Remote Sensing: Principles and Applications

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Lecture-56
LIDAR-Part-1

Hello everyone, welcome to the next lecture in the course. In the last lecture we discussed and concluded the topic platforms used for remote sensing observations, we discussed about several kinds of platforms and we concentrated more on the satellite-based platforms where we discussed the commonly used satellite orbits such as the geostationary orbit, near polar orbit, near polar sun synchronous orbit and all. Also we have discussed how satellites in the near polar orbit can achieve global coverage by staggering the orbital trace the satellite does on the earth. So, today we are going to start a new topic called LIDAR.

LIDAR is primarily developed as a surveying technique in order to measure the coordinates of points. But in recent years maybe a decade or two, it has been used very widely for various applications including vegetation monitoring and so on. So, it is one of the important topic in remote sensing, but here we are not going to discuss it elaborately rather we will talk in brief about LIDAR, its principles and so on. And interested users or interested readers can refer to some other sources like some papers I have cited in the lecture slides during the course I will provide few other websites which you can look upon for additional information and so on.

So, all these things you can look up, those who are really interested to do further research on the topic. Here in this course we will get just briefly introduced to the concepts of LIDAR. So, what LIDAR is? LIDAR is an acronym which stands for light detection and ranging. That is here the term is very similar to radar. So, there in radar we use microwave signals or originally it was radio waves which was used for deduction and ranging of different objects. Here we employ similar concepts but we use laser light for measuring the distances and detecting objects and that is why the name LIDAR light direction and ranging.

It is again an active remote sensing method. In LIDAR too we will generate the wavelength we need, we will transmit it towards the target, get the back scattered signal back, here also we are talking about back scattering, whatever we send, it has to come back to the same sensor in the same direction. So, back scattering only we are talking about. So, whatever is coming back we use that to range the distance between the objects and map them and also to infer some of its properties.

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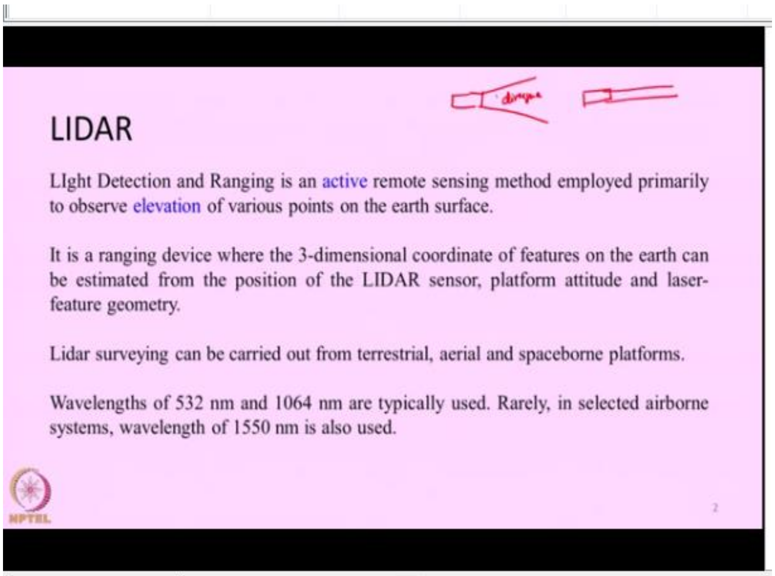

And primarily LIDAR developed as a tool for engineering survey purposes like those students coming in from civil engineering background or earth science background would have done some courses on engineering surveying where our primary aim will be to map the relative position of various points on the earth's surface with respect to your station where your instrument is kept you will try to measure the coordinates of different objects surrounding you or with respect to a boundary or with respect to some sort of control points relative to that we will try to measure the x, y, z coordinates of other points.

So, LIDAR primarily developed or came into use in the field of geoinformatics for that particular purpose, we use it for surveying applications and it first started its use in terrestrial instruments. So, like total stations, electronic distance magnetic measurement, they are different ways in which we use electromagnetic signals for engineering surveying purposes. LIDAR also came into picture that uses laser light for ranging the objects.

Slowly people understood the advantages of LIDAR and it developed into different platforms. Now LIDAR observations are available not only from terrestrial scanners but also from airborne platforms as well as satellite platforms. And now LIDAR has moved from just being a survey technique from a independent remote sensing technique where we not only measure the coordinates of points but we also try to get other useful information about the objects.

So, LIDAR is basically a ranging device, it measures the distance between the transmitter and the object that is in front of it or that is below it, if it is urban platform whatever the objects below it, it will measure the range; essentially it is a ranging device. So, it will measure the three dimensional coordinates. Finally that is what we will get.

It measures the distance which is a one dimensional distance. If the platform is aircraft it will just measure the distance in this particular axis. So, how we are going to translate that into a three dimensional coordinate? That we will see and also LIDAR came into use pretty long ago into ground-based surveying LIDAR was beginning to be used few decades back.

But in order for it to be used properly for airborne surveying or space-borne remote sensing survey and remote sensing purposes, other technologies had to mature which actually prolonged the arrival of LIDAR technology into airborne and space born platforms. So, essentially LIDAR cannot work independently. If you want a perfect three dimensional coordinates of earth surface features we need to use LIDAR in combination with other technologies such as GNSS a global navigation satellite system and we need to have an IMU initial measurement unit and so on.

So, that is the main reason why it took some time for LIDAR technology to mature and come into existence for remote sensing purposes through airborne and space-borne platforms. Since LIDAR is light based ranging system, we use wavelengths in green band or NIR band. Traditionally and characteristically laser lights are monochromatic collimated beam of light.

That is if you take our normal white light what we get from sun or we get from our electric tube lights or whatever we use is not properly monochromatic, they can have a mix of wavelengths that we have already seen. White light composed of 7 different colors or 3 primary colors basically. But laser light are monochromatic.

So, whenever we generate laser light we will ensure that the light comes out in a single wavelength or a frequency. So, practically we may not get as a single frequency but we will have a very narrow bandwidth. But for all practical purposes we can assume it to be a single wavelength and it is a collimated beam of light. Collimated means all the laser pulses that are coming out will be parallel to each other, will be perfectly coming in kind of a straight line.

Say if you switch on a torch, that light diverges very fast right, whereas for a laser beam it is highly collimated the divergence will be very narrow as a example say if you have a torchlight here the light may suddenly spread like this, they are non-collimated, divergence, may be large. But for a laser pulse or a laser light which is highly collimated, the light may come out and the divergence will be very narrow. Divergence will be there, but it will be very narrow when we compare this with our normal light. So, here we use monochromatic collimated light source that is laser beams as the medium of remote sensing and conventionally green wavelength roughly about 532 nanometers or NIR wavelength roughly 1064 nanometers like 1.064 micrometers or 0.532 micrometers.

They are the conventionally used wavelengths for laser remote sensing or LIDAR remote sensing. Basically for land surfaces remote sensing NIR may produce a very high reflectance. So, that is why NIR is often produced; whatever be the feature whether it is vegetation or bare soil etcetera, NIR traditionally has a higher reflectance, that is one and also among vegetation, green again can produce higher reflectance compared to other visible wavelengths. So, basically if you look at land surface, green or NIR typically has high reflectance among its counterparts. If you look in visible green, it will have slightly higher reflectance than others like red and blue visible wavelengths. Similarly, NIR typically has a high wavelength that is one thing. And seeing very rare cases in some selected airborne platforms 1550 nanometers which is a short wave infrared frequency that is also used, but more conventionally green wavelength or NIR wavelength is widely used for LIDAR remote sensing purposes.

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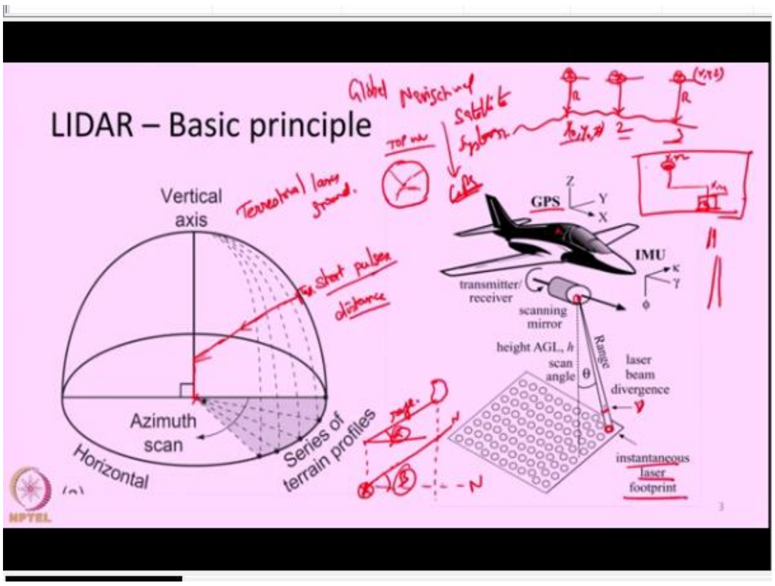

So, how basically a LIDAR system works? We will first start with a terrestrial laser scanner, then we will move on to air-borne systems and briefly have a look at space borne systems. So, first this picture on the left is a schematic representation of terrestrial laser scanner, terrestrial means from ground like the instrument that produces and transmit laser will be fixed in the ground.

So, from this particular instrument it will be sending in short pulses of laser like while discussing about radar we saw like radar the antenna will send in short pulses of radar; similarly here also it will send short pulses of laser light, there are some systems which transmits continuous waves but not very often used, mostly we will discuss about this pulsed laser system, but continuous laser transmission is also possible. But for our discussions we will restrict ourselves to pulsed laser. So, it will send in or the instrument will transmit short pulses of laser and whatever object is present in front of it this pulse will be reflected back. So, once this pulse is reflected back the instrument can measure the distance between the instrument station and the target. So, this will produce the ranging in this particular line.

Also if the instrument is able to scan in the entire hemisphere surrounding it, say if I look from the top view this is the instrument location. So, if you look at from the top instrument can potentially scan in all the 360 degrees angle surrounding it. Normally when we do ground based surveying using a total station or something that instrument is able to rotate in the horizontal plane for the entire 360 degrees. Same thing is applicable with LIDAR sensor too; it can rotate freely in 360 degrees. Similarly, it can rotate in the vertical plane from a horizontal to vertical like this. So, it can rotate in both directions. When it will be sending in pulses in all directions, and say there is a building in front of you, you are just keeping the laser instrument pointed upwards. So, all the laser beams will be targeting the top portion of the building. Then slowly you come back and target up to the bottom of the building. Then we move from left to right covering the entire portion, it is kind of doing a scanning and stitching images, you do multiple scans to collect the entire feature present before you. So, essentially this radar system will store information about the distance and in which direction and which angle the laser beam was transmitted.

If we know the angle of elevation or angle of depression, from horizontal by which angle the instrument was looking up, that is angle of elevation or from horizontal at which angle the instrument was looking down that is angle of depression. If we know this angle and also if we know the azimuth angle with respect to one particular direction, let us say this is my north; with respect to my north in which direction my instrument is pointing at. Say here maybe 30 degrees from north. If you know these angles in both horizontal and vertical directions and if you know the distance from the point of instrument to the target then relative to the instrument station we will be able to locate this point.

So, alpha is the elevation angle, beta is a depression angle, I know this range, it can be calculated by laser pulse. So, with respect to my position the instrument station, I will be able to locate the target in front of me. So, if I have 100 measurements of the building, if I take range for 100 different points on the building, I will be able to locate all the 100 points with respect to my station.

Imagine if I know the three dimensional coordinate of my station with respect to some reference data say students who learn surveying will know that we will always have some sort of reference system like an origin from which we will measure our horizontal coordinates and vertical coordinates. Similarly for earth, a lot of datum available.

Let us take for example we are using this WGS 1984 reference system. Like you have some x, y origin and some z origin, z origin means above which you measure all the elevation x, y means from which you measure all the horizontal coordinates. And if we know the coordinate of the instrument station using in that particular reference system then with all the measurements we made we will be in a position to calculate the three dimensional coordinates of all the points that we measure.

So, that is why LIDAR cannot work independently if your aim is to get three dimensional coordinates of all the points with respect to some reference system. First of all you need to know the coordinate of your instrument station with respect to the reference system you are working on. Then only from that position you can calculate the relative position of all other features.

So, this is the basic working principle of a terrestrial LIDAR system. Coming to aircraft, exactly same principle is used. Aircraft will be moving like this, we will have a LIDAR system attached with it, looking down, vertically downwards. So, let us say the LIDAR system is just fixed like this looking at the nadir. So, as the aircraft flies it will measure the range between the instrument and the target along the line of its flight path.

Say aircraft is flying like this; this is the terrain, when it flies if it sends in laser pulses, aircraft is moving continuously. So, each of this position or the range for each of this point will be measured by this laser system. So, if you know the coordinate that is the x, y, z coordinate of the instrument station from which you measure the range, we will be able to estimate the x, y and z coordinate of each of this ground points.

So, again we need to know the coordinates of the instrument station from which the laser beam is transmitted. So, this will produce what we just saw, it will produce a profile or a (x, y, z) coordinate information along the line of light. Traditionally this will give elevation, the LIDAR will only give like if you look at in terms of vertical direction it will measure elevation or if you talk in terms of horizontal direction you are measuring distance, basically it is a distance measuring device.

So, using this distance and if you know the coordinate of your instrument station you can calculate the coordinate of ground point. Imagine the aircraft system now the LIDAR is also fitted with a scanner, across track scanning mechanism like a mirror or something. So, what it will do? The laser beam will be transmitted but now since scanner is present it will be able to scan across a swath width.

So, it will scan like this while it is moving. So, in analogy with the ground based scanner, aircraft is moving continuously recording the coordinates of your aircraft station, you are also measuring the angle at which the laser beam is transmitted and received. So, we know the coordinate, we know the angle and the direction in that particular angle.

So, using this geometry we will be able to calculate the coordinates of the ground points. So, essentially this is the working mechanism of LIDAR. But how do we get the coordinate of our platforms? In ground-based terrestrial laser scanners, we already have established ground control points from that we can take it or we can do our own surveying using a total station based survey or you can extend the control net and establish new control points from which you can do the surveying.

So, that is a different topic engineering surveying. That is possible, but to do it from an aircraft or a spacecraft we need a independent source of data which provides the coordinates that is where the role of GNSS comes in, like global navigational satellite system are very commonly one of the most widely used GNSS system is GPS global pushing system.

GPS is just one of the GNSS. It is deployed and maintained by United States which we commonly use. But apart from GPS there are other systems available that are implemented and maintained by different countries. India has its own, china has its own, Russia has its own and so on. So, collectively all these systems are called GNSS global navigation satellite system.

So, it is a satellite based coordinate measurement system. It uses observations from multiple satellites and it uses basic surveying principles using which we can establish the coordinate of our instrument station. So, our aircraft should have this GNSS receiver which will collect measurements from all the satellites surrounding it whatever the system that is there and whatever the system the receiver is capable of receiving, like certain GNSS receiver may receive only like GPS.

Certain may receive GPS, Galileo, Glonass some may receive Indian IRNSS and so on. It depends on which receiver we use. So, based on our receiver's capacity we can receive signals from several satellites in space from which the coordinate of our own ground point or our own platform can be established. So, essentially your aircraft should have a high response, high quality GPS receiver which will give the coordinates of the aircraft continuously.

So, that will give you the x, y, z of the aircraft location. Let us know within the aircraft we know where the laser system say the GPS antenna may be kept here, the laser scanner may be kept here. So, the GPS will give the coordinates of this particular point of the antenna position. With respect to this antenna position we can measure at which location this is installed within the aircraft. So, basically we know the coordinate of this LIDAR system also. So, that coordinate can be established as the aircraft flies continuously. Then we also have what is known as an IMU inertial measurement unit which will tell us in which direction or what is the attitude of the platform.

Attitude means when an aircraft is flying we normally expect the aircraft to fly perfectly straight but sometimes due to any disturbances it can change its attitude, like it can undergo a roll, it can undergo pitch, it can undergo yaw. If it rotates around the x-axis along the direction of flight, it is called roll. If it moves the nose up and down, we call it as pitch or if it rotates about the vertical axis we call it yaw, it can happen anytime. So, when the attitude changes maybe the angle in which the instrument is pointed will be changing.

When a roll is given what will happen? We will be thinking the laser beam is pointing downwards. So, the range is measured like this, but at that instant of this roll the laser beam is now pointing not at the nadir but with certain angle, we have to account for that angle of roll if we want to properly establish the ground point at which the distance is measured right, we need to know the angle of roll from the vertical then only we will be able to calculate the range.

Some range it would have measured, but not the intended point. But even in order to measure that particular point properly we know this roll. So, this is not the only case attitude can change in all 3 axis together a plane may completely look like this in three dimensions, there can be a roll, there can be a pitch, there can be a yaw.

Everything can happen simultaneously which will totally change the way or change the point in which we are doing the measurement. That is the need for having an IMU initial measurement unit which will measure the attitude of this aircraft. So, once we know the attitude of the aircraft we will be able to establish geometrically at which point our system is looking at.

So, by knowing the coordinates, our positions x, y, z and by knowing the attitude of the aircraft at the time of data acquisition and by knowing the range we will be able to establish the distance between each point that is being illuminated by the laser light in the ground. This is again the basic working principle of how airborne LIDAR remote sensing is done.

Similar concepts apply even to space-borne systems, like from satellites, it measures the distance and the satellite also has its own GPS receivers and IMUs, it also has some sort of stabilization mechanisms in order to keep the beams perfectly pointed downwards and all. So, it is a combination of different technologies. All the technologies had to mature like measuring your coordinates using GPS from an aircraft is not an easy task.

It needs a very high quality precision grade GPS receiver. So, everything matured in the recent few decades. So, the laser technology was there in the last 4, 5 decades but for other technologies to develop and mature it took some time and when everything came together we are now able to move the LIDAR system to airborne platforms, it developed quite extensively in the last two and half decades.

And also the LIDAR beam that is being transmitted have a collimated beam, like perfectly straight and there will be some minimal divergence. So, when it starts it may start like this slowly it may diverge, very slowly. So, this is the laser beam divergence γ. So, each laser pulse after its divergence it will produce a small footprint on the ground. So, whatever be the objects there that will reflect this particular laser beam back towards the sensor. So, whatever the objects there, it we will be measuring a kind of average elevation.

So, as a summary in this particular lecture we just got introduced to a LIDAR system which uses laser for surveying purposes. LIDAR stands for light reduction and ranging and we also seen the basic working principle of LIDAR system. With this we end this particular lecture.

Thank you very much.