SUSTAINABLE MINING AND GEOINFORMATION

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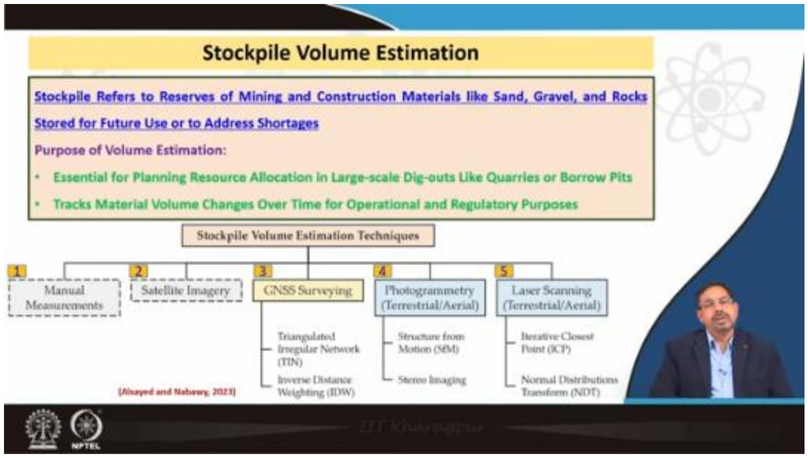
Week – 03

Lecture 15: Volume Measurement and Geospatial Techniques

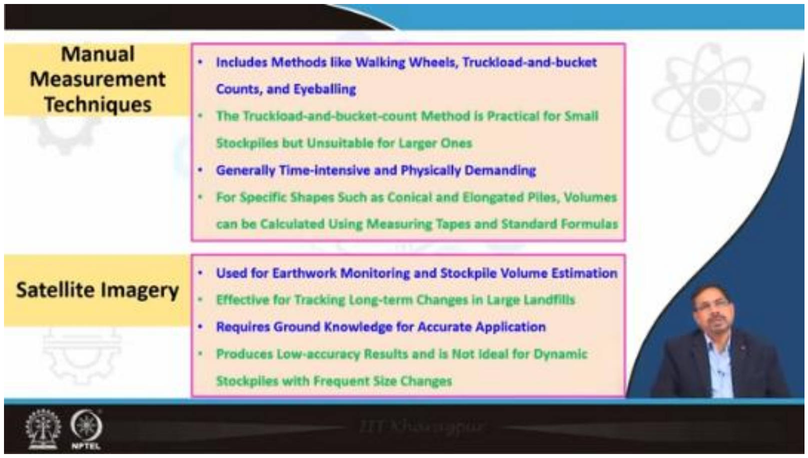
Welcome, welcome to the 15th lecture on volume measurement using geospatial techniques. here we will be ah introducing you to different measurements as far as stockpile and volumetric changes are concerned in mining areas using photogrammetry and lidar based principles. Friends, in our second week, in one of the lectures, we have discussed in general the different data sources to give us the three-dimensional or volumetric measurement or estimation of the substances which is present around the mining industries. So, as far as the technique is concerned, as far as the data sources are concerned, we have already had a discussion, but few of them we will be also repeating here for our clarity in terms of how in different conditions we come out with measurement as far as stockpiling or different volumetric changes are concerned. Then we will discuss about the estimation of excavation volumes and how they can be tracked in terms of the material movement in industry sector particularly mining industry.

So at the end we will also take two case studies in terms of volumetric analysis for resource management and mining planning. What do we understand by stock volume or stockpile volume estimation? The stockpile refers to reserves of mining and construction materials like sand, gravel and rocks stored for future use or to address any kind of shortages. So, that means it has to be it is a regular activities. So, the ores the mineral ores the materials the other substances like sand gravel and rocks they need to be stockpiled for use or to address any kind of shortages.



So now the question is how to come out with the estimation of how much quantity of the stock has been piled. So how much remote sensing GIS or in general the geo information tools have a role to play here in this assessment and monitoring exercises. so the purpose of volume estimation are essential for planning resource allocation in large-scale digouts like quarries or borrows and pits so this will also be linked to economy to marketing how much we have in stock how much is is the demand how much more we have we have to generate or how much we have in excess so it helps the stockpiling estimation helps in linking to market demand as well and this stockpiling in terms of volume estimation helps in tracking the material volume and that the change over time for different operational regulatory processes or purposes so stockpile volume estimation techniques as far as geo information is concerned could be of these five categories we can put them one is the manual measurements so by using the traditional methods the way we have been measuring them second using satellite imageries third using the global navigation survey based system or surveying principle fourth using the photogrammetry the digital photogrammetry principle

And then the fifth is using the LiDAR scanning. So LiDAR scanning as we already understood it gives us very high precise data in terms of generating lot of data clouds. So let us study and understand these five techniques as far as the stockpile volume estimation is concerned. So, what is the manual measurement? So, the techniques that we usually follow in terms of manual measurement are methods like walking wheels, truck load and bucket counts and eyeballing.

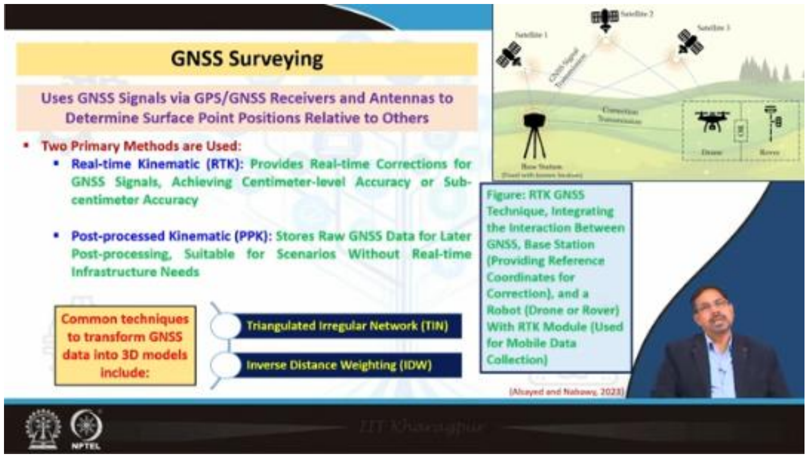


So what happens you say that okay this much of torque can load has gone so this accounts to this much tons so accordingly this more is left kind of approximation in terms of counting how much has gone how much could be left approximately. Another is eyeballing. Based on our own experience by seeing it again and again over time, we can come out with an approximation by just seeing or rotating our eye called as eyeballing that okay this much probably is the stock which is available with us. so this is a kind of traditional method the truckload and bucket count methods is practical for small stockpiles but not suitable for very large ones generally it is time intensive and physically demanding you need to go and be there on ground on spot to see it again and again how much and estimate it how much is there or how much is gone or what is the change or what is the dynamics So for specific shapes such as conical elongated piles, the volume calculation may be little tricky.

We need to use some measurement tapes or some standard formula, but they may be always a kind of approximation. Then let us take the use of satellite. Let us understand how satellite imagery can have a role to play in terms of giving us good or accurate estimation as far as the stockpile volume is concerned. So, satellite data are used and effective for tracking long-term changes in large landfills or depositions. It requires little bit of ground-based knowledge for accurate application, for validation, for input.

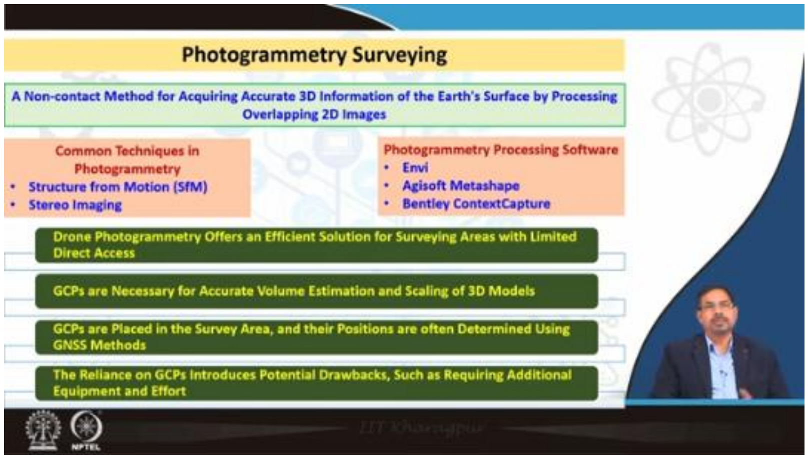
And thereby it produces low accuracy results and is not ideal for dynamic this is it produces good result the it is little bit typo error here and it is it gives us very how do you say a good situation for frequent monitoring in terms of the change in terms of the change in the stockpile activities. And let us come to GPS or GNSS. Traditionally it is called GPS Global

Position System. We have already studied it in one of the past class lectures. So the Global Navigation Survey System.



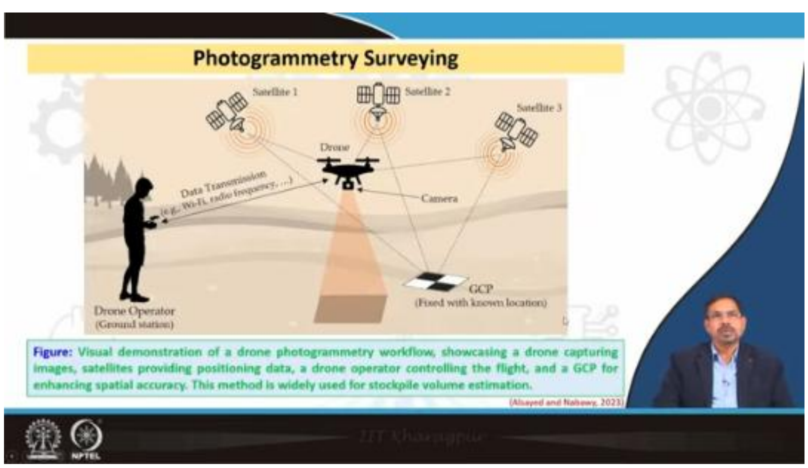
So you have the signals received by receivers and antenna and that helps us in terms of detecting the surface point position relative to other. So, there are two modes the RTK and PPK. In RTK it provides real time corrections for GNSS signals achieving centimeter level accuracy but sub centimeter or sub centimeter level accuracy depending on the what you say positioning of different satellites from how many satellites we are calculating the position. And then the post-processed kinematics PPK, here it stores raw GNSS data for post-processing at a later stage. That is how it is suitable for scenarios without real-time infrastructure need.

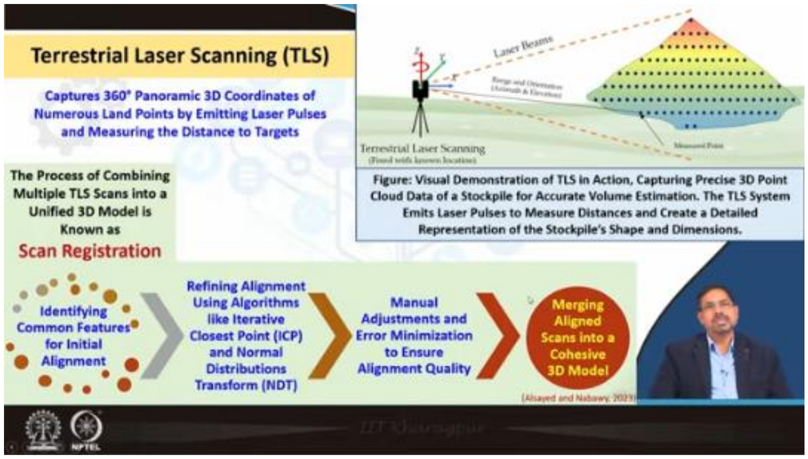
The figure on the right hand side tells us the different satellites positions from where the signals are received and you have a surveying system where drone and other things are also can be linked and you have a rover, you have a base station that is how the GNSS functions. So, the common techniques to transform GNSS data into 3D models include generating a TIN, a kind of vector based triangulated irregular network model that gives us impression about the three dimension of the volume or doing a kind of inverse distance weighing IDW principle. So, let us see in terms of the photogrammetry based survey a non-contact method for acquiring accurate three-dimensional information of the earth surface or the stockpile areas can be processed overlapping the two-dimensional images. So, the common techniques are coming out with a structure from motion or using stereo pairs or the stereo imaging principle. so we have different softwares available so the drone photogrammetry offers an efficient solution for surveying areas with limited direct access we know that drone



offers a platform for giving the stereopairs, the photogrammetry based survey over a small area which has no access or limited access or limited direct access. The ground control points, the GCPs are necessary for accurate volume estimation and scaling off to a kind of three-dimensional models. The GCPs are placed in the survey areas and their positions are often determined using the GNSS methods. The reliance of these ground control points introduces potential drawbacks such as requiring additional equipment and efforts. So, friends this is how we collect lot of ground based points and the stereo pair imaging using the GCPs or the drone based platforms.

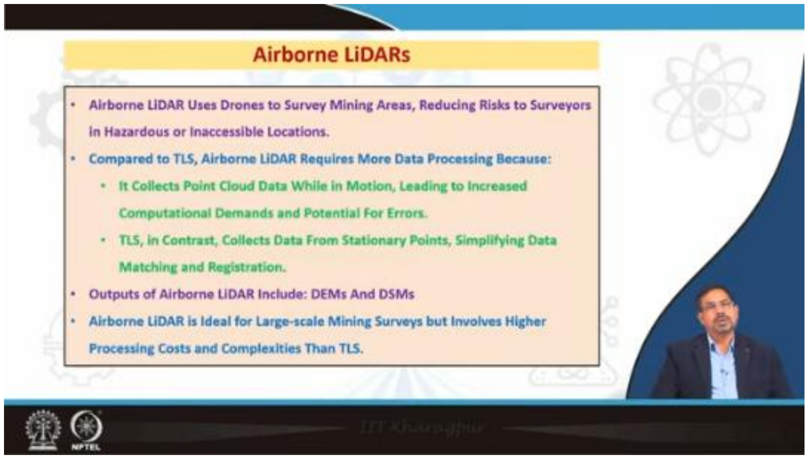
So, once this is done, you can see a picture here, the visual demonstration of a drone photogrammetry surveying. And similarly, we also have discussed as far as the TLS, the terrestrial laser scanner is concerned. It captures 360 panoramic three-dimensional coordinates of numerous land points by emitting laser pulses and measuring the distances to the targets. On the upper right hand side the figure itself is so clearly depicting the principle of terrestrial laser scanning where the laser beams on both up and down is shown in red dotted lines.





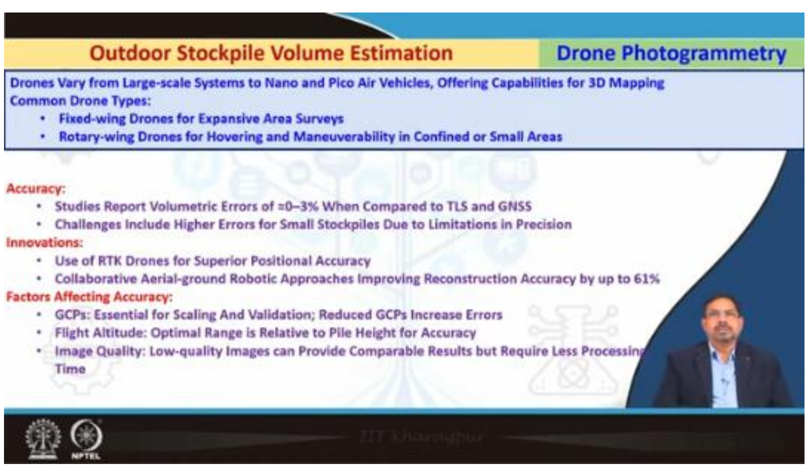
And the visual demonstration of the terrestrial radar scanner which says that it captures the precise 3D points or the 3D point clouds data of a stockpile for accurate volume estimation. The TLS system emits laser pulses to measure the distance and creates a detailed representation of stockpile shape and dimension. So, in essence the volume can be very well generated using the data clouds coming or three-dimensional data clouds coming point data clouds coming from the terrestrial laser scanning system. The process of combining multiple TLS scans into a unified 3D model, which is known also as scan registration. So this helps in identifying the common features for initial alignment.

Once the common feature are identified for initial alignment, then we go to the next step of refining this alignment. Once little bit adjustment and refinement is done using the algorithms like ICP iterative closest points and NDT the normal distributions transfer function. further what is done manually adjustments and error minimization is done to ensure the alignment quality so this finally is merger align the scans into a cohesive three-dimensional model which is in form of a what you say which is coming from stockpile or any kind of volumetric deposition on a mining industry. So, now coming to the airborne lidars.



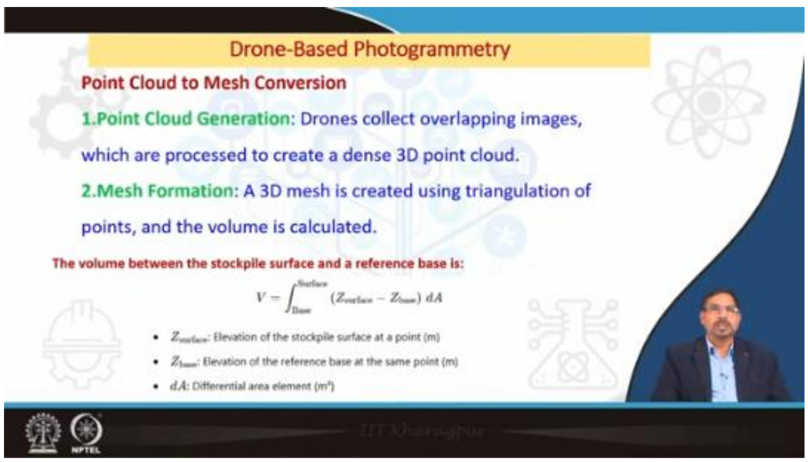
The airborne lidar uses drones to survey mining areas that reduces the risk of surveyors compared to the terrestrial lidar scanner airborne lidar requires more data processing because It collects point clouds while in motion, leading to increased computational demands and potential for errors. So in contrast to TLS, airborne requires more data because it captures in motion. So there could be a lot of errors also incorporated into that. Whereas TLS collects the data in stationary points, so simplifying the matching and registration process.

So in either case, particularly for airborne LiDAR, it gives DEM elevation model and DSM the surface model. So this airborne LiDAR is ideal for large scale mining service but involves higher processing cost and complexities. So TLS has more control because it is from a stationary platform. So let us come to the drone photogrammetry for outdoor stockpiling or volume estimation. Drones vary.



So principle is the same. You put the camera, the sensor on this and that gives you the potential as far as the fixed wing drones are concerned or the rotary wing drones are concerned. So, the accuracy of the study is in terms of 0 to 3 percent errors when compared to TLS or GNSS based the volume estimation for stockpiles. So, this kind of techniques are available these days and the mathematics goes behind that is point cloud as far as the drone based photogrammetry the point cloud to mesh conversion

So, point cloud generation drones collect overlapping images. So, also TLS and whatever imaging done from the airborne platform. So, these are processed to create a dense three-dimensional point cloud and then a three-dimensional mesh is created using the triangulation of the points and that is how the volume is calculated. So, the volume between the stockpile surface and a reference base is calculated using such a formula. V transfer that is going between integral of base to surface in terms of the height or the volume.



So, Z surface minus Z base and delta A. Z surface represents the elevation of the stockpile surface at a point M. Whereas Z base refers to the elevation of the reference base at the same point m. And dA is the differential area element which is calculated in terms of meter square if all of them are in meter.

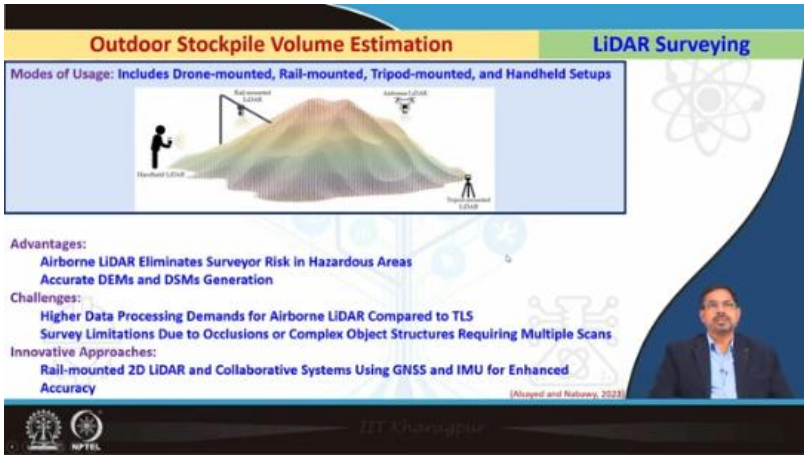
$$\int_{Base}^{Surface} (Z_{Surface} - Z_{Base})dA$$

$Z_{Surface}$: Elevation of the stockpile surface at a point (m)

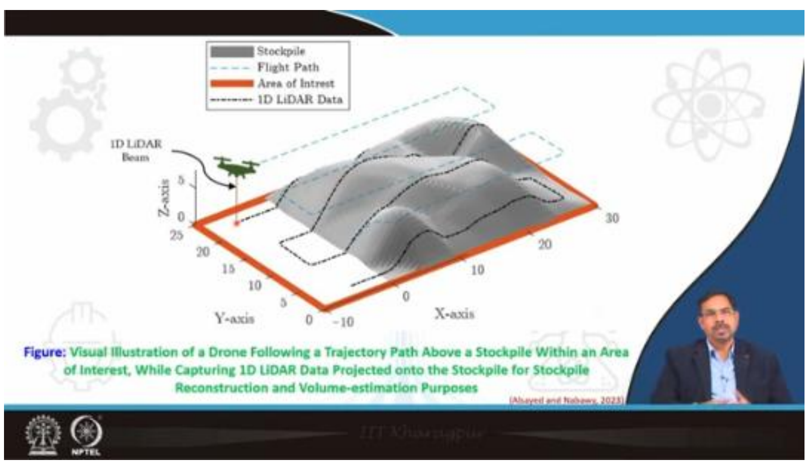
Z_{Base}: Elevation of the reference base at the same point (m)

dA: Differential area element (m^2)

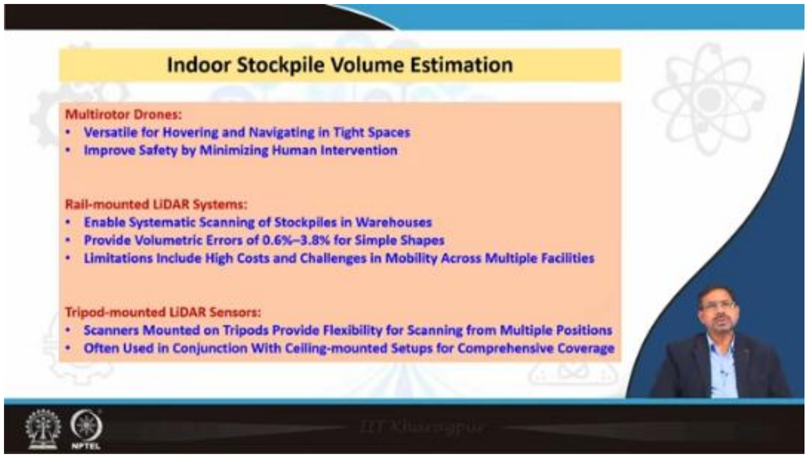
So, the outdoor stockpile information, you can see the stockpile in form of a defiction. The advantage of airborne is that you have accurate DEM and DSMs. So, the innovative approaches, rail-mounted two-dimensional LIDAR and collective systems using GNSS and the IMU for enhanced accuracy as far as the LIDAR-based survey is concerned.



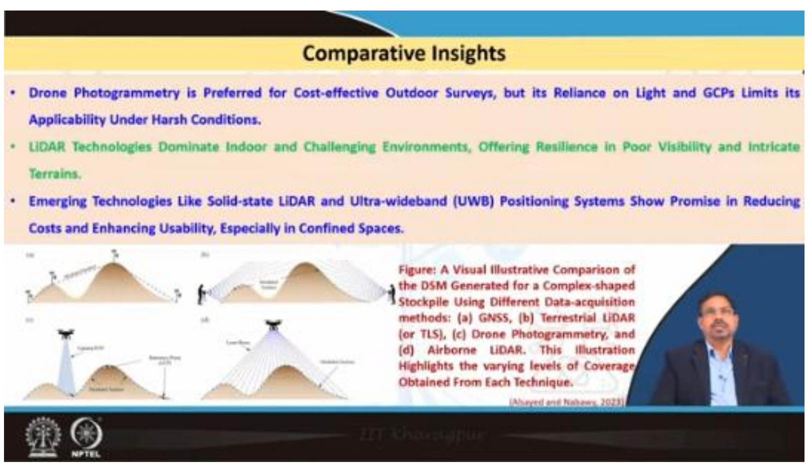
So look at this illustration where it is visually shown a drone following the trajectory in terms of path above a stockpile within an area of interest while the drone has captured one dimensional LiDAR projected onto the ground. while capturing one-dimensional LiDAR data projected onto the stockpile for stockpile reconstruction and volume estimation process. The gray three-dimensional things are the stockpile and the flight path are also shown and the area of interest, the total area where the stock is piled is the area of interest. Now, once the single or one-dimensional LiDAR beams are thrown and you get the LiDAR backscatter and you come out with a tin and a mesh and a three-dimensional model which gives us the volume. Then the volume is linked to the, what you say, mass or the quantity and throw some allometric equation and then you come out with the amount or quantity of the stock which is filed there.



So, ah indoor stockpile volume estimation for this we have multi rotor drones. So, these are actually versatile for hovering and navigating in tight space where where in in contrast to the outdoor in in the indoor stockpile you have less space available. So, there the the what you say multi rotor drones are useful. And even if the rail mounted lidar systems enable schematic scanning of stockpiles in warehouses, they can also provide volumetric errors up to 0.6% to 3.8% for simple shapes. Whereas the limitation include high cost and challenges as far as the mobility across the multiple facilities is concerned.

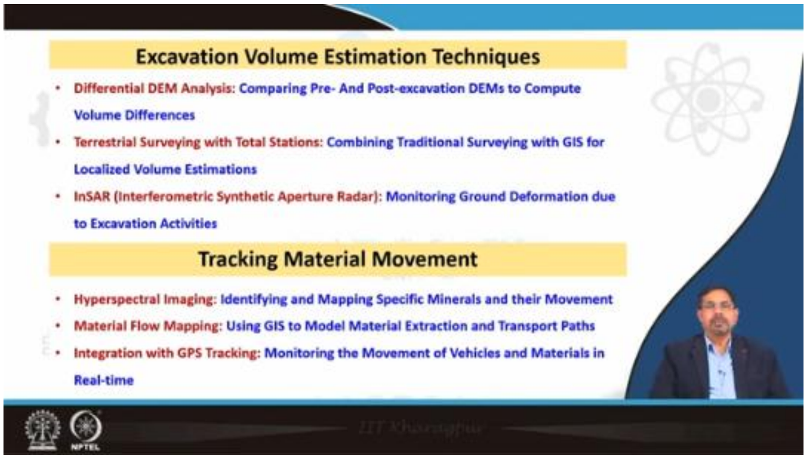


Let us have a look at the other one is the tripod mounted lidar sensors. So, these scanners mounted on tripod provide flexibility for scanning from multiple positions, but often used in conjunction with ceiling mounted setups for comprehensive coverage. Friends, these three ways the indoor stockpile information is derived from multirotor drones, rail mounted lidar systems and from tripod mounted lidar systems. So, the comparative insights as far as drone photogrammetry is concerned, it is preferred for a cost effective outdoor service, but its reliance on light and GCPs limits its applicability under harsh conditions.



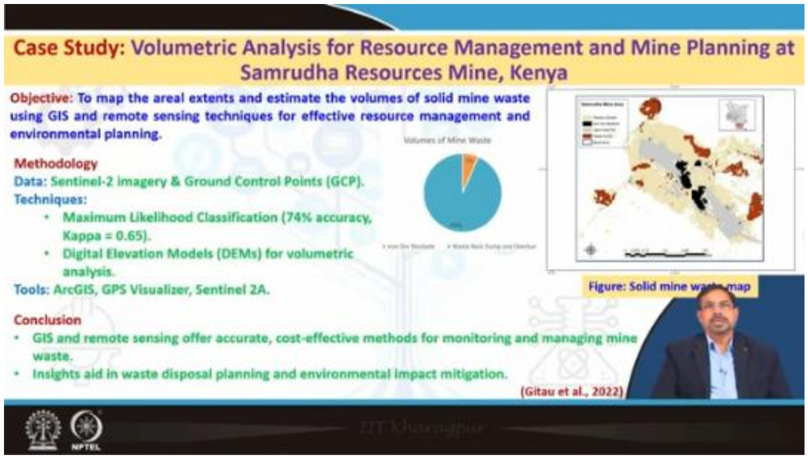
So, optical has that limitation as far as light availability is concerned. Or all other capabilities are concerned. Whereas LiDAR technology dominates indoor and challenging environments, offering resilience in terms of poor visibility and in terms of challenging terrains. So, emerging technologies like solid-state LiDAR, ultra-wideband positioning systems, show promise in reducing cost and thereby enhancing usability, especially in confined spaces. So, down below, we have given four different definitions as far as how the four different ways of data acquisition can be shown: first one is GNSS-based, second one is terrestrial LiDAR scanner, third one is drone photogrammetry, and the fourth one is the airborne LiDAR system.

So, this illustration highlights the varying levels of coverage obtained from different techniques, all four different techniques. Coming to the excavation volume estimation techniques, three ways we want to discuss here. First one is the differential DEM analysis, comparing the pre- and post-excavation DEMs to capture the volume differences. Second, terrestrial surveying with a total station kind of approach where the GNSS principle is used. So, that combines traditional surveying with GIS for localized volume estimation.



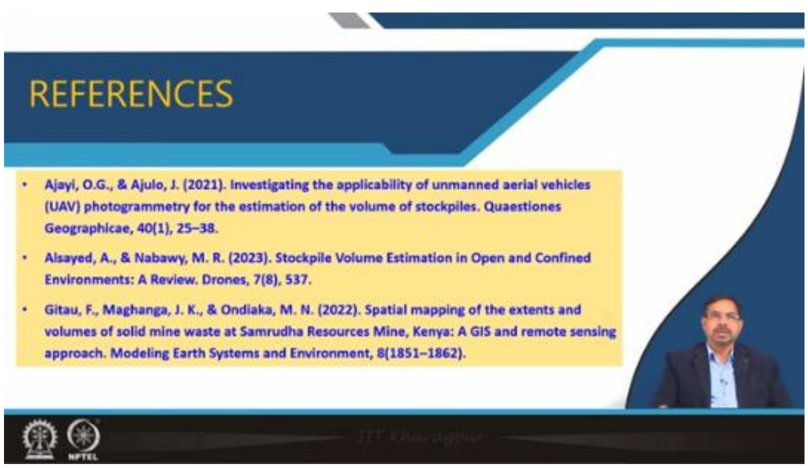
Whereas the SAR-based, particularly interferometric SAR or you say InSAR-based monitoring, gives us very fine information as far as the ground deformation due to the excavation activities is concerned. Now, coming to tracking the material movement. So, hyperspectral material flow mapping and integration with GPS tracking. So, hyperspectral imaging helps in identification and mapping because of the minerals, because of very high spectral resolution, as all of us know. The material flow mapping uses GIS to model material extraction along the different transport paths given.

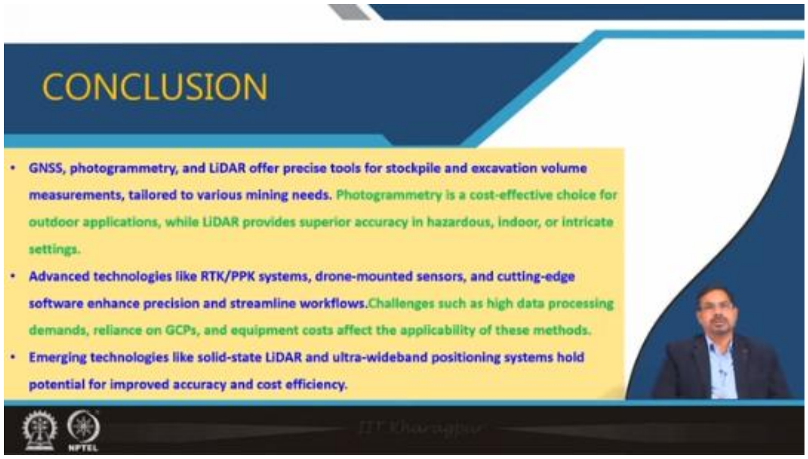
So, integrating this with GPS tracking helps in monitoring the movement of vehicles and materials in real-time mode. So, let us have a look at these two case studies. Volumetric analysis for resource management and mine planning at Samrudha Resource Mine in Kenya. So, the objectives defined by Gitau et al. in 2022



are to map the aerial extents and estimate the volumes of solid mine waste using GIS and remote sensing techniques. In terms of methodology, the data used are Sentinel-2 images and ground waste control points. The techniques in terms of classification use maximum likelihood (MXL), which gave 74% accuracy, and the DEM was used for volumetric analysis. The professional tools used were ArcGIS, GPS Visualizer, and Sentinel-based Snap software. So, on the right-hand side, what could be found is the solid mine waste map, shown in different color formations. So, the conclusion: G1 formation offers accurate, cost-effective methods for monitoring and managing mine waste.

Insights aid in waste disposal planning, environmental impact mitigation, and stockpile assessment and monitoring. So, these are the references that have been used for this particular study. So, let us conclude. The global navigation surveying system, photogrammetry, and LiDAR together offer precise tools for stockpile and excavation volume measurement, tailored to various mining needs. So, these are the four different tools we discussed.





One is how the points, the particular GCPs (ground control points), are gathered using the Global Navigation Satellite System (GNSS). Second, the photogrammetry where you take the image from two different angles. So, in a fore or aft mode, we put them under a stereo pair. So, photogrammetry uses the principle of a stereo pair, meaning by looking at the same point from two different angles, the third dimension is generated. We also discussed interferometric SAR.

So, differential SAR means SAR interferometry, and the differential SAR interferometry principle provides information that helps generate the third dimension or volumetric information. And LiDAR. LiDAR gives us numerous data points or point clouds. This LiDAR can be mounted on different platforms. It can be mounted on a drone platform.

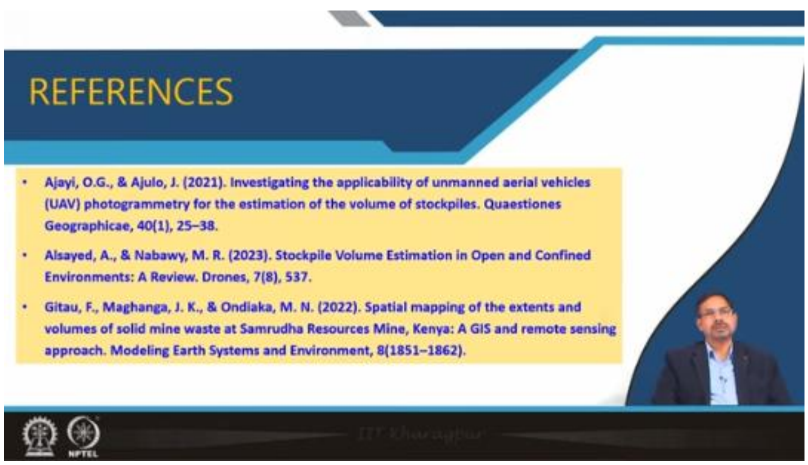
It can be mounted on an airborne platform. It can be mounted on a tripod or on a rail. So, based on the situation, whether outdoor or indoor monitoring or data capture, the platform can differ. So, they provide different types of information which are useful for volumetric assessment, whether for stockpiling or excavation volume—how much we need to excavate to achieve a certain amount of stockpile. That is how we perform what you might call a

very planned very planned way we go for excavation and we go for the managing the stock so that is how the geo information is extremely useful for this so photogrammetry is a cost effective choice for outdoor application whereas lidar provides superior accuracy in terms of hazardous or indoor or intricate settings are concerned Now, let us we also have discussed about the advanced technologies like RTK and PPK as far as the GNSS is concerned. The drone mounted sensors and cutting edge software that enhance together enhance the precision of this volumetric estimation as far as the stockpiling is concerned. And also the streamlining of the workflow that yes this is what is the demand, this is what is the excavation volume, the amount of volume to be excavated so that we can have this much of stockpiling. This much is available, this much is required.

So in terms it gives information for very good pre-planning. So, the challenges in such activities are high data processing demands. Yes, when we deal with the volume, we also deal with voluminous data, which is coming in terms of data point clouds, both from LiDAR or from the digital photogrammetry or from GPS or GNSS based GCPs or data points. Whereas, the reliance on the GCP is higher or we need to always improve the reliance on GCP. So, that means it has to be collected using maximum care.

And the equipment cost also affect applicability of these methods. So the cost of these drones, the lidars for indoor and outdoor mapping and generating the data clouds is very, very high. But it gives you an accurate measurement. So we need to also work on minimizing the cost as far as the equipment is concerned. Now, coming to the emerging technologies.

So, emerging technologies like solid-state LiDAR and ultra-band positioning systems are considered. They hold potential for improved accuracy and cost efficiency. So, these references have been used in detail. So, the first one is Ajayi and Ajulo. So, they have investigated the applicability of UAV (unmanned aerial vehicle) photogrammetry for the estimation of the volume of stockpiles.



It was published in 2021. So, very means in a kind of regular way or in an operational way. Now, the volume of the stockpile is estimated using satellite data or, as we mentioned, in general, using either of these four principles coming from the either of the four. I am eliminating the traditional one. So, I am talking of the satellite-based, maybe digital photogrammetry using. Stereo pairs, talking of GCPs coming from GNSS, talking of the

SAR interferometry, that is coming from the LiDAR platform. Be it airborne, be the sensor on a drone, on a rail track, or on a tripod.

But their data processing techniques differ, and so does the accuracy. So, the second one by Asayet and Nabowe, published in 2023, talked about the stockpile volume estimation in open and confined environments. So, using—so it was published in Drone. So, in both open and confined environments, they have done a study and come out with the stockpile volume estimation. So, similarly, another study by Gitao et al. in 2022,

And they found, or they have done, the spatial mapping of the extent and volume of solid mine waste in a mine area in Kenya using remote sensing. So, what I mean to say is that these days, the utilization of geo-information tools is giving us accurate information as far as stockpile and volume estimation are concerned. Thank you very much.