LiDAR TECHNOLOGY AND ITS APPLICATIONS

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Abstract: The acquisition of geo-data has long been, and continues to be, a cumbersome, labour-intensive and expensive task. The past decade has been witness to a favorable development, which is the rise of new remote-sensing techniques able to collect geo-data in an automated manner. In particular, techniques enabling the highly automated collection of 3D geo-data in the form of Digital Elevation Models have rapidly emerged and are now at the leading edge. Discovery of different laser sources, improvements in detector technology, data collection and analysis techniques have made the LiDAR a reliable tool for atmospheric science research.

This paper provides study of available LiDAR systems like Differential Absorption LiDAR(DIAL), LiDAR Technology Experiment(LITE), Giant Aperture LiDAR Experiment(GALE), Purple Crow LiDAR, SHOALS Airborne LiDAR, Scanning Aerosol Backscatter LiDAR(SABL), CO_2 Doppler Pulsed LiDAR, ULM Airborne LiDAR, TopoSys LiDAR System), ALS50 LiDAR System with their specification and specific use.

The varied application in areas particularly in Environmental Engineering where this technology has been successfully employed is reviewed in detail. The paper also outlines the potential of this technology, and use of this Technology in reference to India with some case studies as LiDAR study of air quality in the atmospheric boundary layer in Pune, Monitoring of vertical profiles of minor constituents in the atmosphere of New Delhi, Study on planetary atmospheres and ssurface measurements of ozone in downwind side of major industrial region of Gujarat from India.

Keywords: Laser, Radar, Electromagnetic radiation and Scanning

I. INTRODUCTION

Remote Sensing is the science and art of acquiring information (spectral, spatial, and temporal) about material objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation. In remote sensing, information transfer is accomplished by use of electromagnetic radiation (EMR). EMR is a form of energy that reveals its presence by the observable effects it produces when it strikes the matter.

1.1. Indian Remote Sensing Satellites

The Indian Remote Sensing (IRS) satellites that are in operation at present include IRS-1C, IRS-1D, IRS-P3, IRS-P4 and Technology Experiment Satellite (TES), IRS-P5 (Resourcesat-I). IRS-1B, which was launched in August 1991, was decommissioned during the year after it served for more than 10 years, even though it was designed for only three years life.

1.2 Remote Sensing Centres in India

Regional Remote Sensing Service Centres located at Bangalore, Dehradun, Jodhpur, Kharagpur and Nagpur is carrying out a number of remote sensing application projects. The State government of Uttar Pradesh, Madhya Pradesh, Arunachal Pradesh, Sikkim, Gujarat, Mizoram, Orissa, Rajasthan, Haryana, West Bengal and Manipur has already set up SNRMS and efforts are being made in generation of natural resources census and human resources development in the area of remote sensing and GIS. The North Eastern Space Applications Centre (NE-SAC) established in December 2000.

1.3 LiDAR Remote Sensing and Advantages

LiDAR (Light Detection and Ranging) is an active remote sensing system which employs a laser as the light source. Ligda (1963) made the first LiDAR measurements of cloud heights and tropospheric heights. LiDAR has great potential to provide solutions which were not deemed feasible hitherto. There are following advantages by LiDAR Remote Sensing:

Accuracy: The ability of LiDAR to measure terrain with an accuracy of order 10-15 cm in the vertical and 50-200 cm in the horizontal is claimed by manufactures and has been demonstrated by many field studies.

Time of Data Acquisition and Processing: The data capture and processing time is significantly less for LiDAR compared to other techniques. LiDAR can allow surveying rates of up to 90 km^2 per hour.

Minimum User Interference: User interference is minimized as most of the data capture and data processing steps are done automatically by the software. User involvement is only needed in maintaining the ground GPS station and, if required, processing of the raw data for more specific information.

Weather Independence: LiDAR is an active illumination sensor and can collect data at night and is operated in slightly bad weather and low sun angle conditions, which prohibit the aerial photography. Only substantial precipitation or fog or extremely bad weather, which restricts the operation of an aircraft, prevents the data capture.

Canopy Penetration: Unlike photogrammetry, LiDAR can see below canopy in forested areas and provide topographic measurements of the surface underneath. Additionally, LiDAR generates multiple returns from single plus travel, thus providing information about understory.

Data Density: LiDAR has the ability of measurement subtle changes in the terrain as it generates a very high data density (2000-25000pulses per second).

Ground Control Point Independence: Each LiDAR Pulses is individually georeferenced using the GPS, INS and laser measurements onboard. Only one or two GPS ground stations are required for improving the GPS accuracy by the differential method.

Digital Compatibility: Data produced from LiDAR flights are in digital format with Easting, Northing and elevation values of each laser target. This makes the importing of data to GIS and other image processing packages straightforward.

II. MECHANISM OF LiDAR SYSTEM

A LiDAR is similar to the more familiar Radar, and can be thought of as laser radar. RADAR is an acronym for Radio Detection and Ranging. It operates in part of the microwave region of the electromagnetic spectrum, specifically in the frequency interval from 40,000 to 300 megahertz (MHz). In radar, radio waves are transmitted into the atmosphere, which scatters some of the power back to the radar's receiver.

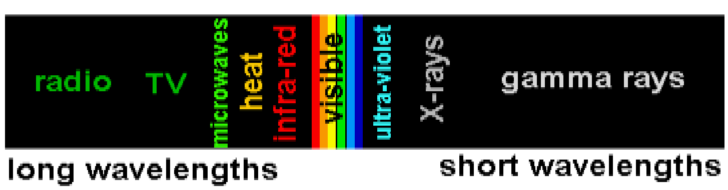

Figure 1: Different Wavelength Range for Rays

A LiDAR also transmits and receives electromagnetic radiation, but at a higher frequency. LiDAR operates in the ultraviolet, visible and infrared region of the electromagnetic spectrum (Fig.1). Different types of physical processes in the atmosphere are related to different types of light scattering. The receiving system (Detector, mounted on Telescope) records the scattered light received by the receiver at fixed time intervals. LiDAR typically uses extremely sensitive detectors called photomultiplier tubes to detect the backscattered light.

Photomultiplier tubes convert the individual quanta of light, photons, first into electric currents and then into digital photo counts which can be stored and processed on a computer.

Fig. 2 given below is showing different LiDAR components. Trigger is used to measure time of flight and then signal comes from detector as well as trigger processed in computer through transient Recorder.

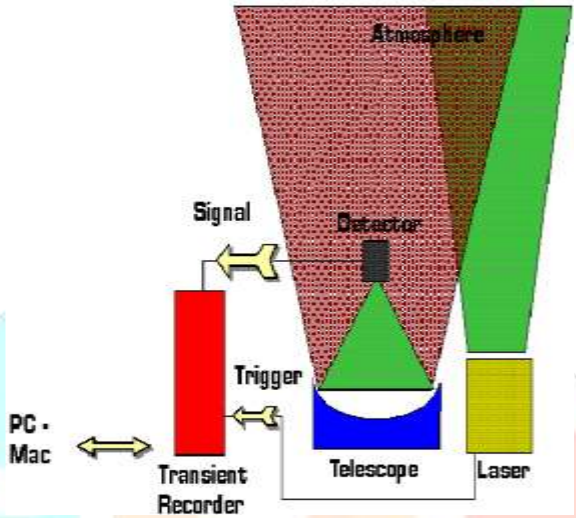

Figure 2: Showing Components and Working Principle of LiDAR System

2.1 Operational Details of LiDAR

A Flow Chart given below shows operational steps (Fig. 3):

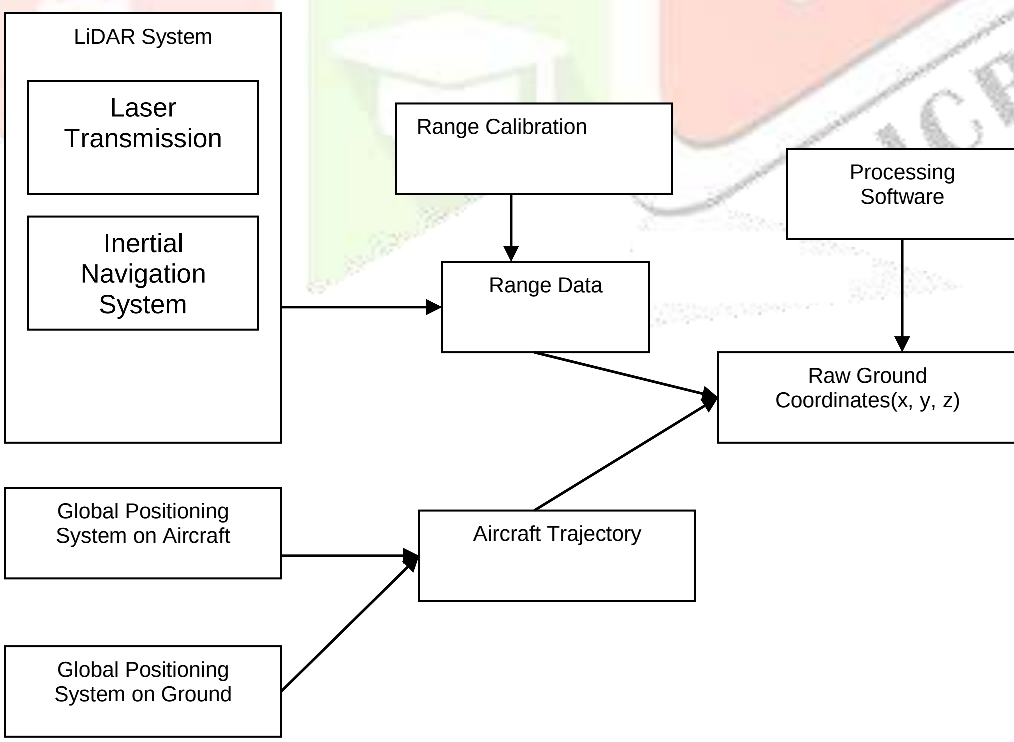

Figure 3: Operations in LiDAR Remote Sensing

Laser Transmission: It is the central part of a LiDAR system. An intense pulse of the optical energy emitted by a Laser is directed through some appropriate output optics towards the target of interest. The function of the output optics can be three fold to improve the beam collimation, provide spatial filtering, and block the transmission of any unwanted broad radiation, including the emission that arises from some Lasers.
Scanning: The laser scanner records the time difference between the emission and reflection. Combined with accurate information about the position and orientation of the aircraft during flight, the elevation of the 'scanned' area can be determined (Fig. 4).

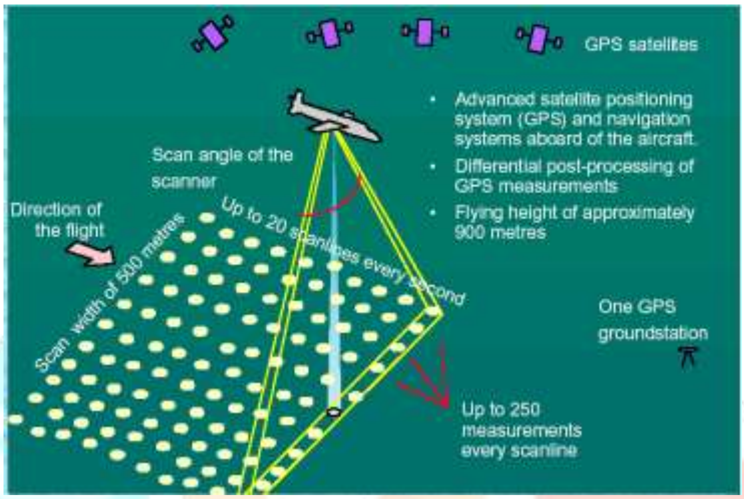

Figure 4: Scanning Measuring over a Finite Width of Corridor

Range Measurement: It is distance measurement from the laser to the point where it strikes the object of spectrum analyzer on its way to the photo detection system. The spectrum analyzer serves to select the observation wavelength interval and thereby discriminate against background radiation at other wavelengths. The time-of-flight measurement of laser is used to determine the range (i.e. distance) from aircraft to ground.
Aircraft Positioning: The position of aircraft at the instance of firing the pulse is determined by differential Global Positioning System. Preferably, more than one GPS receiver is installed. More accurate aircraft positioning is possibly by employing a differential GPS, where an extra GPS is installed on a known ground station, within a set distance from the aircraft.
Inertial Navigation: It measures the aircraft roll, pitch, and heading angles. The direction of laser travel is of paramount importance in accurately determining the ground location of the point intersection. The angular movements of the airborne platform about its axes change the direction of laser travel. Rotational positions of the laser pulse direction are combined with aircraft roll, pitch, and heading values determined with an Inertial Navigation System (INS), and with the range measurements, to obtain range vectors from the aircraft to the ground points. When these vectors are combined with the aircraft locations they yield accurate coordinates of points on the surface of the terrain.
Calibration of Instrument: Before obtaining the measurements, the LiDAR instrument needs to be calibrated for laser range, GPS, and INS (Huising and Pereira, 1998). Depending upon its type the calibration could be done in the laboratory, on the ground, or in the air, before, during, and after a flight.

2.2 Geo-Referencing of LiDAR Data

The laser range recorded during the flight is a slant range to the target of interest. Its orientation is defined in the aircraft coordinate system determined by the INS. The aircraft coordinate system keeps on changing relative to the geographical coordinate system with time, as the pitch, roll and heading of aircraft changes. To georefernce the laser footprint correctly on the ground, the slant range vector, which is known in the local aircraft coordinate system, must be transformed in the geographical coordinate system.

2.3 Types LiDAR Systems

These systems are similar in that they all use lasers for transmitters and telescopes of various sizes for their receivers. However, they each use a different type of scattering:

DIAL LiDAR (Differential Absorption LiDAR): It is used to determine amount of Ozone. Wavelengths can be used to determine the amount of ozone.
LITE (LiDAR Technology Experiment): It is used for detecting Clouds and Aerosols from Space.
GALE (Giant Aperture LiDAR Experiment): It has been used to measures wind, temperature and waves.
SHOALS Airborne LiDAR (Scanning Hydrographic Operational Airborne Survey LiDAR): It has been used for underwater bathymetry.
CO_2 Doppler Pulsed LiDAR: This system is designed for Industrial particulate pollution control, Environmental protection, Cloud ceiling detection,
TopoSys LiDAR System: TopoSys LiDAR DEM is raster DEM typically available at raster widths between 0.5m and 2 m. At an aircraft speed of 70 m/sec and a survey altitude of e.g. 900 m above ground the LIDAR pro-vides an average density of 4 to 5 measurements per m^2. The processing of the data will be adapted to the final use of the elevation data. So, the application determines which of the measurements will be the best representatives within a raster cell, i.e. whether highest or lowest measurements are the best or whether measurements will be averaged.

III. LiDAR APPLICATIONS

LiDAR, as a special analysis tool, has used in many applications viz. measurement of atmospheric density, water–content ,and temperature, minor-constituent detection, cloud studies, atmospheric-dust observation, upper–atmospheric probing, and remote pollution measurement (measure,1984). Furthermore, it has been used for measuring the turbidity and temperature of seawater (Measure, 1984). As a flurosensor, laser have been applied to algae surveying, agricultural application, oil spill detection and identification, marine baseline hydrocarbon survey, fish detection, oil pipeline surveillance, dispersion studies, and pollution monitoring (Measure,1984).

3.1 Study for Ozone (O3) and Minor Constituents Measurement

Fig. 5 shows typical ozone profile recorded during a deployment of the instrument to New Zealand during 1994. Also shown is an ozone profile from a locally flown balloon sonde. The altitude range for an ozone measurement is typically from 10 km to 50 km.

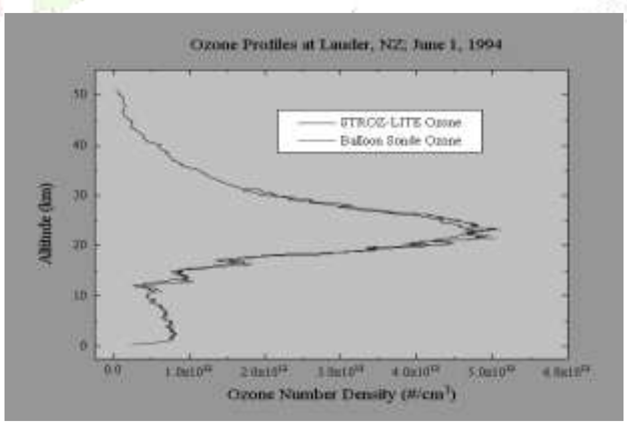

Figure 5: Shows Ozone Profile at Lauder, NZ

3.2 Temperature Measurement

Temperature can be extracted using the LiDAR return from the 351 nm laser. Fig. 6 shows a LiDAR measured temperature profile recorded in New Zealand in 1994. Along with the LiDAR profile, the NMC data, and the data from a locally flown sonde are also presented.

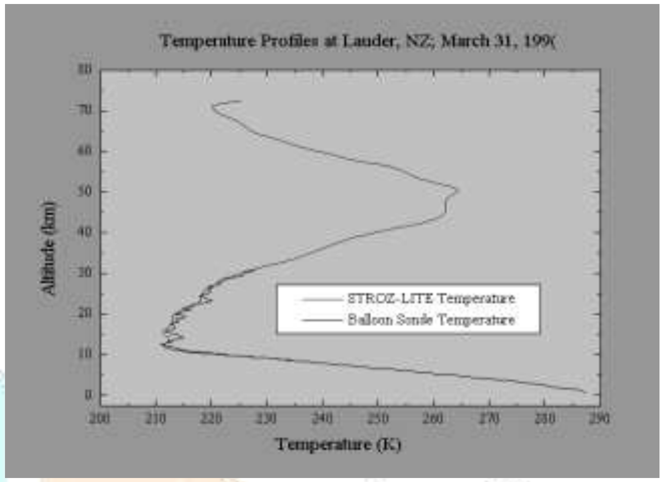

Figure 6: Shows temperature profile recorded in New Zealand in 1994

3.3 Weather Forecasting

Clouds are formed by the ascent of moist air in the lower atmosphere. Different kinds of clouds form a different altitude and are an indicator of atmospheric stability. The arrival of different types of clouds helps us to predict the next day's weather. Fig. 7 is shown below presenting cloud formation at different height for forecasting raining by Doppler spectrum.

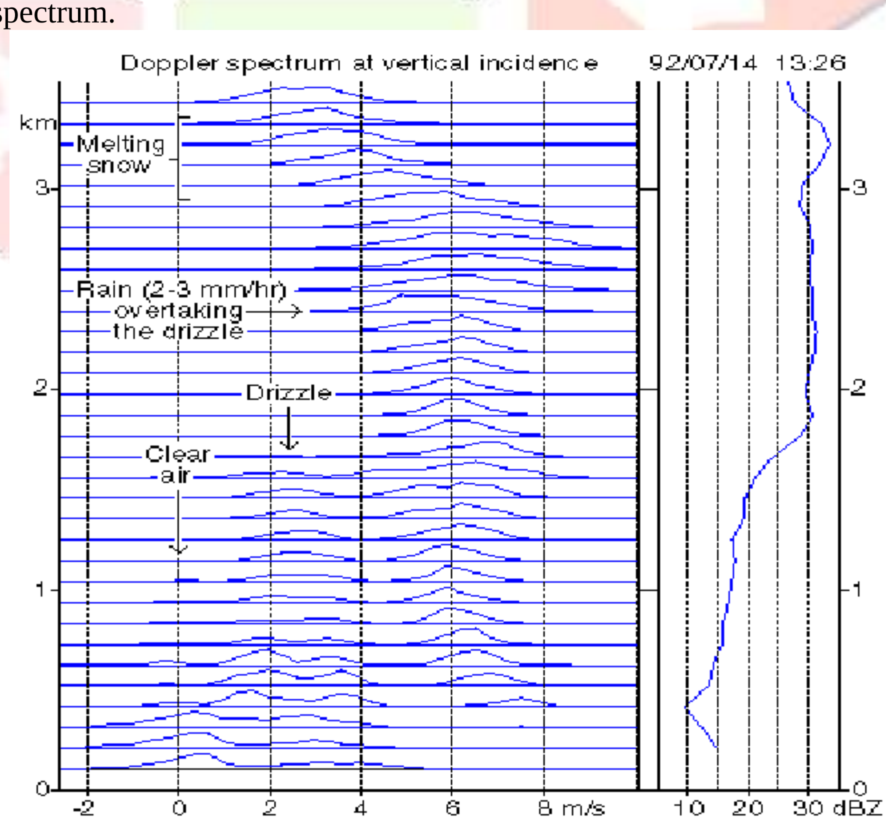

Figure 7: Shows cloud formation at different height for forecasting raining

3.4 Wind Measurement

LiDAR is the most promising of the wind measurement concepts under consideration and would be used to measure atmospheric winds. The LIDAR sensor measures velocity by determining the Doppler shift of laser radiation from atmospheric aerosols carried by the wind. Fig. 4.4 is showing the average zonal (east/west) wind pattern in the lower and middle atmosphere and four strong jet streams. In the fig. 8 wind speeds are in m/s, with redder colors eastward and bluer colors westward.

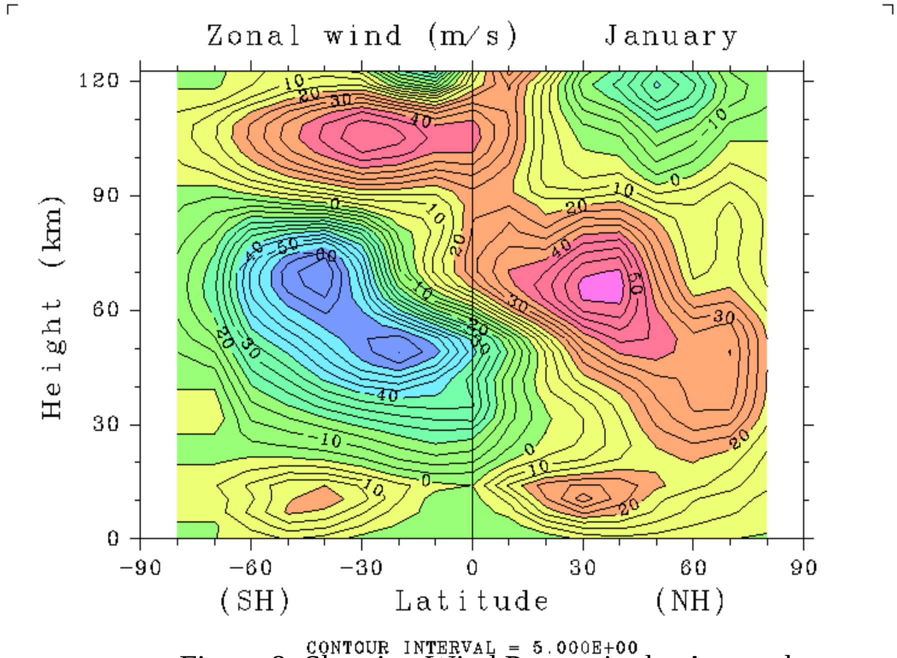

Figure 8: Showing Wind Pattern in the Atmosphere

3.5 Coastal Application and Bathymetry

More recently, Parson et al. (1997) used scanning hydrographic operational airborne LiDAR survey (SHOALS) system to collect shallow water bathymetry of Florida Bay. Depending upon the clarity of the water SHOALS can measure depths from 0.9m to 40 m with a vertical accuracy of ±15cm and horizontal accuracy of ±3m.

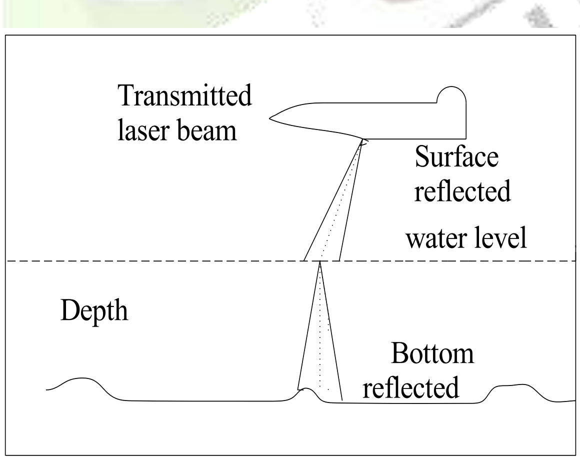

Figure 9: Measurement of Depth

As shown in fig. 9 a laser pulse is transmitted to the water surface where, through Fresnel reflection, a portion of the energy is retuned to airborne optical receiver, while the reminder of the pulse continues through the water column to the bottom and is subsequently reflected back to the receiver.

3.6 Ice Sheet/ Glacier Mapping

NASA's scanning laser altimeter AOL was employed to measure numerous transects of the Greenland ice sheet during 1991 to 1993(Krabill et al., 1995). Result from flight data showed that ice-surface elevations could be reliably measured to an accuracy of 10cm to 20 cm. Kennett and Eiken (1997) have used the ALTM instrument for mapping the glacial topography. They found laser scanning to be ideally suited for such mapping as smooth snow-covered glaciers were highly reflective, and reported very low noise levels at around 2 cm and repeatability between overlapping swaths of approximately ±10cm.

3.7 Forest Mapping

LiDAR data also have been used to predict biophysical characteristics of plant communities, most notably forests.

3.8 Creating Accurate Terrain Elevation Models for Flood Plain Mapping

Floodplain management depends on accurate elevation data to determine various levels of flood risk within the floodplains of rivers and streams. In the past, detailed high-accuracy mapping has been an expensive proposition, requiring many man-hours of field surveying or work using photogrammetric soft-copy techniques. A LiDAR has proven to be particularly effective in gathering this type of data both quickly and relatively cheaply.

3.9 LiDAR Study of Air Quality

A number of atmospheric boundary layer parameters that influence the air quality have been studied extensively by using the LiDAR technique. The quantitative retrieval of aerosol pollutant structures is often used for establishing criteria for meaningful sampling of air quality and environmental pollution, and for verifying model predictions. LiDAR enables one to make both temporal and spatial measurements of mixed layer, which acts as an interface between the dirtier air within it and cleaner air above it. Airborne aerosol LiDAR, Which provide information on density of particulate distributions in terms of backscatter of the laser signal from aerosol easily available. (James L, 1992).

3.10 Landslides Study

LiDAR has made it possible to monitor and predict slope failure by rapidly obtaining highly accurate and dense elevation data. In post-slide conditions rapid damage assessment and mapping can be realised using LiDAR.

IV. RELEVANCE OF LiDAR TECHNOLOGY IN INDIAN SCENARIO

LiDAR Technology has been used successfully in various fields like Atmospheric Science, Ecological Survey, Petroleum Industry, Urban Planning, Landslide Detection and Bathymetry in Developed countries for speedy collection of data. India, still in the developmental phase, has to embark on several major infrastructure projects related to roadways, railways, oil and gas pipelines, electric transmission lines, communication network, and ports and harbours.

India is prone to natural disasters of varied form resulting in heavy losses of life and wealth. LiDAR data have potential to be effective in many disaster management programmes, including the most frequently occurring floods. High-resolution and accurate topography generated by LiDAR is most suitable to further the scientific understanding of natural phenomena, e.g. the floods and coastal environment.

4.1 LiDAR Studies in India

In India, Laser systems have been successfully deployed for regular Atmospheric Science studies at following institutions.

Indian Institute of Tropical Meteorology (IITM), Pune: Ar-Ion Laser, Continuous Wave bistatic laser for lower atmospheric aerosols. Currently a LiDAR system based on a CO_2 tunable laser for minor constituent studies is under development.
National Physical Laboratory (NPL), New Delhi: Laser heterodyne system (IR) for ozone profile measurements (other traces gases, such as NO_2 have also been measured with this system). NPL has also deployed this system in the Indian Antarctic station, MAITRI for Ozone Hole studies.
Physical Research Laboratory (PRL), Ahmedabad: Multi-wavelength LiDAR for Aerosols up to 35 km altitude and Rayleigh scatter measurements (densities and temperatures) in the 35-55 km region.

V. CONCLUSION

Much geo-information, crucial to national development can be acquired by means of LiDAR. The technology has passed through a rapid and successful history of development. It offers many advantages over the conventional techniques of DEM generation as accuracy, time of data acquisition and processing, minimum user interference, canopy penetration, ground control point independence and digital compatibility. It has been successfully used in a variety of applications like weather forecasting, temperature measurement, minor constituent measurement, wind measurement, bathymetry, air quality study and coastal application. In addition, the typical characteristics of LiDAR data have opened up the possibility of using them for many other applications like glacier mapping, landslides study and flood mapping, which were not thought of earlier. This technology has the potential of saving the precious national resources and providing better understanding of several problems which are difficult to comprehend otherwise, due to the limitations imposed by conventional data collection techniques.
At present, it has reached the stage of being a stabilised, although still rapidly emerging technique. The only restriction on new applications seems to be unfamiliarity and unawareness among users about its full potential. The viability of the technique depends upon a balanced involvement on the part of governmental, private and academic parties. In developed countries it is used in different areas of environmental study. Crucial to its success in India is liberalization of India's airborne remote sensing policy. The Indian Department of Science and Technology and the Department of the Space have already shown interest in the technology in the area of ozone profile measurement, minor constituent measurement and aerosol, which may result in the initiation of pilot campaigns in the near future.

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