LIDAR Technology and Applications

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Abstract—— **LiDAR is an instrument that measures distance to a reflecting object by emitting timed pulses of laser light and measuring the time between emission and reception of reflected pulses. The measured time interval is converted to distance. LiDAR is a method of remote sensing that obtains three dimensional data points by using a laser mounted on an aircraft. Airborne LiDAR provides the ability to acquire detailed three-dimensional data over a large area in a relatively short period of time. It is a powerful tool for identifying and mapping features with a topographic expression, but is best used as part of a remote sensing toolkit that encompasses aerial photography and ground-based approaches to landscape archaeology.**

***Index Terms*—** Lidar, Radar, Laser, Stimulated emission.

I. Introduction

LIDAR is an acronym for Light Detection And Ranging. It is an optical remote sensing technology that can measure the distance or other properties of, targets by illuminating the target with laser light and analyzing the backscattered light.

The acronym "laser" stands for "light amplification by stimulated emission of radiation". A laser is a device which generates a stream of high energy particles (photons) within an extremely narrow range of wavelengths (Figure 1). Lasers produce a coherent light source designed for a specific purpose. A laser light source forms the basis for a lidar system. The term "lidar" is an acronym for "light detection and ranging". The wavelength chosen for most airborne topographic mapping lasers is 1064 nanometers, which is in the near-infrared band of the electromagnetic spectrum.

Lidar has become an established method for collecting very dense and accurate elevation data across shallow-water areas, landscapes, and project sites. This active remote sensing technique is similar to radar but uses laser light pulses instead of radio waves.

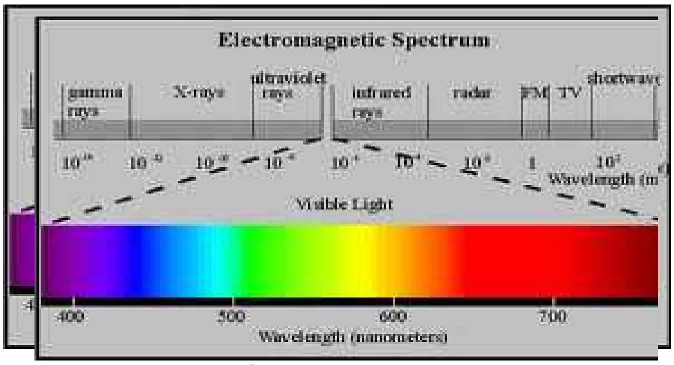

Figure 1 : Electromagnetic Spectrum

Lidar is typically collected from planes where it can rapidly collect points over large areas (Figure 2). Lidar is also collected from ground-based stationary and mobile platforms. These collection techniques are popular within the surveying and engineering communities because they are capable of producing extremely high accuracies and point densities, thus permitting the development of precise, realistic, three- dimensional representations of roadways, railroads, buildings, and bridges.

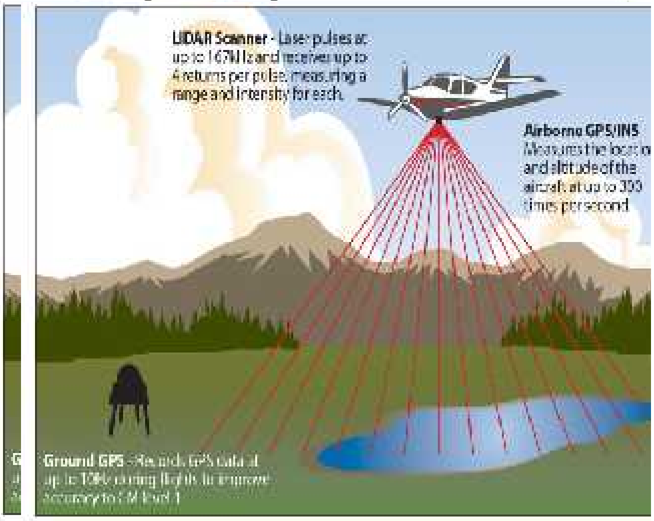

Figure 2 : Basic lidar data collection schematic from aircraft

II. DIFFERENCE BETWEEN RADAR AND LIDAR

While LIDAR and radar both use similar technologies and approaches to tracking position and movement of objects, there are differences in how each technology works and the types of applications for which each can best be used. Both technologies use energy reflected from objects to determine various aspects of those objects, but the types of energy used in each one is different. The types of objects that can be accurately located and measured through LIDAR and radar are also different in size and nature. Both LIDAR and radar use the same basic concept in locating objects and determining different properties of such objects. In both LIDAR and radar an energy transmission is sent out from a source as a signal. When the signal hits an object, that object then reflects some of the energy from the original signal. This reflected energy is then received at the source location and used to determine the distance, size, and other attributes of the object.

LIDAR is an alternate form of the technology used in radar to determine the orientation and position of an object or objects. LIDAR uses energy with smaller wavelengths such as ultraviolet energy for the source signal. These smaller wavelength signals can be reflected back by smaller objects than can usually be detected through radar, so LIDAR can be used to detect very small objects such as dust particles or various aspects of different weather and atmospheric phenomena. This makes LIDAR a better choice for studying weather patterns using fairly small technology, which is especially useful for studying distant atmospheres through satellites.

III. BASIC PRINCIPLE AND TECHNIQUES

Lidar is an acronym for light detection and ranging. It refers to a remote sensing technology that emits focused, intense beams of light and measures the time it takes for the reflections to be detected by the sensor. This information is used to compute ranges, or distances, to objects. In this manner, lidar is analogous to radar (radio detecting and ranging), except that it is based on discrete pulses of laser light. The three-dimensional coordinates (e.g., x, y, z or latitude, longitude, and elevation) of the target objects are computed from 1) the time difference between the laser pulse being emitted and returned, 2) the angle at which the pulse was “fired,” and 3) the absolute location of the sensor on or above the surface of the Earth.

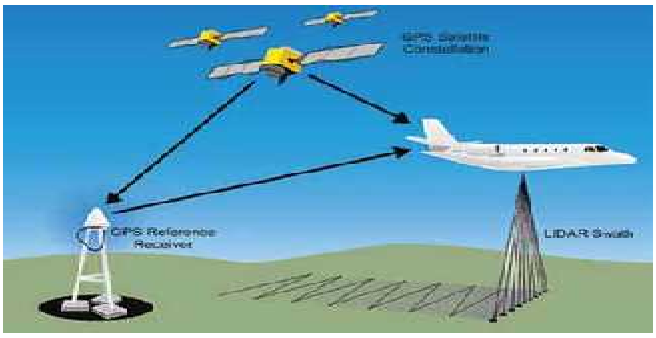

Figure 3 : Principles of LiDAR collection

There are two classes of remote sensing technologies that are differentiated by the source of energy used to detect a target: passive systems and active systems. Passive systems detect radiation that is generated by an external source of energy, such as the sun, while active systems generate and direct energy toward a target and subsequently detect the radiation. Lidar systems are active systems because they emit pulses of light (i.e. the laser beams) and detect the reflected light. This characteristic allows lidar data to be collected at night when the air is usually clearer and the sky contains less air traffic than in the daytime. In fact, most lidar data are collected at night. Unlike radar, lidar cannot penetrate clouds, rain, or dense haze and must be flown during fair weather.

Lidar instruments can rapidly measure the Earth’s surface, at sampling rates greater than 150 kHz (i.e., 150,000 pulses per second). The resulting product is a densely spaced network of highly accurate georeferenced elevation points (Figure 2-2)—often called a point cloud—that can be used to generate three-dimensional representations of the Earth’s surface and its features. Many lidar systems operate in the near-infrared region of the electromagnetic spectrum, although some sensors also operate in the green band to penetrate water and detect bottom features. These bathymetric lidar systems can be used in areas with relatively clear water to measure seafloor elevations. Typically, lidar-derived elevations have absolute accuracies of about 6 to 12 inches (15 to 30 centimeters) for older data and 4 to 8 inches (10 to 20 centimeters) for more recent data; relative accuracies (e.g., heights of roofs, hills, banks, and dunes) are even better. The description of accuracy is an important aspect of lidar and will be covered in detail in the following sections.

Most LIDAR systems use four main components:

1) Lasers

Lasers are categorized by their wavelength. 600-1000nm lasers are more commonly used for non-scientific purposes but, as they can be focused and easily absorbed by the eye, the maximum power has to be limited to make them 'eye-safe'. Lasers with a wavelength of 1550nm are a common alternative as they are not focused by the eye and are 'eye-safe' at much higher power levels. These wavelengths are used for longer range and lower accuracy purposes. Another advantage of 1550nm wavelengths is that they do not show under night-vision goggles and are therefore well suited to military applications. Airborne LiDAR systems use 1064nm diode pumped YAG lasers whilst Bathymetric systems use 532nm double diode pumped YAG lasers which penetrate water with much less attenuation than the airborne 1064nm version. Better resolution can be achieved with shorter pulses provided the receiver detector and electronics have sufficient bandwidth to cope with the increased data flow.

2) Scanners and Optics

The speed at which images can be developed is affected by the speed at which it can be scanned into the system. A variety of scanning methods are available for different purposes such as azimuth and elevation, dual oscillating plane mirrors, dual axis scanner and polygonal mirrors. They type of optic determines the resolution and range that can be detected by a system.

3) Photo detector and receiver electronics

The photo detector is the device that reads and records the signal being returned to the system. There are two main types of photo detector technologies, solid state detectors, such as silicon avalanche photodiodes and photomultipliers.

4) Navigation and positioning systems

When a LIDAR sensor is mounted on a mobile platform such as satellites, airplanes or automobiles, it is necessary to determine the absolute position and the orientation of the sensor to retain useable data. Global Positioning Systems provide accurate geographical information regarding the position of the sensor and an Inertia Measurement Unit (IMU) records the precise orientation of the sensor at that location. These two devices provide the method for translating sensor data into static points for use in a variety of systems.

IV. HOW IS LIDAR DATA COLLECTED???

In order to collect data the LIDAR sensor is mounted below an aircraft where it emits short infrared laser pulses towards the earth's surface, fan-shaped across the flight path (Figure 3). Each pulse results in multiple echoes or 'returns'. The first return will usually be received from the tops of trees and vegetation, but as the laser penetrates the canopy further returns are received from branches and understory.

Typically, the last return is received from the ground surface. As the aero plane moves forward the position of each return, or point, can be calculated using a satellite navigation system in tandem with a fixed ground-base system, while the pitch, roll and yaw of the aircraft is recorded by an inertial measurement unit to increase accuracy. Each point therefore has a set of x, y, and z coordinates to reflect its position and elevation.

Multiple return systems, which are common, can capture up to five returns per pulse (Figure 4). This can increase the amount of data by 30% or more (100,000 pulses/second˜130,000 returns/second) and increases the ability to look at the three- dimensional structure of the "features above the ground surface," such as the forest canopy and understory.

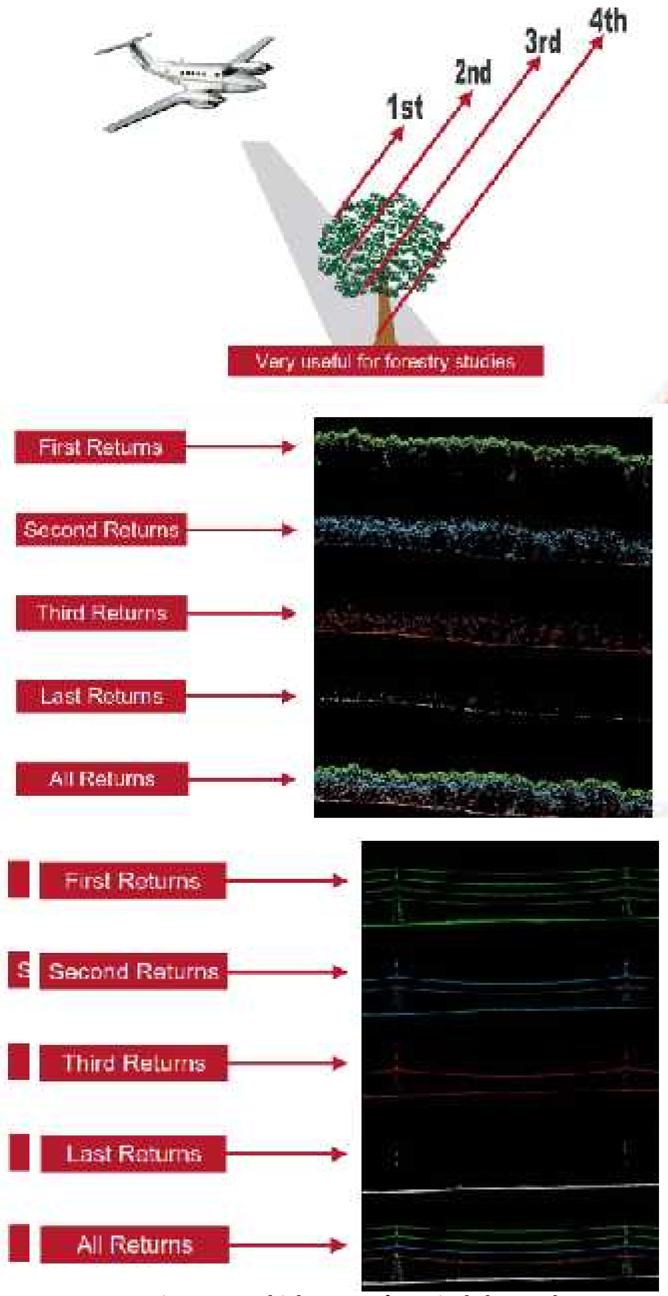

Figure 4 : Multiple returns from single laser pulse

The essential measurement made by a lidar sensor is of time, the time that elapses from the moment the pulse is emitted until it returns after being reflected by the target surface. Because the laser pulse travels at the speed of light, a known constant, time can be directly converted to distance, by the following equation:

Distance from the sensor to the target and back = (elapsed time) * (speed of light)

We must divide this result by two to get the distance from the sensor to the target; this distance is often referred to as the range. With knowledge about the absolute position and "pointing angle" of the laser system, the X-Y-Z coordinates of the reflecting object can be calculated. For topographic mapping applications, we need lidar-derived elevation points to be distributed over a large swath on either side of the flight track on the ground. In order to achieve this, some sort of scanning capability must be added to the sensor to deflect the pulses being emitted by the laser over a broad area on the target surface.

V. APPLICATIONS

i) Flood Modeling

Features like roads, constructed river banks or buildings have a great effect on flow dynamics and flood propagation. Only high-resolution input data can solve the purpose that relates to the systems topography as well as to the identified features. Frequent urban flooding is observed in many parts of the world over the past decades and an urgent need is identified to improve and increase our modeling efforts to address the effect model input data has on the simulation results. Even differences of a few meters can means a lot in loss calculations in urban areas. LiDAR has brought this level of detail to the industry allowing for much more accurate flood prediction models to be created.

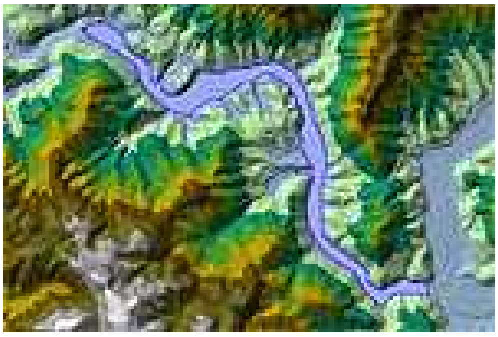

Figure 5: Bare Earth models may be generated to sub canopy details

LiDAR data can also be incorporated into relief, rescue and flood simulation software to provide advanced topographical information.

ii) Pollution Modeling

LiDAR has a unique ability to detect particles in both air and water. As LiDAR uses short wavelengths of light in the visible spectrum, typically ultraviolet, visible or near infrared, is it possible to image an object or feature only about the same size as the wavelength or larger. This makes it particularly sensitive to aerosols, cloud particles and air molecules. Pollutants such as carbon dioxide, sulphur dioxide and methane are all detectable with LiDAR.

iii) Transport Planning

Transportation corridor mapping to support engineering planning and change detection of road networks requires high spatial resolution and high scale engineering mapping accuracy. With the latest developments of LiDAR sensors the accuracy potential of LiDAR data has improved significantly. Airborne LiDAR data can be used to capture large amounts of data over large areas and ground based LiDAR can be used to add a greater amount of details in specific areas. This method allows the most cost effective process for site-specific LiDAR capture.

iv) Forestry Management and Planning

LiDAR is unique in its ability to measure the vertical structure of forest canopies. As well as mapping the ground beneath the forest, LiDAR is able to predict canopy base height and canopy bulk density. Both of these factors can be used for, amongst other things, canopy fuel capacity for use in fire behaviour models. LiDAR surveys allow large scale surveys to be taken with a level of cost-effectiveness not previously available. Another use of LiDAR is the measurement of peak height to estimate the root expanse.

v) Cellular Network Planning

With the ability to collect large areas of high-resolution data in a relatively short space of time, LiDAR provides the perfect data for cellular network planning. The detailed information can be incorporated into statistical or GIS software and used to provide accurate analysis for determining line of sight and view shed for proposed cellular antenna. This analysis has the benefit of creating the optimal site for the masts ensuring coverage is optimal whilst reducing costs in the process.

vi) Scene of Accident/Crime

Because of its real-world application, LiDAR systems make recording the scene of accidents and crime quick and easy, as well as precise. By using a ground based LiDAR system it is possible to record the scene a car accident within a few minutes, enabling the emergency services to clear the scene and then to reproduce it later on in the digital realm. This reduces traffic jams as well as preserving the evidence before anything is compromised. All of the data is recorded with a geographical position that allows the data to be used in various software packages for an extra level of accuracy.

vii) Physics and astronomy

A world-wide network of observatories uses LiDAR to measure the distance to reflectors placed on the moon, allowing the moon's position to be measured with mm precision and tests of general relativity to be done. MOLA, the Mars Orbiting Laser altimeter, used a LIDAR instrument in a Mars-orbiting satellite (the NASA Mars Global Surveyor) to produce a spectacularly precise global topographic survey of the red planet. In September 2008, NASA's Phoenix Lander used LIDAR to detect snow falling in the atmosphere of Mars. The snow, however, sublimates before reaching the ground.

In atmospheric physics, LIDAR is used as a remote detection instrument to measure densities of certain constituents of the middle and upper atmosphere, such as potassium, sodium, or molecular nitrogen and oxygen. These measurements can be used to calculate temperatures. LIDAR can also be used to measure wind speed and to provide information about vertical distribution of the aerosol particles.

viii) Navigation

LiDAR is becoming more and more popular as a guidance system for autonomous vehicles. The speed and accuracy of a scanner means that data can be passed to a system to process the return in more or less real-time. This allows the device controlling the vehicle to detect obstacles and to update its route in a very small amount of time.

VI. FUTURE ASPECTS

It was first used as a means of finding submarines, but it was subsequently turned to terrestrial use to produce highly detailed terrain models. Lidar remote sensing is an advanced technology that is not only replacing conventional sensors in science study, environmental research, and industry application, but also creating new methods with unique properties that could not be achieved before. Lidar technology has been advanced dramatically in the past 20 years, owing to the new availability of lasers, detectors, creative people involved, and the demanding needs from various aspects.! Potential growing points at this stage include!

(1) Solid-state resonance fluorescence lidar for mobile deployment globally!

(2) Extend measurement range into thermosphere and lower mesosphere!

(3) Doppler, DIAL, HSRL, and Raman lidar for lower atmosphere research!

(4) Fluorescence lidar and laser range finder for novel applications!

(5) Aerosol/cloud lidar with Raman, polarization & multicolor detection capabilities!

(6) Space borne lidar for more sophisticated lidar types

The exciting and growing lidar field is anxious for new "blood" - the creative, intelligent, diligent, and passionate young researchers!

VII. CONCLUSION

Highly accurate, high-resolution lidar data have particular utility in coastal settings where terrain is generally flat and subtle elevation changes often have significant importance.

These examples represent only a small subset of applications of lidar in coastal environments. Other potential applications of lidar include forestry, geology, watershed and water quality studies, transportation, safety, cadastral mapping, and archaeology. A lidar is increasingly available for coastal areas, applications that relied on coarse data are being improved with the use of lidar data. One example of this is the ongoing work with the Federal Emergency Management Agency's Risk MAP program, where more accurate data are used to generate new flood maps.

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