SUSTAINABLE MINING AND GEOINFORMATION

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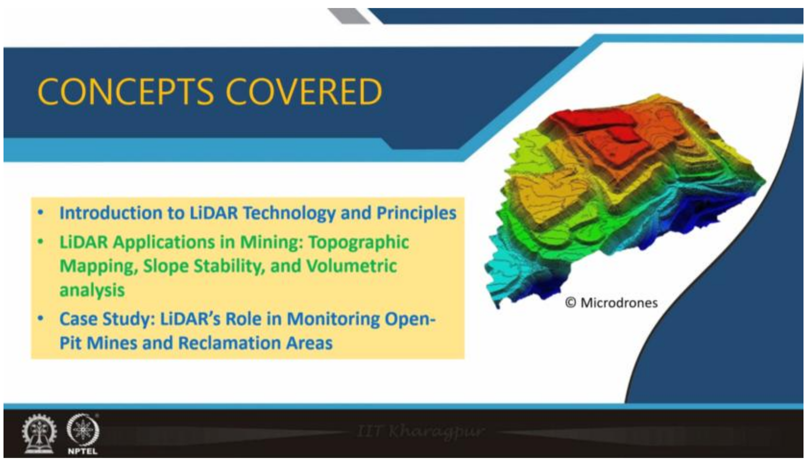
Week – 01

Lecture 03: LiDAR Remote Sensing

Welcome to the third lecture. On LiDAR and the mining industry. This is the third lecture as far as the sustainable mining and geoinformation course is concerned, and today we will be talking about the application of LiDAR remote sensing to the mining industry, and we will understand what LiDAR remote sensing is.

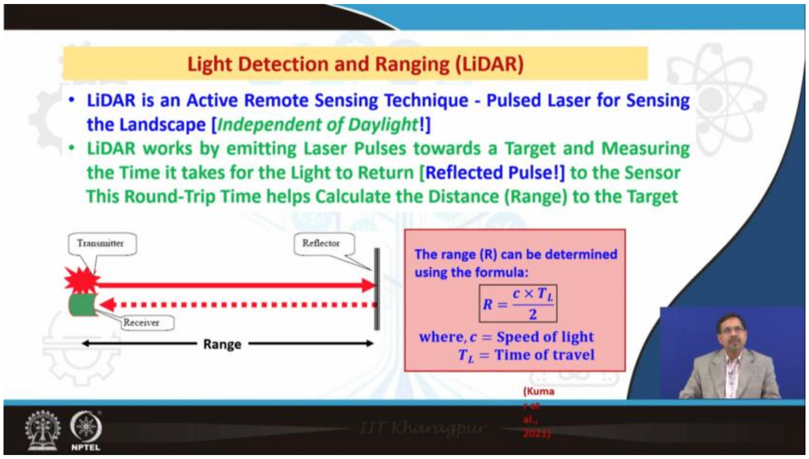
So, the concepts we will be covering today are an introduction to LiDAR technology and



principles, LiDAR applications in mining, particularly we will see topographic mapping, slope stability, and volumetric analysis, and one case study that talks about LiDAR's role in monitoring open pit mines and reclamation areas.

On the right-hand side, you can see a depiction that talks about the LiDAR-based topographic profile of a region, which you can very well see how precisely it has depicted the elevation. So, that means the LiDAR is giving very high-quality topographic maps, thereby helping in the calculation of elevation or mapping of the terrain and also related applications in terms of volumetric analysis and including slope stability. So, let us understand what LiDAR is.

The term LiDAR is expanded as light detection and ranging. So, the term ranging is there, which means it is based on a principle of receiving something and coming back or sending something and receiving back and then dividing the distance by 2. So, that actually takes the key note of ranging. So, friends, LiDAR is an active remote sensing technique, which



means the pulse laser for sensing the landscape is utilized. So, that means it is independent of daylight; the laser is thrown in terms of pulses to an area or to a surface or to a feature of interest.

And then we get back the reflectance pulse, the reflected pulse. So LiDAR works by emitting laser pulses towards a target and measuring the time it takes for the light to return. So, the time it takes to come back or return is defined as the reflected pulse to the sensor from where it was thrown, actually it was emitted, both are at the same place. So, to the sensor, this round trip, that means it goes and comes back. This settling trip, the time it takes is helpful in calculating the distance or the range from the emitter to the target. So, a simple depiction on the lower left corner talks about or gives an impression about the transmitter, which is on the left-hand side, and the reflector, that is the target, which is shown in the middle of the right-hand side. So, the light or the laser pulse is emitted or transmitted from there. and it goes and hits the reflector or the target and then comes back as a reflected pulse. So, the division or the round trip if calculated and divided by 2, it gives us the range, which is shown by the formula. The range, which is depicted as R (capital R), can be determined using the formula,

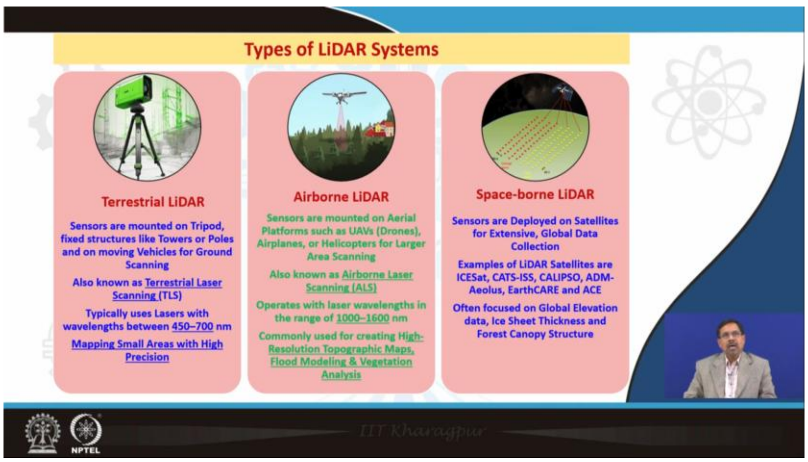
$$R = \frac{c \times T_L}{2}$$

Where, c = Speed of light

T_L = Time of travel

So, this is how the range is calculated as far as the LiDAR pulse or the reflected pulse is concerned.

So, let us see the different types of LiDAR systems available. We broadly categorize the LiDAR systems into three. One is the terrestrial, the second one is the airborne, and the third is the spaceborne, including if something is mounted on the International Space Station, abbreviated as ISS. And the first on the left-hand side, we are seeing the terrestrial LiDAR. So, there the sensors are mounted on a moving platform; it could be a tripod, a tower, poles, or on a moving vehicle for ground scanning.



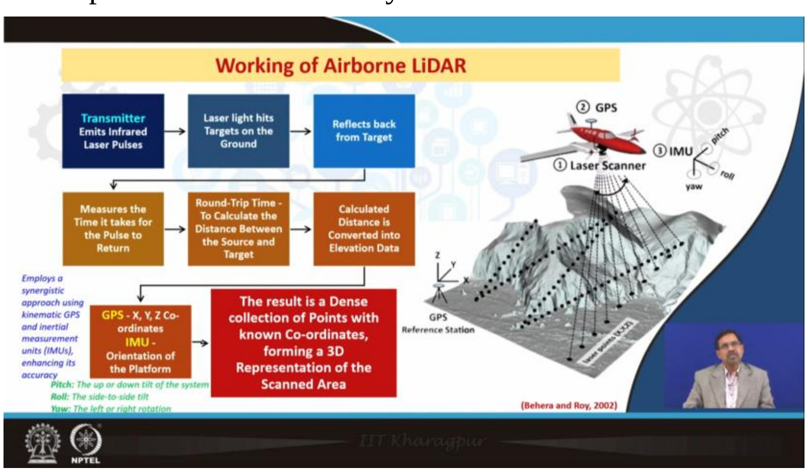
Then, typically, the pulse is thrown to the target, emitted from the emitter or the transmitter, thrown to the target, and it is returned or reflected back. So, this kind of scanning or sensing, which is mounted on a tripod or a moving vehicle, is broadly regarded as or termed as terrestrial laser scanning, abbreviated as TLS. Typically, this uses lasers between wavelengths of 450 to 750, broadly in our visible range, and it is useful in mapping small areas because we have a small field of view as we are mounting it on a tripod or a moving vehicle. But the important thing is that it gives us very high precision, a very high number of what you call pulses or clouds. So, then let us go to the airborne LiDAR.

As the term airborne is mentioned, the sensors are mounted on aerial platforms such as UAVs or drones, airplanes, helicopters, or similar kinds of vehicles for larger area scanning in relation to or relative to the terrestrial LiDAR. This is also known as airborne laser scanning or ALS, in contrast to TLS, terrestrial laser scanning; this is airborne laser scanning, abbreviated as ALS. This operates with laser wavelengths in the range of 1000 to 1600 nanometers, a little broader range. It is commonly used for creating high-resolution topography maps, flood modeling, vegetation analysis, and also some geological and mining applications. Let us come to the third category, which is the spaceborne.

So, spaceborne LiDAR, here the sensors are deployed on satellites for extensive global data collection. Examples are the LiDAR platforms from ICESat and CALIPSO, then EarthCARE, ACE, and GEDI. So, often focused on global elevation data, ice thickness, forest canopy structure, and some of the mining and geological applications. So, here we talked about three types of LiDAR systems: the TLS terrestrial laser scanning, the airborne LiDAR that is airborne laser scanning, and the spaceborne LiDAR.

Let us understand the working principle of airborne LiDAR. So, initially, we need to have a source called a transmitter that emits the infrared laser pulses, and then these laser lights hit the target or the object of interest on the ground, from where the pulse is reflected back from the target. And once the pulse or the laser pulse gets reflected back from the target, it is measured; the time taken for the pulses to return is measured, and this round-trip time is used to calculate the distance between the source of the emitter and the target. And once this is calculated, the distance is converted to elevation, a very high-precision calculation that can differentiate the small difference in the elevation, deformation, or height, whatever it is. So, then what is the synchronization? There is a very high-level synergistic approach employed between the GPS, which is mounted on the platform, and the IMU system, which also takes care of the orientation of the platform. So, the GPS and IMU employ a synergistic approach using kinematic GPS and the inertial measurement units. Thereby, it helps in enhancing the accuracy. So, friends, the GPS, the GNSS, which we broadly say GPS, is particularly for the US navigation system, but GNSS gives us x, y, and z coordinates. And this inertial measurement unit helps us in defining or giving the orientation of the platform in terms of pitch, roll, and yaw.

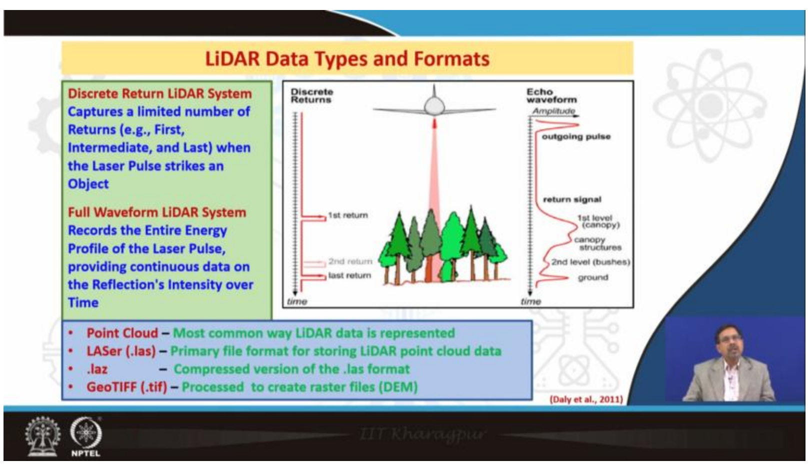
So, the pitch is the up and down tilt of the system. The roll is the side-to-side tilt. And the



yaw is the left or right rotation. This actually happens in terms of the airborne LiDAR, where the tilt, the side-to-side roll, and yaw are sometimes also calculated in terms of kappa, omega, and phi. So, once this synergistic approach is employed, the result is what we find: a dense collection of points, or what we sometimes call point clouds.

The collection of points are the clouds with known coordinates, forming a three-dimensional representation of the scanned area. So, the area over which it is scanned involves the whole process of emitting from the source and then the reflected pulse coming back. And then, finally, we get millions of points, which we call point-clouds, that give us or help us in creating a very good quality three-dimensional representation of the topography or the terrain, including the height as well.

So, the LiDAR data types and formats, once you understand the structure, let us understand the discrete return LiDAR system and the full waveform LiDAR system. As the term indicates, the discrete return LiDAR system captures a limited number of returns, for example, the first return, the last return, or one or two intermediate returns. So, that means the laser pulse is not in a continuous mode, and it depends on where we want to strike to reduce the number of data points. But the other one is the full waveform LiDAR system, which records the entire energy profile of the laser pulse. On the right-hand side, we can see the echo waveform where the amplitude, and a red color curve is shown, which is the depiction of the full waveform LiDAR, recording the entire energy profile of the laser pulse, providing continuous data on reflection intensity over time.



Look at the forest area or the depiction in terms of the few graphs. On the left-hand side, we have the discrete returns, which are the first, second, and last returns that probably give us the height in terms of where it starts from the ground, the intermediate, and the top tree canopy. But on the right-hand side, using the full waveform LiDAR system, we are getting the complete representation in terms of the canopy structure or any topographic or structural variation as far as the ground component is concerned. So, friends, the three or four terms that are used very frequently as far as data handling is concerned, we use the term point cloud frequently. That indicates the most common way of LiDAR data representation.

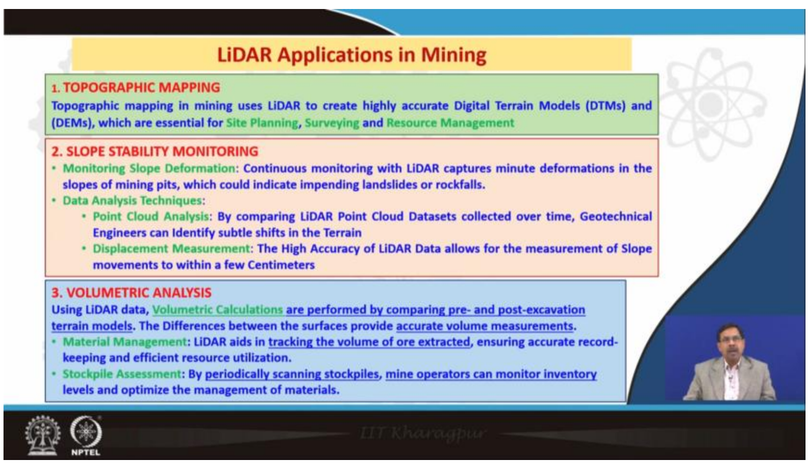
The laser, which has a LAS dot kind of expansion, represents the primary file format for storing the LiDAR point cloud data. .laz is a compressed version of the LAS format because of the letter 'z,' and we also process to create a lot of raster files to represent the digital elevation of the terrain model, which takes a kind of expansion in terms of .tif format.

Now, the advantage of the LiDAR system can be discussed under seven headings. It gives us very high precision and accurate elevation of the topographic data. That means for volume and height calculation or structural calculation, it is very highly precise and accurate because of the very thick data cloud.

Then, rapid data collection—yes, compared to other systems, the laser beams help in giving very rapid data collection or a rapid way of data collection. It has the ability to penetrate vegetation or structures or any other structural objects or objects having different structures on the ground, including some of the mining objects. So, it has the ability to penetrate, which is why it also gives us some information that is below the top canopy or the top surface. Then, coming to high data density—yes, it gives us millions of data clouds or data points over a centimeter square or a meter square area, one meter or one centimeter square area, depending on the data usage or our specification of how accurately we need it, but it has a good potential to give very high data density, thereby very high quality of digital elevation model or topography or terrain representation. It has a good potential to give very high data density, thereby very high quality of digital elevation model or topography or terrain representation.

Then, coming to the next ability is the day and night operation. As we understand, this is an active system; it is independent of night, independent of daylight or sunlight. So, it can operate in either condition because the source of emission or the transmitter is available with the same system. Then, coming to the integration with other data, yes, as an analyst, it depends on us how cleverly we integrate this data with other data coming from other sources so as to give an optimal, so as to bring out an optimum analysis which is useful for our application as far as the mining sector is concerned. Effectively, it is very, very effective over complex terrains. The terrains over which we cannot move, having more undulations, it is very, very effective because of high data density and the rapid, because of high precision and accuracy, and high data density, and also the rapid way of data collection. So, in essence, we would like to understand the advantage of remote sensing, that is, it gives us a very high precise and accurate topographical representation or the structural representation of any feature over Earth's surface.

Coming to some of the applications in the mining sector, we can put them under three. The first one could be the topographic mapping. Yes, topographic mapping in mining areas uses slider to create highly accurate DEMs or DTMs. So, the terrain or the elevation model we get is very highly accurate.



Data because of the high, what you say, level of data cloud and the accuracy. So, this essentially helps us for site planning, surveying, and resource management. If we know how much of the ore or minerals are available, where, and how much time we need for more of the accumulation or more of the distribution, then accordingly, we can do a very good site planning by using the topographical mapping. In other ways, it is also useful as a very good surveying tool and thereby resource management. Coming to the second important application in the mining sector, that is the slope stability. So, once we have a good terrain or the structural mapping or the topographical mapping, it leads to various applications, including the slope stability monitoring.

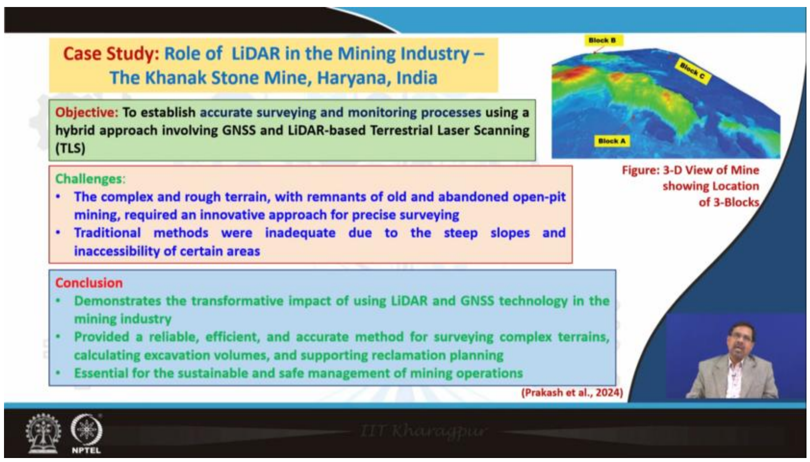
So, the slope deformation monitoring is one of the important areas of application in the mining sector. So, continuous monitoring with LiDAR captures minute deformations in slopes of mining pits, which could indicate impending landslides or rock falls, thereby helping the management or the or the policymakers to look into it and take the appropriate measures. The second one is the data analysis technique. So, broadly, the point cloud and the displacement measurements are the two broad techniques or important techniques as far as the data analysis is concerned.

So, as far as point cloud analysis is concerned, it involves comparing the LiDAR point cloud datasets collected over time. Geotechnical engineers can identify a lot of shifts or shifts with respect to the terrain as far as deformation studies and other applications are concerned. As far as the displacement measurement is concerned, the high accuracy of LiDAR data allows for the measurement of slope movements within a few centimeters, which means it is a very highly accurate source of information as far as LiDAR is concerned. Being able to measure movements within a few centimeters is really very helpful in terms of monitoring a lot of activities in the mining industry. The third one is the volumetric analysis.

Using the LiDAR data, volumetric calculations are performed by comparing pre- and post-excavation terrain models. So, once we have the data clouds, we have the point clouds, which helps us in going to the next step of calculating the volume. So, these are performed by a kind of comparative analysis in terms of post- and pre-excavation, which gives us the difference in terms of accurate volume measurement or the change or shift in the volume content. So, in material management, LiDAR aids in tracking the volume of ore that has been extracted, thereby ensuring accurate record-keeping and efficient resource utilization. This is one of the very important utilizations as far as management is concerned. So, if we have a LiDAR-based survey, we can very well track how much volume of ore is available, how much has been extracted, and how much needs to be extracted. So giving and getting an idea about this ensures a highly accurate record-keeping and efficient resource utilization, including marketing. Coming to the next one, which is similar to this, is stockpile assessment. Periodically, we need to use this technique to scan how much stock is remaining, how much has gone, how much is remaining, and how much is needed. Based on this kind of stockpile assessment, it helps the mining operators in monitoring and inventorying the levels of the ore or the deposition level. Thereby, the management of materials is highly optimized.

Let us have a look with respect to one case study that has been done in Haryana, located at the Khanak stone mine. So, where the LiDAR has been used.

So, the LiDAR has been used to establish accurate surveying and monitoring processes using a hybrid approach involving the GNSS and LiDAR-based terrestrial laser scanning. So, this LiDAR TLS, which is terrestrial laser scanning (TLS), has been used for accurate survey and monitoring. So, what are the challenges? The challenges are the complex and rough terrain with remnants of old and abandoned peat mining. It required an innovative approach for precise surveying.



So, since the terrain was rough and complex, this posed a challenge that it needs a very high-precision surveying tool for monitoring the abandoned old or abandoned pit mining areas. Whereas the traditional methods were not adequate due to steep slopes and inaccessibility as far as certain areas are concerned. So, inaccessible areas require a good topographical terrain topographical survey, and for resource monitoring, the TLS use is very advantageous. So, the conclusions drawn from this study are that the application of LiDAR demonstrated the transformative impact of using LiDAR and GNSS technology in the mining industry.

This study also provided a reliable, efficient, and accurate method for surveying complex terrains. That was done using a lot of calculations as far as volume excavation is concerned. It also helped in supporting the reclamation planning. Another important observation from the study was, It was essential for sustainable and safe management of mining operations. The study, which has been recently published by Prakash et al. this year, has generously observed, found, and demonstrated that using LiDAR over rough and complex terrain, very precise surveying could be done, which has applications as far as resource management is concerned.

The upper right figure demonstrates a 3D view of a mine, showing the location of three blocks: block A, block B, and block C. The color gradation from green to red indicates the terrain or the elevation. You can see how much stockpiling of the mineral ore deposits there is. So, that gives us the first impression, and we can very well calculate how much volume or what the amount of stock of which mineral or ore is available. That helps us in stockpiling assessment as far as laser-based information is concerned.

So, these six references were used for this particular lecture.

At the end, the five points we discussed allow us to conclude that LiDAR technology is crucial in the mining industry. It helps in improving precision, increasing efficiency, and enhancing safety as far as the management of the mining industry is concerned. It also provides accurate three-dimensional spatial data for key applications like topographic mapping, slope stability monitoring, and volumetric analysis. So, it is very important to

use such a high-precision technology for accurate topographic, structural, or volumetric analysis.

LiDAR supports effective mine planning, management, and safe practices by virtue of providing very precise topographic and structural information. This technology, LiDAR technology, aids in sustainable resource management through detailed terrain modeling and monitoring. So, as far as the advances in the mining sector are concerned, LiDAR and remote sensing, or we say LiDAR remote sensing, will have essential implications for very precise, reliable, and efficient surveying. Friends, as we move on, we will use this LiDAR-based technology for different applications as far as the mining industry is concerned, and during that time, we will also get into a lot of illustrations and calculations as far as the LiDAR-based data and the data cloud are concerned. Thank you very much.