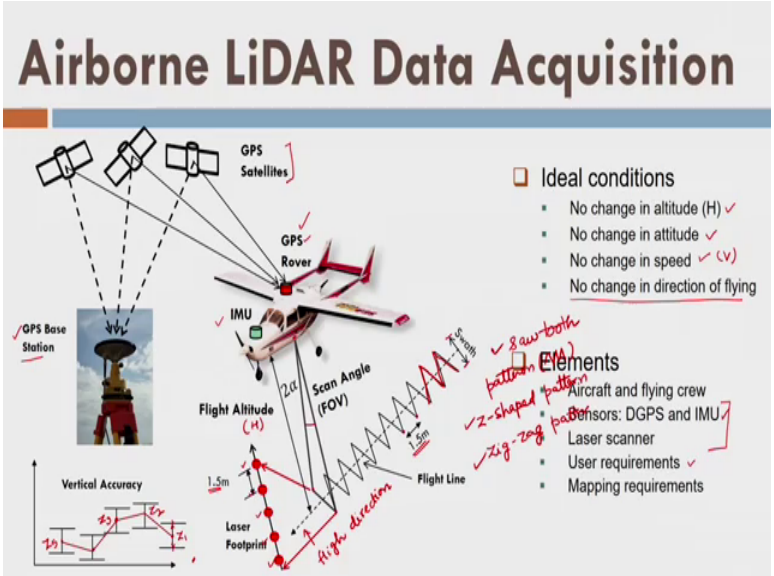

Now, this is an typical example of Airborne LiDAR Data Acquisition. Here I would like to specify that we are first going for the airborne LiDAR data acquisition, and we will see why we do it later in this lecture. In this slide it is shown a typical example of the airborne LiDAR data acquisition. You can see here that there is an aircraft and aircraft is mounted with the 3 sensors, one is GPS, another is inertial measurement unit or what we call IMU and third is the laser scanner, which is sitting at the bottom of the aircraft we are a made that dot, ok.

Now, you can see here that there is a base station on the ground surface of GPS, and using the principle of differential GPS and calculating the position of the aircraft trajectory using GPS rover mounted on the aircraft fine, ok. So, we are showing here some GPS satellites to indicate the differential GPS positioning.

Secondly, if you look at the IMU inertial measurement unit it is measuring some angles that is the attitude angle of the aircraft motion. So, we call it the roll pitch and yaw around certain accesses it is measuring, right. Thirdly we have the laser scanner and we are showing that, it is triggering the laser pulses using time of flight principle and for each pulse it is measuring the distance between the laser scanner and the ground surface and so here is a ground surface. So, now, we can see here that there is a some pattern in the z shape or sawtooth pattern of data acquisition on the ground surface. So, it is like sawtooth or we also call Z shaped pattern or you also call zig-zag pattern, right. So, there are 3 names 1, 2 and 3, right. So, all 3 names are indicating this pattern of the data acquisition, ok.

So, this is the flight altitude of my aircraft which is shown by the arrow here. Now, this is the sawth which is the width of the list data acquisition across the flight line. So, this is the flight direction here or what we call direction of flight line. Now, this 1.5 meter here it is showing you the spacing of the two data points here and here, right, ok. Then if I just take one particular line for example, this line from here to here I can see here that it is acquiring these many number of pulses 1, 2, 3, 4 and 5, each pulse is creating some footprint on the ground surface, right, ok.

So, that is creating the horizontal in accuracy or horizontal uncertainty of the each pulse data of LiDAR. Now, so we are writing here laser footprint fine and this is the spacing 1.5 meter which is existing between the two points in a line. So, there you can see there are so many lines here and now in each a line we have let us say 5 number of points of 5 number of laser pulses are hitting the ground surface and they are reflected back by with the ground surface and now so we are recording the coordinates of each and every pulse point, right.

So, now we can see here that this is the vertical accuracy showing here these boxes from here to here, some kind of vertical accuracy is there z with respect to some data, right. So, let us say z 1, z 2, this is z 3, z 4 and z 5 here, right. So, these are the indicating the height elevation of a point with respect to some datum surface. And now this is indicating this is indicating the uncertainty in the z value of the topography point or the point on the ground surface. Well, so this is the kind of typical example of an airborne LiDAR data acquisition. Now, so what is the ideal conditions here? The ideal condition is that we should not change or there should not be any change of the altitude or the flying height what we call here the flying altitude capital H here.

So, it should not change that means, an aircraft should always fly at a constant height with respect to the ground surface. Further they should not be any change in the attitude which means we say that there should not be any change in the attitude, which means aircraft should not vibrate like this. So, there will not be any change in the attitude or the roll pitch and yaw values of the aircraft.

The third thing is we should not change the speed that means, aircraft is moving a certain speed it is always move with a certain speed only let us say this speed is V. So, we should maintain the speed now. So, only, ok. Now, there should not be any change in direction of flying which means if aircraft is flying in certain direction with respect to north it should always fly in that direction only, and we will see in coming slides why do we expect these kind of ideal conditions, why do we need it, right, ok.

Now, you can see that there are few elements in this airborne LiDAR data acquisition the first is the aircraft and the flying crew. So, flying crew is ensuring that there is a smooth operation of the flying operations and then desired quality of the data should be obtained and that is why they ensure that they should be a smooth operations of the flying, right. Then we have sensors we have DGPS we have IMU and we have a laser scanner. So, these are also be participating elements of my airborne LiDAR data acquisition third thing is the user requirements. For example, if you are a user of the LiDAR data and you have higher some agency to acquire the airborne data you will definitely ask for certain quality of the data, right and those qualities are called the user requirements.

At the same time there are some mapping agencies for example, survey of India or we have United States Geological Survey in USA. So, such agencies they also demand some kind of requirements or they also imposes some kind of conditions. So, that this client as well as the data acquisition party both will be having the standard operational procedures and by following those standard operational procedures they will be acquiring the data of certain quality. So, both party should fulfill those things, and that is why we called an mapping requirements, right, ok. So, we should understand that what are the roles of these elements each and every element.

So, that must understand these elements each and every element then we can ensure that what kind of quality we want and how to ensure that quality of the data, right.

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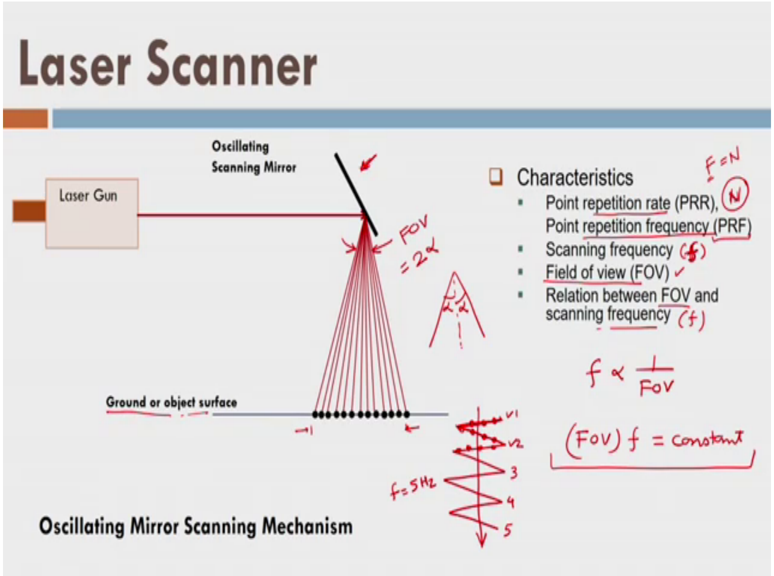

So, let us go ahead and first of all let us look into the first element that is my instrument or the sensors. The sensors are IMU, GPS and we have the laser scanner.

Now, we will talk about the laser scanner because laser scanner is the first and fundamental instrument that is firing the laser pulses towards the ground surface. So, what are the characteristics of the laser scanner? So, I am showing in the screen one laser gun or an overall construction or overall setup of the laser scanner. In the laser scanner there is a laser gun and it is continuously firing the laser pulses, ok. So, laser pulses are continuously interacting with the mirror which is shown here, right.

So, this mirror is oscillating like this it is oscillating and this is the laser gun like that, so right. So, you can see here this is the laser gun and it is oscillating. So, laser pulses are coming this way and this mirror it is diverting the laser pulses toward the ground surface. And as a result if it oscillate like this, so it will be diverting the laser pulses in multiple directions not in A 1 direction, right. And because of that what will happened? I will have some series of points on the ground surface in one line as we have already shown that there are 5 points, and these 5 points are available because of the motion of the mirror, right. So, this is a reflecting mirror and now we can see in animation how does it work.

So, there is a ground surface, right and there is a laser gun there. So, let us see laser gun is firing the pulses and now I am showing the oscillation of the laser scanner, like this. So, it is continuously oscillating laser gun is also firing the laser pulses continuously we are, so continues series of laser pulses fire towards the topographic surface, right. So, now, what is happening here? So, these pulses are sent or fired from the laser scanner towards the ground surface and as a result we get so many number of pulses on the ground surface and once the ground surface reflects those pulses towards the scanner. So, receiver receives those responses and try to record them, ok.

Now, you can see here very easily that this length is called the swath, right, ok. We will talk about all this parameters gradually one by one, ok. So, what are the characteristics of the laser scanner? Let us try to understand this, ok. First of all in the last lecture we have said there are some N number of pulses that can be fired by the laser scanner or by a laser gun in one second.

So, this N number of pulses those are fired in one second we call it point repetition rate or point repetition frequency. PRF is more popular name for this capital N moreover in this lecture and further in this module we are going to indicate PRF by F symbol, right. So, we can say F is equal to N here, right then we have scanning frequency, ok. As we know that F number of pulses are fired in one second by an oscillating mirror and laser gun combination, right. What does it do basically, ok? So, you see that there was a laser gun and it was oscillating like this perpendicular to the laser gun, right and now we can see here that it is not possible to fire all the pulses in one second. So, because number of pulses are very very high maybe 1 lakh or may be 70,000 or 30,000, something in this number, ok.

So, what is mirror does mirror is basically oscillating, right and it is diverting the pulses towards the ground surface. Now, you can see here easily that if I fire 1 lakh number of pulses in one second and this will be diverted with the help of scanner. So, there is a role of this scanner of this motion. And whatever number of cycles this is scanner completes in one second we call it the scanning frequency of the laser scanner and we indicate it by the small f.

So, I have this is, right and because of the small f what happens is we have certain number of lines what we call as the zig-zag motion of the, this one. In general I can say that the laser scanner always oscillates or the laser mirror oscillates in one line only. So, if my aircraft is stable or in a hovering at one point like a drone, right what will happen it will be creating only one line however, because of the motion or the speed of the aircraft it creates zig-zag kind of motion like this and this is the flight line, right.

So, I am showing now, one line here from here to here and that is call one scan line, right. So, now, I can see here that it is one complete oscillation of one mirror from this point to this point, let us say 1, 2, 3, 4 and 5. So, I have F is equal to 5 hertz because 5 times mirror has oscillated and as a result we got 5 number of lines of the data. So, each line contains some data like this. So, now, these data points are indicating the topographic information, right, ok.

What is the field of view? So, it is the maximum angle this angle across which all laser pulses are fired and that is what we called FOV, and we indicated by let say two alpha, ok. So, with respect to the vertical line if I have, so we have this is one alpha and this is another alpha. So, the two alpha is called FOV of the scanner, then what is the relationship between FOV and scanning frequency f, right.

Now, you can see here if this is my FOV and in the FOV a mirror is oscillating like this fine in order to divert the pulses, then what will happen? If this FOV is larger mirror has to travel more distance, right and since we have some limited power in an instrument and as a result we can see that if my FOV is higher or FOV is larger and so the mirror is traveling for more angular distance. And as a result I will not have higher number of scanning frequency that means, if a mirror has to travel for long distance.

It will travel for less number of times that means, if scanning frequency will be less and as a result now, I can write it that the scanning frequency and the FOV are inversely proportional. So, I can write like this, or I can also write now, FOV into F is equal to a constant. So, generally a laser scanner has this kind of characteristics and that is an additional characteristics that, we should always consider when we go for the airborne LiDAR data acquisition, right. So, let us go ahead with this idea that we have. Now, learn about the laser scanner.

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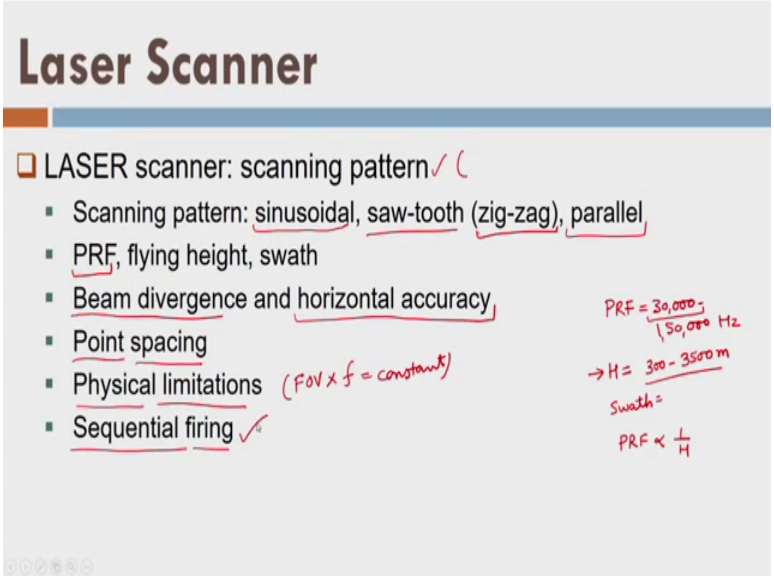

So, laser scanner has some more properties for example, the scanning pattern we have just talked about the one zig-zag pattern or the sawtooth pattern or the Z shaped pattern, ok. It can also create some kind of sinusoidal pattern or parallel pattern will see this patterns in the coming slides. Now, we have some point repetition frequency of the laser scanner.

So, point repetition frequency is generally in the order of 30,000 to 150,000 hertz or so many pulses in one second, flying height. So, flying height is indicated by H it is in general of order of let us say 300 meter to some distance like 3500 although but this flying height is regulated by the some mapping agencies also as well as some kind of civil aviation authorities also, right. So, we need to have some special permission in order to fly at certain height, right. Now, we have this swath and we have already indicated what is the swath and we will go for the mathematical formulation also of the swath in the coming slides. Then each and every laser pulse has some beam divergence and so it create some horizontal accuracy or horizontal uncertainty.

Then we have point spacing, ok. In the slide we have seen that we have two type of point spacing one is along the flight line and one is the across the flight line, right. We will see all the things in the coming slides. Then we have physical limitation that we have indicated, right. Now, that means, FOV into the scanning frequency equal to constant. So, that is the physical imitation here and then we have sequential firing. So, that is an another limitation we should always consider what is the meaning of sequential firing and what is the impact of that.

For example, if we fire let us say 30,000 number of pulses what will happen each pulse will go and interact with the object surface it will come back received at the receiver and then after that only will fire the next pulse, right. So, if we increase the height or increase the flying height each pulse will take more time to travel through this space and so automatically the number of pulses fired in one second or my ORF will be less. So, I can say that PRF is inversely proportional to flying height, ok.

There is one more reason for that and that we have discussed in last lecture also that since we need to have more power if I want to measure the larger distance so each and every pulse should have more power in order to measure the large distance. So, that once it travel through the space and comes back to the receiver it will have enough energy that is reflected from the object surface, and as a result we say if I have a limited power then I can fire limited number of pulses.

So, if I need to provide each and every pulse with a higher energy. So, it can travel in for a larger distance or larger flying height, what will happen? Automatically the number of pulses will be less if I increase the flying height. So, you should understand these two fundamental reasons. So, what is the impact of the sequential firing here, ok. So, now, we have understood what are the characteristics of the laser scanner.

So, now, let us understand the scanning patterns, that is created by the combination of the aircraft speed and the laser scanner movement. So, the laser scanner is diverting the pulses or throwing the pulses across the direction of flight.

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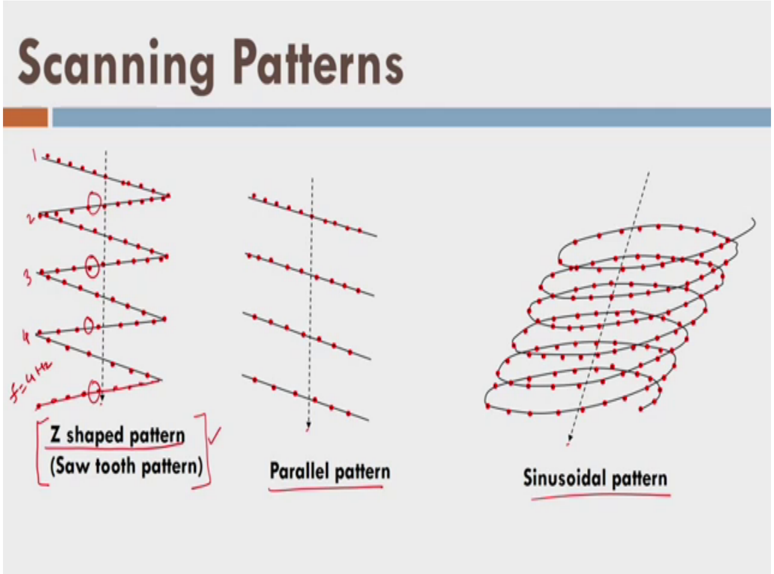

So, these 3 lines are indicating the flight directions, fine, all these 3. And now we are going to show you 3 patterns of the laser scanning, right. This is the first pattern where laser pulses are fired and because of the aircraft speed they are being collected in the Z shaped or what we call sawtooth pattern. So, this is the sawtooth pattern or the Z shaped pattern, right. So, these are so many pulses fired in one second. Now, we can see here that what is my scanning frequency I can see here that is let us say point 1, then point 2, point 3, point 4, right. So, we have 1, 2, 3; so and it is showing 3 and half. In fact, it does not happen generally we have complete 4 here. So, let us draw few more points here and it is my scanning frequency is F equal to 4 hertz here, right, ok.

Now, let us look into the next pattern that is parallel pattern. So, parallel pattern is like that where we have create parallel lines. So, now, we can imagine that in case of Z shaped pattern if we remove this lines alternate lines this line this line and then this line and this line I can create this parallel patterns. That means, oscillating mirror is acquiring the data in only one turn not in the return turn and we can have the parallel pattern apart from that we have one more pattern, which is called sinusoidal pattern where data is acquired in this fashion as aircraft is moving and laser scan is mounted over the aircraft. And so because of the movement of aircraft and laser scanning firing we can create this kind of pattern and that is called a sinusoidal pattern here, right see. This is the sinusoidal pattern we have created here.

So, these 3 kinds of patterns are possible to create also there are some other patterns also are possible. However, if you see that Z shaped pattern is most dense data collecting pattern, and so it is most popular among the all scanning patterns and so we are going to use this Z shaped pattern only in this lecture and again I can say that it is very easy to understand so ones you understand the Z shaped pattern or sawtooth pattern or zig-zag pattern then you can derive other patterns also.

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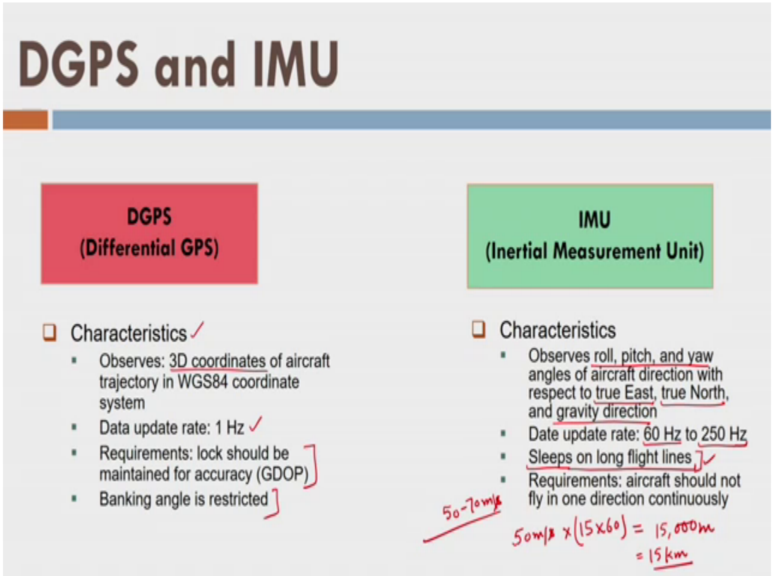

So, now, let us understand the role of the DGPS and IMU. So, DGPS is differential global positioning system and now you can imagine that aircraft has DGPS mounted over the top of that, so now, it is in connection with the all satellites and satellite lock is maintained, right. So, what happens here? It is acquiring the data at every one second. So, at every one second it is acquiring x, y and z position of the aircraft trajectory, right.

Doing that one second as we have said that we are firing F number of pulses, so what will happen during that one second? During that one second in which we fire F number of pulses. IMU acquires roll pitch and yaw of the aircraft trajectory or the aircraft motion because of that we come to know what is the you know motion of the scanner or how scanner is behaving like that with the aircraft. As a result we can see that if we interpolate the values using the roll pitch and yaw so then we can find out the trajectory of the aircraft between that one second also. And now we can see that for each and every pulse we know what is the value of aircraft trajectory, and using that information we can find out what is the coordinate for each and every pulse and that is the role of IMU here, ok.

So, these are the characteristic of the DGPS. It basically observed the 3D coordinates of aircraft trajectory and it updates the data at every one second or what we call one hertz. So, the lock should be maintained. That means, if my aircraft is moving like that and it turns after sometime back to the next line what happens is my lock should be maintained otherwise if lock is lost I will not get the GPS data, and that is the first condition we should consider when we integrate so many sensors and the all the elements like aircraft and others other things, ok. So, banking angle is restricted as I already told you, ok.

Let us see the characteristics of the IMU. It observe the roll pitch and yaw fine and then it measures the roll pitch and yaw with respect to east to north and the gravity direction, ok. So, data rate is 60 Hertz to 250 Hertz it depends like which quality of the IMU you are using, ok. Now, there is another problem with the IMU it sleeps on the long flight lines. What is the meaning here?

So, if we are caring the IMU in an aircraft and aircraft is continuously travelling in one line in one direction for more than 15 minutes. Now, what will happen? IMU will start accumulating the errors and that is the problem with the IMU, and as a result we should regularly turn the aircraft so that IMU should not sleep, ok. Now, if you see that if aircraft is moving at a speed of 50 meters per second which is a common speed generally we have the speed in the range of 50 to 70 meter per second, let us say it is moving at a speed of 15 meter per second.

And for 15 minutes how many seconds we have so many seconds and so what is a distance here 15 thousand meters which is 15 kilometers. So, in general we can say that flight line or one flight line it is not. So, long of 15 kilometers and as a result we have to take a turn and so this condition does not create much of the problem in the data acquisition. So, now, the days we are very much relaxed as far as IMU is concerned for the airborne data acquisition, right, ok. So, now, we have understood what is the role of the DGPS and IMU, ok.

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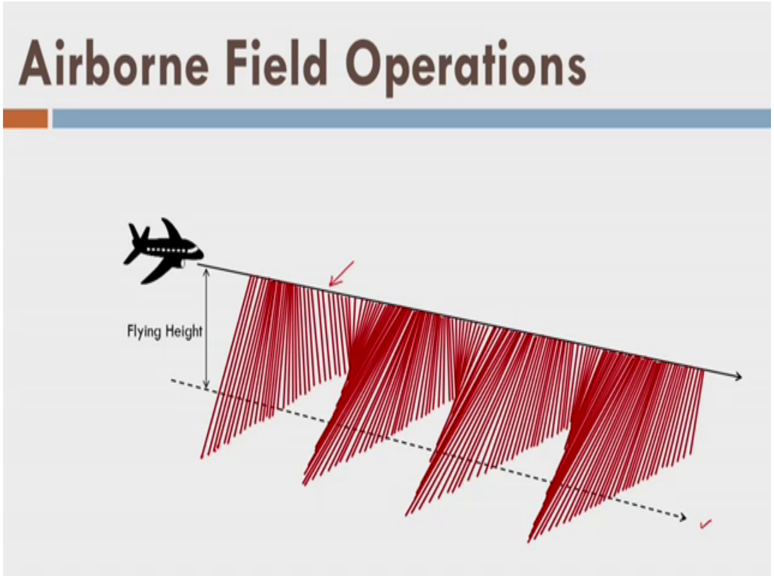

Now, let us say that we have used IMU, we have used DGPS and we have find out the trajectory of my aircraft. So, this is the ideal trajectory and this is the flight line on the ground surface fine, what will happen now, because we know that trajectory points on each and every point within one second also, ok. So, now, we can say that laser scanner when mounted on an aircraft it is acquiring the data at each and every even the fraction of second. So, let us look this thing by animation what does it mean.

So, this is my flying height. So, now my data, data is acquired by movement of the aircraft and operation of the laser scanner. So, it is zig-zag pattern or the Z shaped pattern where acquiring the data, right. So, this is my aircraft trajectory here and we know the coordinate of this trajectory from even the point to point or even over a fraction of second we know and as a result now, we can find out what is the coordinate of each and every pulse on the ground surface, right. So, that is the mechanism one should understand for the airborne LiDAR data acquisition, ok.

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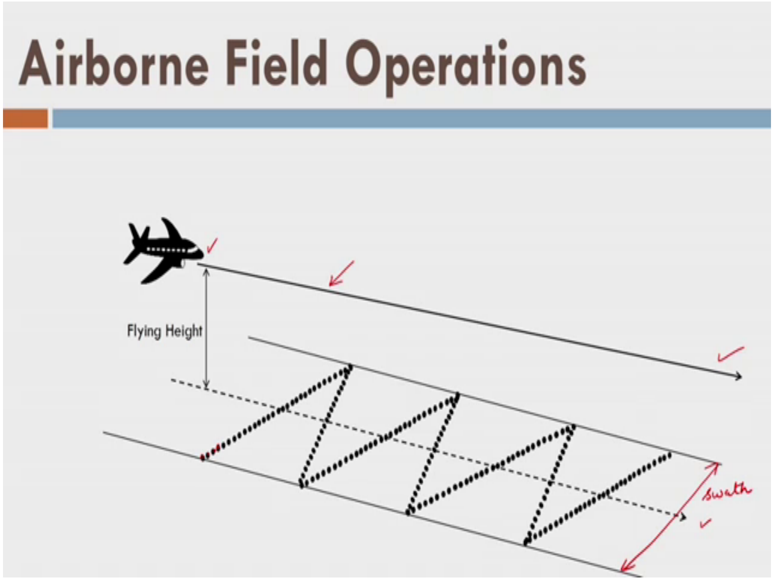

So, we have got this kind of data over the time as aircraft moves from this point to this point because this kind of data or what we call is in the zig-zag pattern of the data. Now, this is two lines are indicating the swath here, right, ok.

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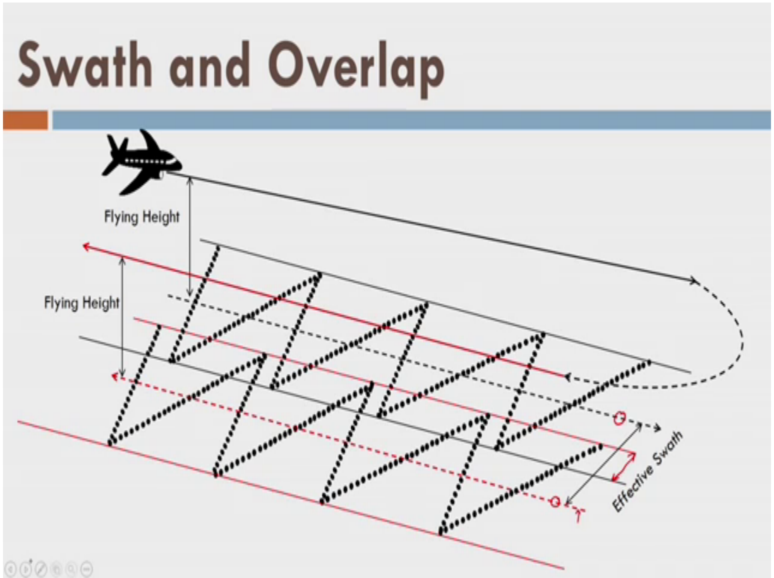

Once again try to learn what is the swath, and so let us say this is a flight line and this is my flying height fine. So, we have acquired this data, right. Now, aircraft will turn on the next line. So, this is my swath here, right. So, now, aircraft will turne on the next line.

So, this is the next line here and so this is the flight line and this is my flight line on the ground surface this one, ok.

Let us acquire the data like this aircraft is its can again in acquiring the data. Now, we can see one more swath, this is the swath again, right and we can see there is a overlap here. This is my overlap here between the two swath and that is called the overlap, ok. So, now, you can understand what do you mean by overlap and what is the swath, ok. So, we are plotting the flight lines on the ground surface or on the map. So, we are getting these two flight paths.

So, the difference between the two flight paths it is called effective swath or the spacing between the flight lines is also called the effective swath, right.

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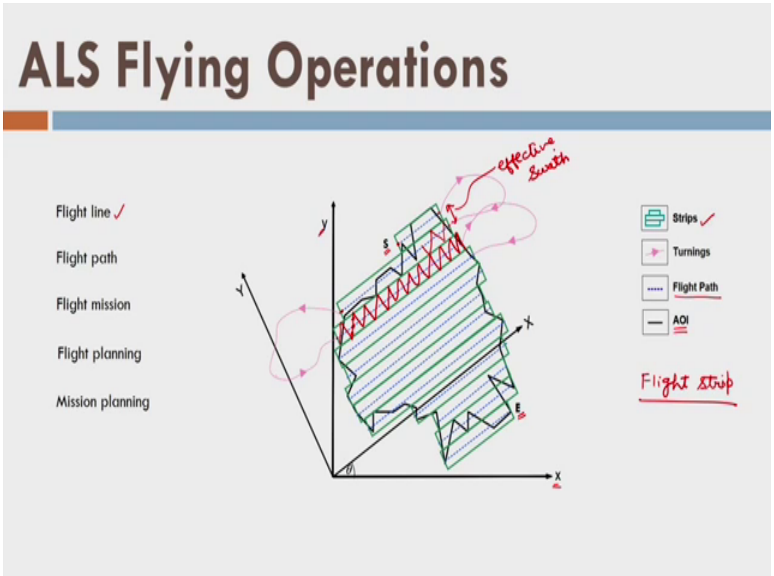

So, now we can see here we will go for the derivation later, ok. Now, we can see here the we are indicating the flight lines here and you can see here the flight lines and then flight path flight path is indicated on the map. So, this is my map here which is showing by x y and so we have an area of interest which is written here s, AOI and indicated by the black line you can see there is a closed polygon indicating the AOI. Now, we have divided these AOI into the parallel lines and each parallel line is called flight strip, right.

So, I write it the each strip is called flight strip and the centre line of the flight strip is called the flight path and which is nothing but the vertical projection of the flight line, right. So, let us say in order to acquire the data aircraft is a starting from point s that is my starting point and it will travel over this line from this point to this point, then it makes a turned like this and again from this point to this point it travels in a straight line over the flight strip and it acquires the data in a zig-zag fashion like this. And then it will exit from this point here again it will go and come back to this next line and again it will acquire the data like this in the zig-zag pattern.

So, each line is indicating some data and it will then exit from this point and it will repeat the whole process and finally, from point E aircraft will exit and go to the air strip, ok. So, now, you can see at each and every line has some data like this, right. I hope that you have understood the mechanism of the airborne laser flying operation as well as airborne LiDAR data acquisition.

So, before we go into any derivation we should know this thing, ok. What about the spacing between the flight lines? This is spacing, it is nothing but the effective swath that we have shown in the last slide, right, ok.

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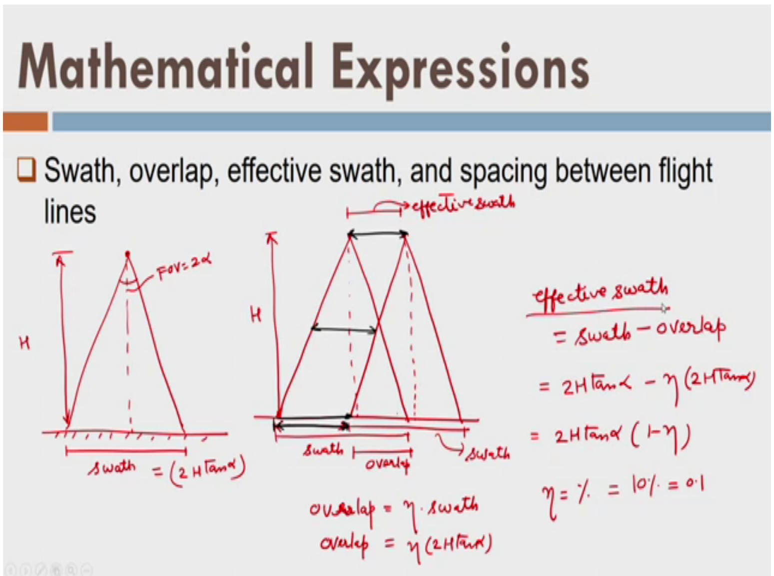

So, now let us go for the small small derivations, ok. What is the swath? Now, if I take this is my FOV as 2 alpha and this is the flying height, and this is the ground surface which I assume as flat and horizontal for simplicity. So, this is the flying height H and as a result I see that this is my swath.

So, now, the flight path is perpendicular to these plain and so swath is given by 2 H tangent of alpha, right, ok. What is the overlap? If I have two swaths we can refer back the slides again in order to better conceptualization. So, let us say this is my one swath here. So, this is my flying height again H here, ok. Now, let us say we have some effect to swath and again we are repeating the process.

So, this is my flying height again and so aircraft is moving from this point and coming back on to this point. So, this is my effective swath or the spacing between the flight lines, ok. This is my overlap from here to here and this is an another swath here to here. So, between the two swath we have overlap and overlap is given by some percentage of the swath. So, let us say if eta percentage of my swath. So, I can write here eta times 2 H tangent of alpha and that is my overlap, ok.

What is the spacing between the lines or effective swath? You can see here that this is my overlap, right and now this distance from here to here this distance from here to here it is constant that means, here it is like this, here it is like this and here it is like this and so this is called the effective swath or the spacing between the flight lines and it is given by you can see here that effective swath is nothing but swath minus overlap.

So, I can write here 2 H tangent of alpha minus eta times 2 H tangent of alpha or I can also write 2 H tangent of alpha in to 1 minus eta. Eta which is my overlap percentage is generally expressed in the percentage for example, 10 percent, so it becomes 0.1. So, if I put here 0.1 I will get 0.9 times of my swath as my effective swath.

So, this is the simple concept of this swath effective swath and the spacing between the flight lines. So, now, we can easily correlate each and everything, ok. So, we have learnt what how scanners are there like DGPS GPS and laser scanner, right. So, what are their characteristics? Then how do the create swath? How do we create each and every laser pulse and each; and every laser pulse is creating some kind of footprint, and it is also create in some kind of vertical accuracy. So, we have seen all this thing in this lecture in the previous slide or in the last lecture.

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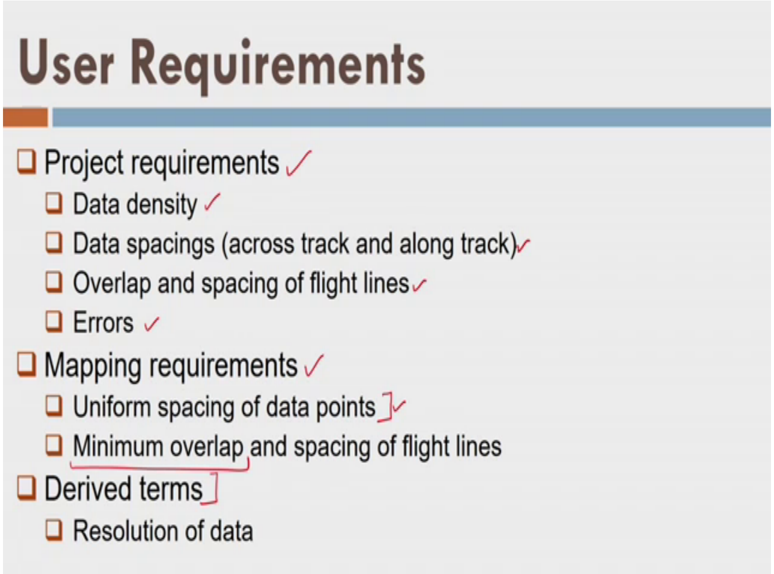

Let us look into the user requirements. So, what is the user requirement? User requirement consist of two aspects one is the project requirements and the second is the mapping requirements and then we derive some terms call resolution of the data that will see later but before that try to understand what is the project requirement.

So, each and every project has some requirement about the data quality as well as data quantity and these are called the project requirements. And these are data density data spacing overlap and the errors. We will see one by one all this but before that let us look into the mapping requirements.

So, what is the mapping requirements? Each and every mapping agency demands some kind of attributes or some kind of quality or some kind of conditions in the data acquisition process. So, that data should have some minimum quality and so we say that my data should be uniformly spaced, which means if the data is uniformly spaced I can create a uniform product or the 3D data on the 3D digital elevation model will be uniform and we will have more confidence into that.

Now, they should be minimum overlap. We can see here if I increase the overlap first of all I will not get any additional information because we are getting some information in one side or one swath. Again there is no point of repeating that information again, right. As a result we have minimum overlap moreover there is one more reason for that. Minimum overlap will increase the distance between the flight lines and I will acquire the data of a given area in minimum time why because I will have less number of flight lines we can see this thing there. That means, if the effective swath is more I will have less number of flight line and less number of flight lines means less number of turns and so overall time of data acquisition in air will be minimum.

And that is a reason we preferred the minimum overlap of the data. At the same time we should understand that overlap cannot be made 0 because overlap is must or it is required in order to maintain the continuity of the data between the two swath of between the two flight strips, which are adjacently located, right. And that is the reason we do not minimize or do not make the overlap equal to 0; we have minimum overlap always, right. So, let us go into each and every term one by one.

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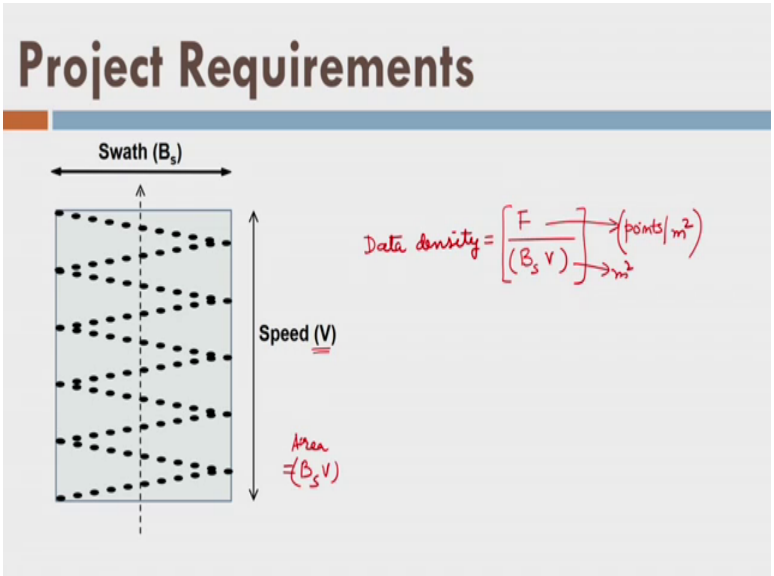

First of all we will go for the data density let us see this is the flight line. Now, we have acquired this data in one second. What does it mean basically? This is the swath you can see here across the flight line and this is the speed of the aircraft that means, aircraft is travelling by so many meters in one second and that is what we call the speed of the aircraft, right.

So, I can find out what is the area of this data I can see here the rectangle of the area of the rectangle here is B s into V. Now, this area is containing so much of point data what we call LiDAR data. Now, I want to find out what is the quantity of the data per unit square area and as a result I can say that since I am firing F number of pulses. So, I define the data density or number of points over unit meter square or unit area as F that is number of pulses fired in one second and bring that one second area covered by the area covered, right. So, this is the data density.

Generally if I take the unit of data density it will be points or divided by meter square because this is the unit of area meter square and F has number of points. So, I have unit call points per meter square, right. So, this is my data density, ok. Let us look further.

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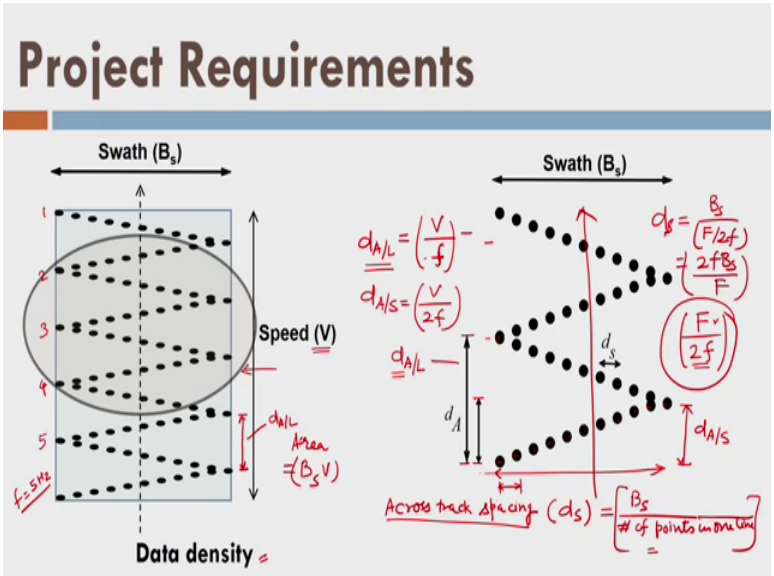

So, if I zoom in this area we can see that there are two lines of the data here and it has some data spacing what does it mean? This two points which are falling in one scan line or we can say two scan line and one oscillation or one cycle.

So, this is the data spacing between these two points. Moreover I can say this is the shorter data spacing between this point and this point or this is my. So, let us call as a long spacing this one my along track spacing, long spacing or this is one spacing is the along track spacing in the short spacing. Why because this is the flying direction here, right. Now, we can see that this is the along the flight line so I am saying along flight line spacing or along spacing.

And you can see here that along spacing is given by d A let us say I am writing it l first this one is given by this V by F where we have the scanning frequency F, why because you can see here we have ones one cycle here, then we have second cycle starts here, third cycle 4 cycle and 5th cycle. So, I have F is equal to 5 hertz here. Now, if I divide here I will get this distance or I will get this distance as my d along the spacing the longer spacing.

Now, what about the shorter spacing? The shorter spacing will be given by V divided by 2 times of F is very simple you can understand it now. So it is up to you with spacing you specify if you want to acquire the LiDAR data by airborne method, ok. Let us go ahead. So, these are my project requirements one is data density and one is the data spacing because data spacing is going to tell me how much data is apart from each other, ok.

One more thing I would like to introduce here these spacing between the two points here or the average spacing between any two points here along the swath and that is spacing is called the across track spacing, right fine, and I am writing it with the help of d S symbol. So, d S is given by I can say that is my swath here swath divided by number of points in one line or one scan line, right.

So, what about the number of points in one scan line? These many points are there, right how can I estimate it is very simple, ok. Let us say we have F number of points in one second and now we have scanning frequency is 2 f sorry f. So, if we divide F by 2 f I will come to know about this many points in one line, right because there are 2 f number of lines and these lines are containing total F number of data.

So, now the number of data is this much. So, what is my d S? It is given by B s upon F by 2 f or I can write it 2 f B s upon capital F this is my d S or the spacing or the average spacing in the acrostic direction. At the same time data density is going to tell us that how much data is available in unit square area.

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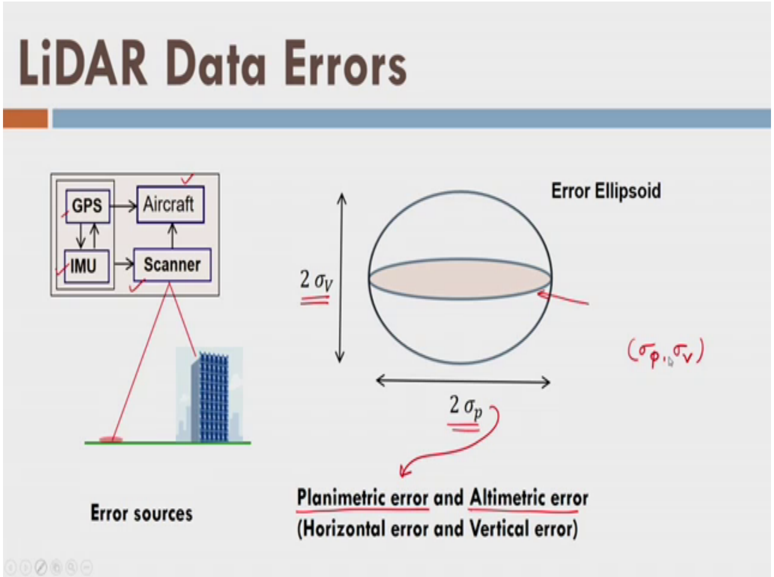

Now, we see the LiDAR data errors this is A 1 more requirement that is errors. We can see here there are 4 elements are there for example, 3 scanners, GPS, IMU scanner and then they are mounted in the aircraft. So, aircraft trajectory also has some error. And as a result what happens is a user is specify that I want the data quality up to so and so limit and similarly he has some criteria for the vertical direction error.

Now, all these 4 elements are contributing to the error of the data and as a result we have some planimetric error and we have altimetric or vertical error. So, let us see this is my error ellipsoid and this is the planimetric error ellipse how the planimetric error here. And then we have 2 sigma p here, right sigma p is nothing but the planimetric error. Now, we have altimetric error also here. So, this is my altimetric error sigma v here. So, we are writing that, ok, we can tolerate a user can tolerate this much of error given by sigma p in horizontal and sigma v in vertical. So, we should also try to meet this requirements once we acquire the data in the field.

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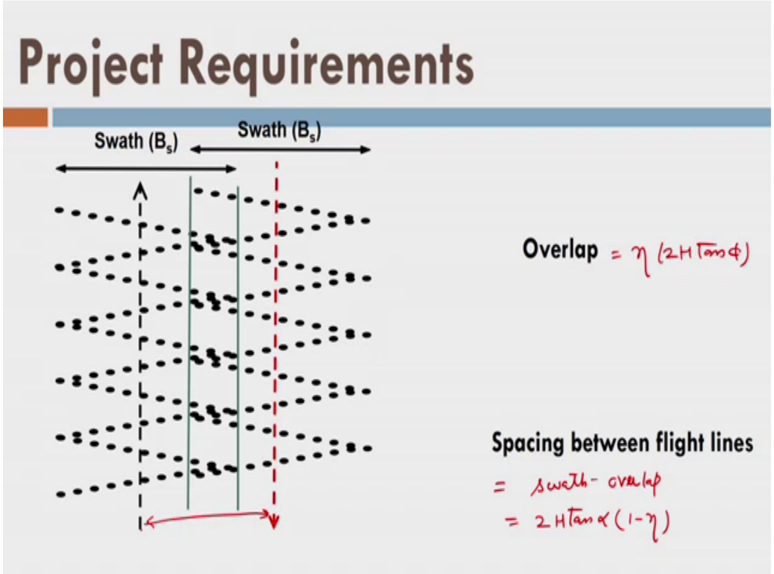

So, now if you see the overlap and the spacing between the flight lines, again we are looking at very carefully this is also overlap and we have already given the formula of overlap eta in times 2 H tangent of phi. So, the spacing between the flight line is given as swath minus overlap. I am repeating it and so we have 2 H tangent alpha 1 minus eta, right. So, this is spacing is this much, ok. As we know that spacing is higher, it is beneficial to us because it will reduce the overall cost of the acquired data. So, it is required at the same time we cannot make the overlap equal to 0 because overlap is also required in order to maintain the continuity of the data between the data of two flight strips.

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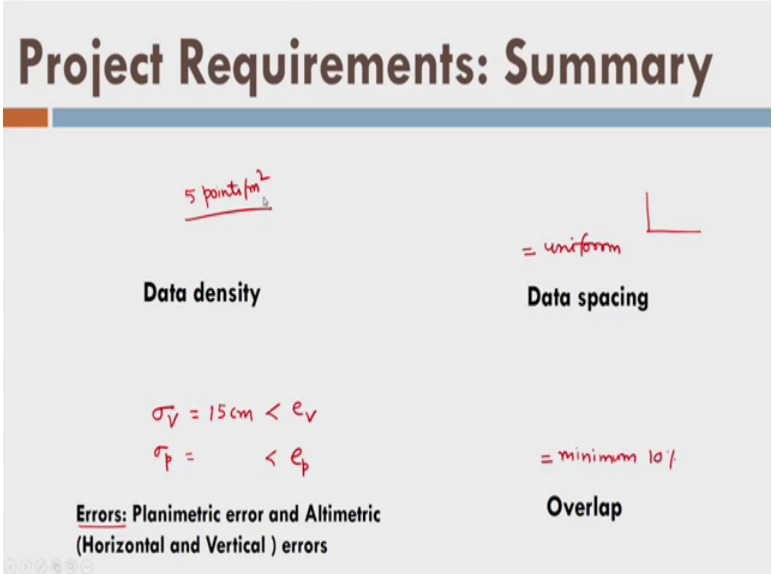

Finally, I am now summarizing the all project requirements. So, first is a error, then we have data density, then we have data spacing, then we have overlap, ok.

So, let me write the minimum quantity. So, minimum quantity of the overlap is we have 10 percent fine. Data spacing it should be uniform that means, the along track spacing and the acrostic spacing should be uniform, ok. What about the errors? Errors should be generally given by sigma V let us say some 15 centimeter and similarly it is given sigma p equal to something. So, these errors which are obtained in the LiDAR data should be less than by the maximum error like this, ok. What about the data density? Data density is for example, a user says I want 5 points per meter square. So, this kind of requirements we should be able to satisfy by the airborne data operation using scanner, GPS and IMU, right.

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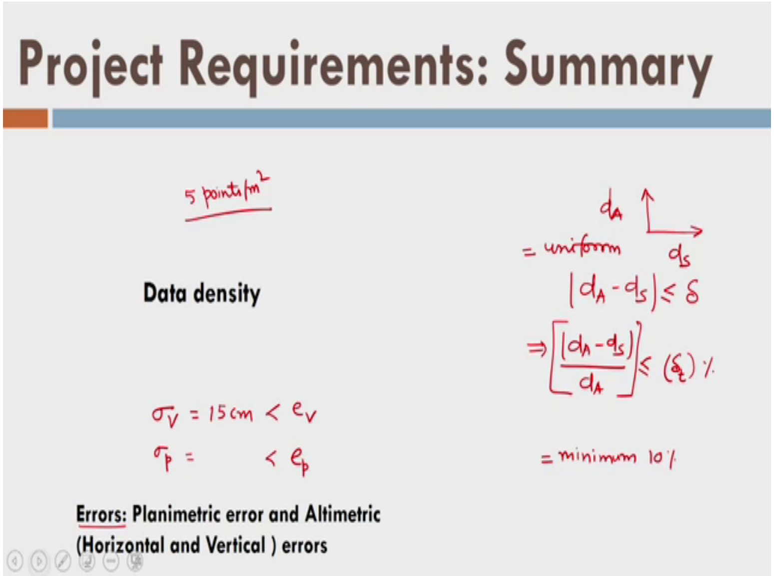

So, generally a user demands that the spacing in the two directions that is my d S and d A it can be longest spacing or short spacing. They should follow some uniform direction that means, we say that d A minus d S they should be within some threshold let us say delta, right or I can also write that d A minus d S both divided by d A should be less than equal to some threshold delta t which is in percentage, ok. So, these are the important things we should understand as project requirements. Let us go ahead, ok.

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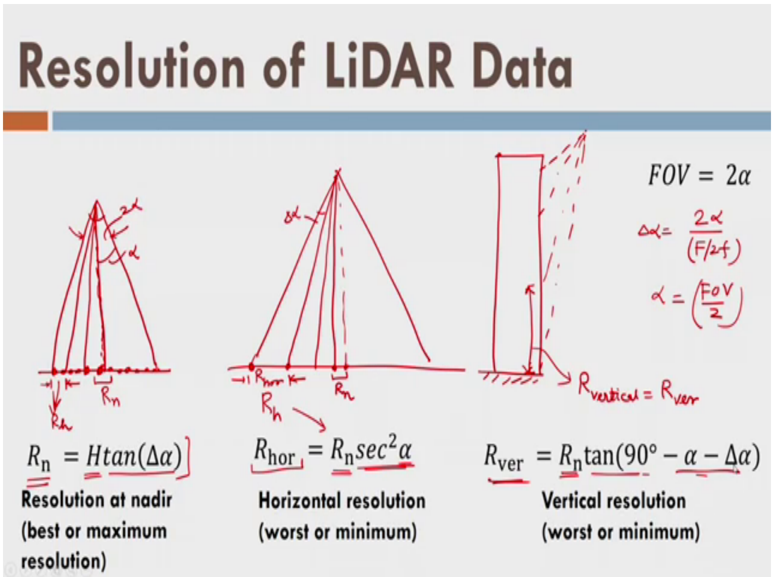

What about the resolution of the data? So far we have talked about the data density and we are saying that the data density is number of data points over a unit square area. However, if you see carefully the data density is determined by a large area that is swath into speed, so that is the kind of an average criteria over a very large area call swath into velocity or the speed of the aircraft, right.

Now, I want to estimate my resolution or the quality at each point in the data set. What can I do? I can find out the resolution. Now, and the resolution is nothing but the distance the between the two points or two data points. Now, if you see here carefully if I draw the mechanism again here so we are firing some points in one line let say these many points we are firing. So, we can see here that my alpha value that is the alpha here this alpha value is 0 here and as a result we get some kind of footprint here, right and.

So, what will happen? The spacing between the points from here to here will be less like this for the two consecutive or sequentially fired pluses. But if you see here the data distance between the two data sets two data points from here it will be very very large and so we defined two terms one is the worst case resolution and one is the best resolution the best resolution we get at the nadir this and that is given by R n H into tangent of delta alpha. And delta alpha if you remember that if I divide 2 alpha into number of points in 1 line I will get my delta alpha. So, this is nothing but the delta alpha is the angle between two sequentially fired pulses by the scanner. So, that is the resolution here I get, ok.

Now, we can see what is my horizontal resolution in the worst case which is here R h here. So, this is my R n here, and this is my R h here. So, this is my R h or R horizontal, right and it is given by R n into sec square alpha where this complete angle is my 2 alpha or the half angle is my alpha. So, this is my half angle here or half of the FOV. So, I can write here alpha is nothing but FOV by 2, right.

Now, what about the vertical resolution? So, we have determined that there is a horizontal resolution here for the given delta alpha, this is my delta alpha and so we have higher spacing here. So, it is my worst case resolution or what we call is R horizontal, right. Now, if is for same delta alpha I have points very high resolution over there. So, this is my R n at Nadir. Now, what about the vertical? Let us say there is a building like this and then these data points of fired like this. So, you can see here that the vertical resolution is worst at the bottom of a building, right. So, now, this vertical resolution are vertical or R ver is given by R n times tangent of 90 degree minus alpha minus delta alpha, right. So, it is again the worst or of the minimum resolution. So, we should understand this also, fine.

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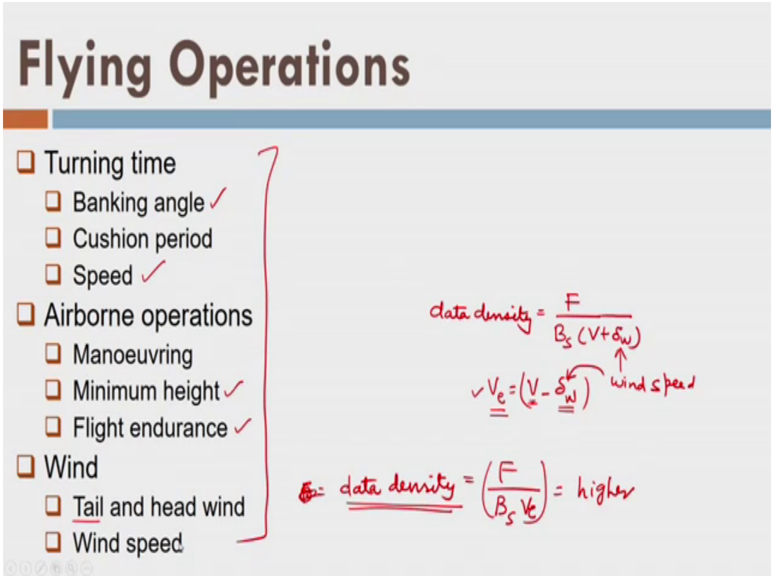

Now, come in to the flying operations. So far we have discussed about the all the data quality, project requirement, mapping requirement, scanner quality, GPS, IMU and so on.

Now, we will talk about the flying operations, what are the flying operations? First of all if you see the first slide we have drawn some flight strips and aircraft is making the turned. So, while making the turn aircraft turns like this and it banks and again it turns back like this in order to reach to the next flight line. So, we have some banking angle and banking angle is limited to 25 degrees to 30 degrees.

And what is the reason? Reason is first of all the flight crew should be comfortable and they are generally comfortable around this value, right because this value will ensure that I will take minimum time to fly at the same time this turned should be comfortable also. If I increase the turn to 45 degrees it is possible to make the turns but flying crew will not be comfortable. At the same time I will have a danger of losing the GPS lock. So, we should be very very careful on that part. So, that is the role of banking angle here.

Then we have cushion period, what is the cushion period? Ok, when aircraft turns from one flight line to next flight line it will have some kind of cushion before it is starts the data acquisition that is the starting of the next flight line, and this period we should have to provide to the pilot and that period is around 30 seconds to 60 seconds and it depends on the pilot person to person.

In case of helicopter since helicopter can do the sharp turning this period reduces to 15 to 30 seconds and in case of aircraft it is 30 to 60 seconds. So, it depends on pilot which value he prefers. So, we have to provide some provision for this kind of cushion also, and that cushion period is very very important, because during this period only a flight a pilot ensures that aircraft is smoothly flying or it is going to fly smoothly over the next flight strip after turning. So, after turning he takes this much of time, right. So, then a speed its speed of the aircraft should be constant, ok.

Now, what about the manoeuvring? Ok, manoeuvring can be done on the consecutive lines or it can be turn with the larger turns and so it will be not on the consecutive flight line but it will be non consecutive flight lines. So, we have some kind of non-consecutive turning and we have consecutive turnings well we are not talking all this thing in detail but I am just giving you some hints here.

Then we have minimum height, that director general of civil aviation it specifies the minimum height and that minimum height in India is 300 meter as per the DGCA governance. So, a pilot has to maintain that minimum height. That means, for higher data density if you see if I have lower height or lower flying height I can acquire very high data density or high quality of data, but we can still not come below 300 metres. So, these things has to be taken care when we performed the air borne data operation.

Then flight endurance, what is the meaning of flight endurance? We have certain capacity of flying in an air. And in general whatever aircraft we use they have some capacity around 4 to 6 hours because according to the fuel capacity of that aircraft. So, after 6 hours or within 6 hours aircraft has to take off it has to acquire the data and again it comes back to the airstrip. So, this flight endurance we should always considered when we perform the data acquisition in air.

Now, coming to the wind, ok. Let us assume that wind is flying and aircraft is heading towards the wind that is called head wind and as a result the speed of the aircraft is lower and we get less data density we can see the expression of the data density the data density equals to F by B s, B V. So, if I have head wind what will happen? Wind will be reducing the effective values speed of the aircraft will be V minus sum delta wind and as a result the data density will increase because wind speed is reduced. We can see when there is a head wind what will happen? The data density will increase. So, you can see the formula here. If my V is there and V e is the wind aircraft speed minus wind speed I will have less effective speed of the aircraft and I will get higher quality of the data or higher data density.

At the same time let us assume that there is a tail wind what will happen the effective speed of the aircraft will increase, and as a result we can see here that in case of tail wind we have data density equals to F upon B s upon V plus delta w here, right. So, delta w is nothing but wind speed here, right. So, I will have inferior quality of my data or data density will be less. So, we should consider all these factors when we perform the air borne data acquisition, ok.

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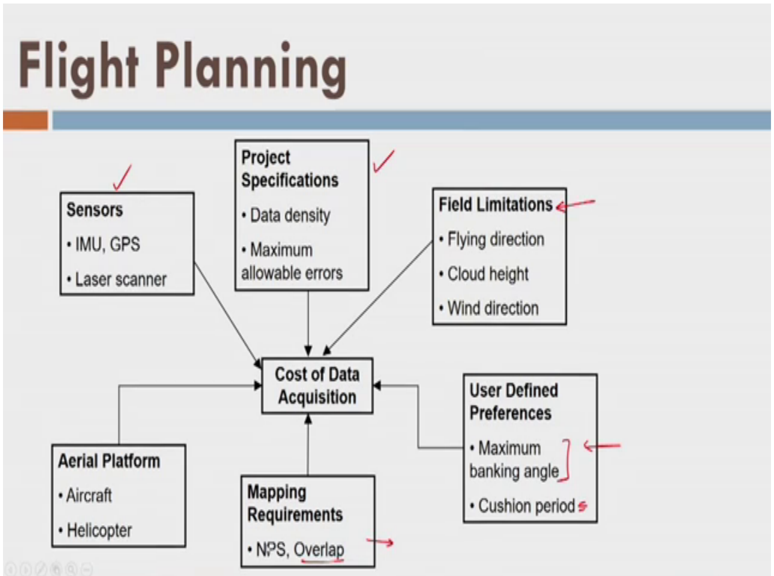

Now, I considered all this factors like sensors we have project requirements. We have field limitations that I already explained you. Then we have some user defined preferences like cushion period of pilot or maximum banking angle for the flying crew. Then we have mapping requirements like what is the overlap and what is the data density or nominal pulse spacing and then. So, all these things are contributing to the cost of the data acquisition.

So, when we integrate all this factors together, and we planned the data acquisition exercise by simulation exercise, and this simulation exercise is called flight planning. And flight planning is very very essential before the data acquisition is really performed in the field. Why because flight planning only ensures that certain quality of the data will be acquired with certain mapping conditions with so and so sensors, with so and so aircraft, with so and so characteristics of the all the elements involved in the data acquisition. So, that is very very important aspect of the air borne LiDAR data acquisition.

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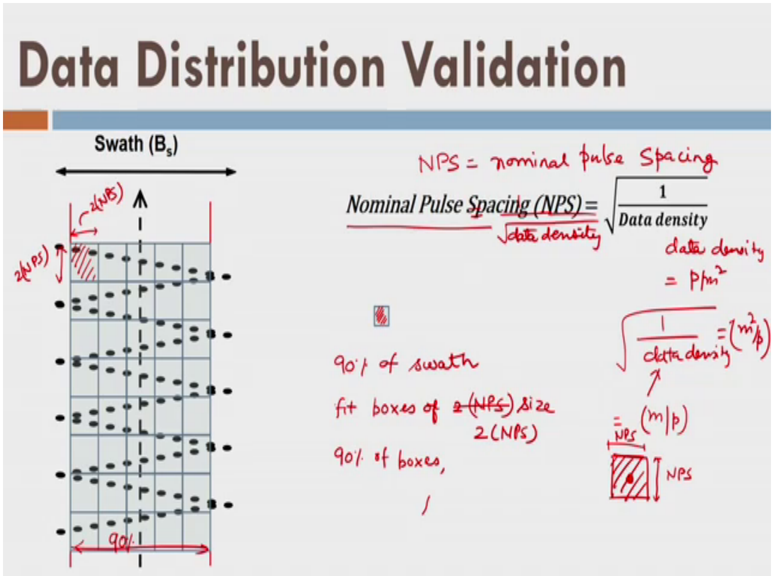

Now, let us see that how to find out the validation or how to validate whether we get the appropriate data or not. So, once let us see your acquired the data after flight planning you went to the field and you acquired the data. Now, you how to ensure that your data distribution is uniform or not that simple checks are there. And we are going to learn all these checks here in this lecture.

First of all we define a quantity call NPS. What is NPS? Nominal Pulse Spacing, and that is nothing but 1 upon root of data density. And I will tell you the, what is the reason here. See the data density is given by in points per metre square, right that is number of points in unit square area. Now, I want to find out what is each point is representing, or what how much area is represented by the each point of laser data. So, I can say that if I inverse the data density I will get the area per point, right.

Now, I can say if I take the route I will get the size of the area that is metre per point that means, I will get some area like this and I call this as dimension NPS NPS. So, I can say that each this box is having one LiDAR point inside that, right. So, again it is an average criteria because it is calculated from the another average criteria data density, right. So, we should understand that how to now validate this data density or the NPS.

So, what will do? Let us say there is A 1 swath here and then this is my NPS, ok. So, now, this is the cell of NPS, right. So, we have calculated what is my NPS. So, now, I will take the 90 percent of the swath this is the 90 percent of the swath, right. Now, I will divide this 90 percent into the boxes of NPS size. So, how many boxes are there I can see here, right 1, 2, 3, 4, 5, ok. So, let us put these boxes in the centre 90 percent swath.

Now, we will check that each and every box should have the 1 LiDAR data point into this box, but again we know that since this is an random sampling of data. What will happen? We say that first of all we will take the 90 percent of the swath or the centre of the swath then we will take that we will fit boxes of 2 times NPS. So, boxes of size 2 times NPS. So, these boxes are basically this is my 2 times NPS, this length is also 2 times NPS, right. So, now, such boxes are there, ok. So, 90 percent of such boxes each of the 90 percent of the such boxes should have the laser data and then we say that if it is so we have the data distribution as uniformly distributed data. So, we have the uniformly distributed LiDAR data. So, that is the check we always perform, right, ok.

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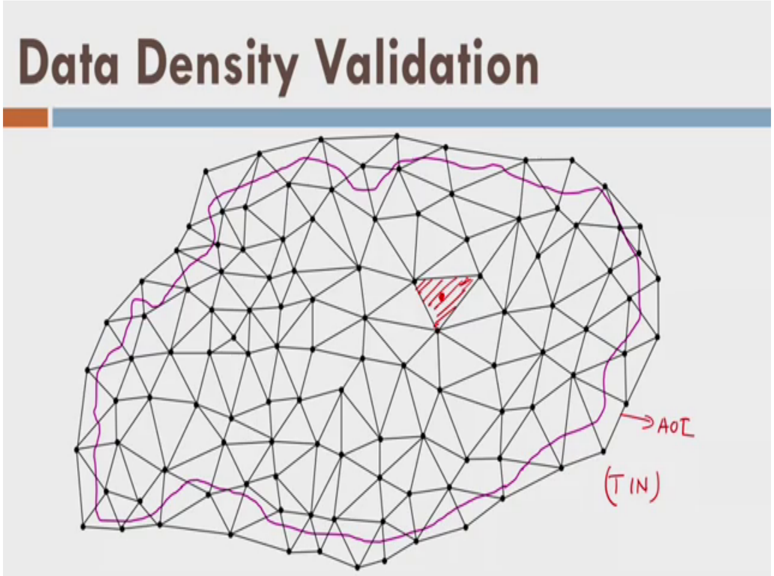

Now, what about the data density validation? Ok, so let us see there is a area or what we call is AOI, right. So, you might be thinking we have already verified the NPS or indirectly we have verify the data density, but there is some debate here. And debate is the data density is again an average criteria, right. It is used for uniform distribution validation however, it cannot be used for the data density validation and so we have device a new method now. What is this method?

We will take let us say these are the LiDAR data points and now we will divide this data points into the triangles, and what we call here is triangular irregular network or tin. So, now, I know that each and every tin here or the each and every triangle is representing 1 LiDAR data set or 1 LiDAR data point is representing one triangle, but we have different different areas of each triangle what is the consequence here? We have to find some way in order to report that data density. So, what do we do? Ok, I will tell you are simply we take the 95th percentile of the triangular areas, right. So, let us see in the next slide.

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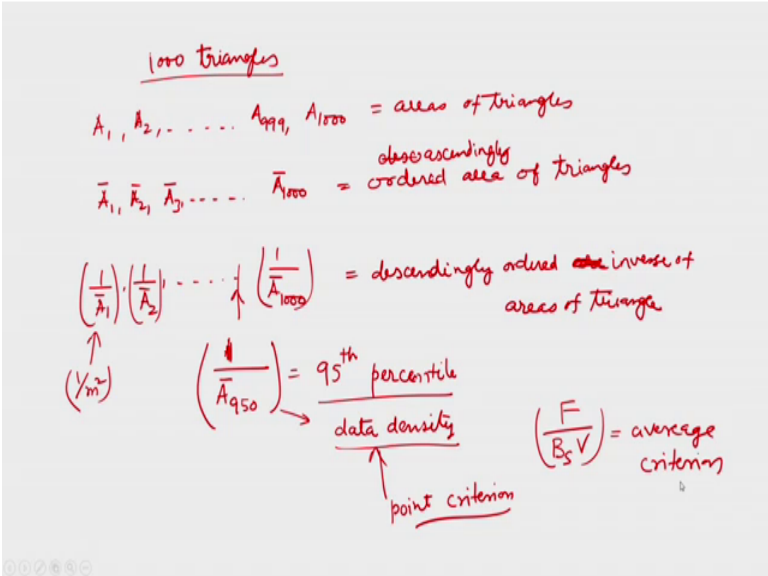

Let us see you have complete area you are total 1000 triangles say for example, ok. Now, you have A 1 to A 2 and let us say A 999 and A 1000. So, these are the areas of triangles, right.

What will you do? First of all you will take the order data that means, your order the data I am writing let us A 1, A 2 bar, A 3 bar your order this data. So, ultimately we have some ordered areas. So, higher to lower or lower to higher whatever, right. Now, you will find out 1 upon A 1 bar 1 upon A 2 bar and so on, ok. So, each and every term is now, representing the data density, right because it is sum point divided by 1 upon meter square, right each and this quantity, ok.

Since they are ordered one what will you do? You will take the descending order and then you will take the 95th percentile. So, what will you do? What will you do? Let us say this is the descending order or they can say ascending order here ascendingly order, so it will become automatically decsendingly ordered inverse of areas of triangle, right. Now, what will do? We will take here a data it will be 1 upon A bar 950 here, because we want to take my 95th percentile. And so are they are in the descending order what will happen? This quantity will indicate the data density or I can say it is the point data density of the air mol LiDAR data and this is the way we finally, calculate the data density, right.

The other way round is that if I take the F divided by B V that is an average data average criteria but this way I have a point criteria or the point data density. So, that is a better one the point criteria is much better than the average criteria over a large area, right. So, now, we have validated my uniformity of the data as well as data density after the data acquisition, ok.

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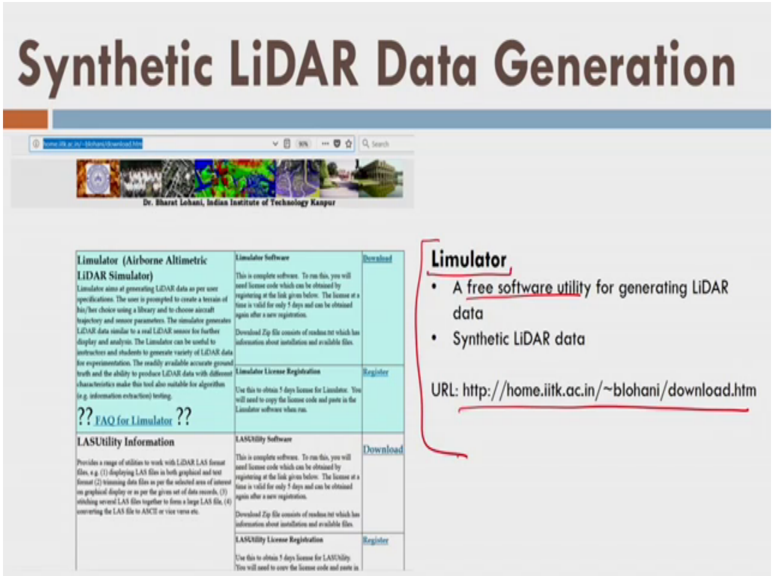

Now, after that I would like to tell you that it is very difficult you might have understood by this time that it is very very difficult to acquire the LiDAR data. Why because the LiDAR data is very very expensive because it involves many expensive resources. First of all the aircraft, then we have the scanner, then we have GPS, IMU and the whole logistics of the air borne data acquisition is very very complicated as we have seen in the whole lecture. And as a result we can see it is not a night game ball or very simple game ball to find the, or the acquired the LiDAR data, right, it requires lot of resources, lot of cost. Although the cost will be minimized after we acquire the data for very large area and we use the data for many many applications.

However, in order to understand, if you have some facilities that can provide me synthetic LiDAR data that will be good enough for me. So, here there is A 1 synthetic LiDAR data generation application what we call is limulator and that is developed by IIT, Kanpur especially by Pprofessor Bharat Lohani and this is a free software utility and this is the link you can download this data, this software utility in free you can download this software utility from this link. And you can use it and you can see that how can you generate the artificial LiDAR data for no cost.

And now you can generate different different trees different different buildings and this software utility and you fix the parameters of the flight. That means, you can fix the speed of the aircraft, you can fix the scanner characteristics, like repetition rate, the PRF, you can fix the scanning frequency, you can fix any number of parameters that you want of the scanner IMU, GPS everything.

And then you can see that what kind of data you get the synthetic data, and then you can understand that how that laser data you can play with. So, that is the best utility is available today and that is free also. So, use the limulator try to make some hands on experience on that. It is very easy, right. So, with this thing we understand that how to acquire the airborne LiDAR data.

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Next I would like to tell you what about the terrestrial laser data acquisition. It is very easy it is not that complicated. So, we have some laser scanner like this which is looking like this on the front face and back face, right. So, now, I want to acquire the laser data using terrestrial laser scanner and let us see I have put my laser scanner in order to acquire the data of a railway bridge, right. So, you can assume that train is not passing and you are acquiring the data. So, what do you do? You specify the field of view, right. So, that is my 3D field of view and then you acquired the data like that.

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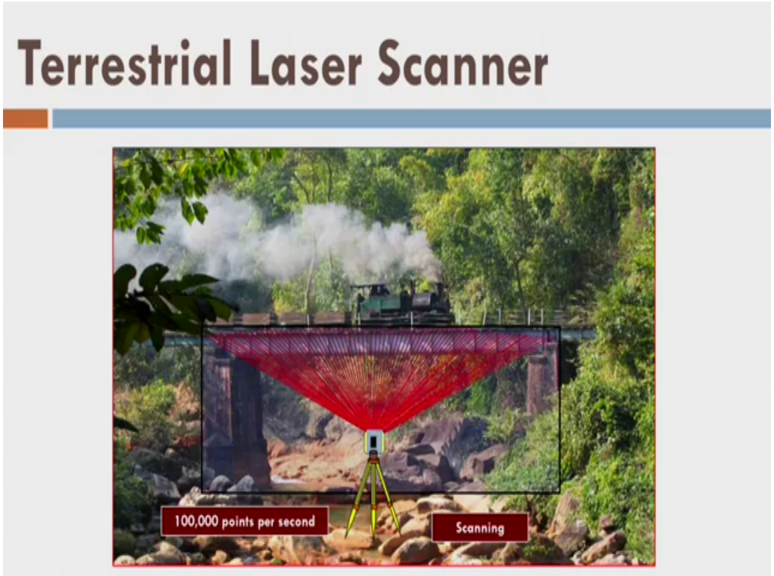

So, this data acquisition animation is shown here. So, you firing sequentially fired pulses and by these pulses you are acquiring the data of the bridge site. So, this is the way the terrestrial laser scanner works.

Similarly, now we have the mobile laser scanner. In case of mobile laser scanner the same laser scanner is mounted on the vehicle like jeep or car or may be a roads 4 wheeler. In that 4 wheeler we have GPS as well as IMU, and as a result, when it moves on the road it will acquire the data of the buildings, and it is also registering the data at every second or even the fraction of the second. So, that is the idea about the mobile laser scanner. So, now, we have learnt that how to acquire the LiDAR data using airborne platforms, using terrestrial platforms and using mobile platforms, ok. We also learnt what is the quantity of the data that is data density and what is the quality, of the data that is the uniform distribution, right and other parameters we have already learned like swath overlap and all these quantities.

So, in this lecture we have learnt completely, what are the attributes of LiDAR data and how to ensure those. In the next lecture we will learn about the geo referencing or the geo location process of the acquired data and we will also learn what are the errors that is available in the LiDAR data, ok.

Thank you very much.