LIDAR REMOTE SENSING – ITS APPLICATIONS IN AGRICULTURE AND FORESTRY

Abstract

LiDAR (Light Detection And Ranging) is a popular advanced technology used since the 1960s. LiDAR was used in many fields like agriculture, automation, archaeology, forestry, astronomy, geology, green energy, mining, law enforcement and the quantification of various atmospheric components. The chapter aims to cover principles, components, accuracy assessment, applications in agriculture and forestry and advantages of using LiDAR.

Keywords: LiDAR; Principles, components, Laser, accuracy, applications, agriculture, forestry.

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I. INTRODUCTION

Light Detection And Ranging (LiDAR) is a popular active remote sensing method which involves projecting laser light onto the target and detecting the light that is reflected to identify the variation in wavelength and arrival time of the reflected light. LiDAR is used to calculate distances and survey the earth's surface. LiDAR technology uses laser pulses which measure laser return timings and their wavelengths. LiDAR is a potential technology that offers detailed, three-dimensional spatial data about the land in high resolution. With the ability to use high-resolution digital surface and elevation models (DSMs and DEMs), LIDAR has quickly developed into a great tool for acquiring topographic data, giving Earth-science modellers the foundational datasets, they need for a wide range of applications [30].

The first LiDAR system was introduced in 1961 by Malcolm Stitch, for the Hughes Aircraft Company. LiDAR was initially used for tracking. In 1963, the term LiDAR was first used. It was a blend of the words "light" and "radar". NASA began laser-based remote sensing in the 1970s, focusing on airborne prototypes for subsequent LiDAR sensor deployment. Its ultimate focus was to measure the properties of ocean waters and the atmosphere.

A LiDAR is an innovative system that enables fast and precise georeferencing of distance-from-sensor data. LiDAR can generate the Number of Returns, Return Number, Digital Elevation Models, Digital Surface Models, Canopy Height models, Light Intensity and Point Classification.

LiDAR has proven useful in a variety of industries, including astronomy, atmosphere, automation, biology and conservation, forestry, green energy, image recognition, surveying, mining, transport including agriculture, where LiDAR robots in sowing seeds, detect weeds, and application of fertilizers automatically, allowing farmers to grow fruits, vegetables, and other crops profitably. LiDAR is a tool that can be used to study the forest canopy, identify previously undetectable surface features, profile rain clouds, look into particles, and quantify a variety of atmospheric elements, all of which can be used to compute surface pressure, greenhouse gases emissions, photosynthetic activity, fires, and humidity. LiDAR technology is also used in autonomous cars to identify and avoid obstacles which use laser beams to navigate the road [5].

II. WORKING PRINCIPLE OF LiDAR

The LiDAR is based on the principle - **reflection of light.** The basic concept behind LiDAR technology involves projecting a light beam on a surface and measuring how long it takes for the light to rebound/return to its origin. LiDAR uses the basic characteristics of laser light for accurate detection, which are as follows 1) Monochromatic – i.e., one colour (one wavelength), 2) Collimated – i.e., very small divergence over large distances, 3) Very intense – i.e., lots of energy in a small area, 4) Polarized – i.e., energy is aligned in one direction. The LiDAR source emits laser light onto the target and measures the light that is reflected to determine the variation in wavelength and time of arrival. It is used to determine the distance needed to create the target's digital representation based on these data [5,26]. LiDAR calculates the precise distance very quickly as the light moves at a rapid rate. The equation for calculating distance is given below,

$$D = c\,(\Delta T/2)$$

Where,
D = the distance of the object
c = Speed of light
ΔT = Time required by the light to travel

Numerous (1000 to 200000 beams/second) laser beams are fired onto the surface by the LiDAR system. The system's sensor calculates the amount of time it takes for the reflected light to arrive at the sensor. This continues until a detailed map of the surface has been created.

III. COMPONENTS OF LiDAR SYSTEM

The LiDAR consists of major components such as an aircraft, Inertial Navigation System (INS), GNSS/GPS and LASER scanning system [9,27]. Even though these components must be quite tightly connected, which are explained as follows

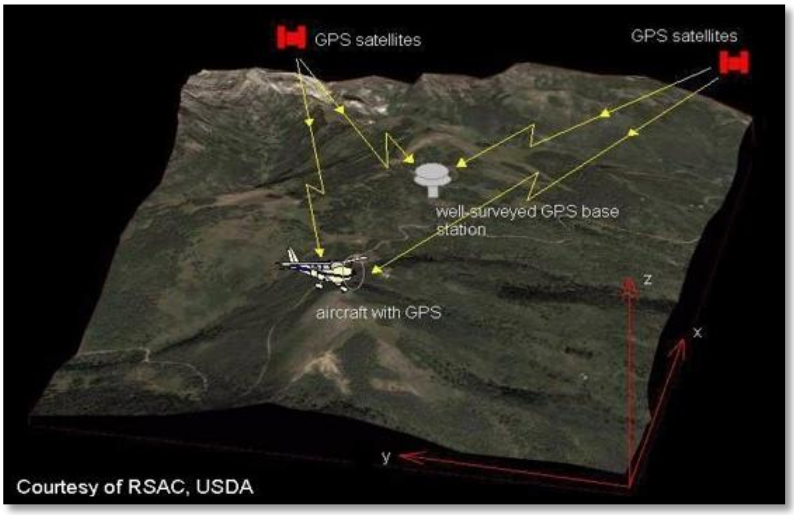

Figure 1 : Components of the LiDAR System

1. **Aircraft:** LiDAR data is acquired using both fixed-wing (aeroplanes) and rotor-wing (helicopter) aircraft. As much as mapping cameras, the laser scanner is precisely positioned on the underside of the aircraft. Although some systems can be transported and flown successfully in single-engine, light fixed-wing aircraft, twin-engine aircraft are more frequently used. Typically, a minimum two-person crew (pilot and operator) is required.

2. **GNSS/GPS:** LiDAR data needs accurate real-time positions. The position solution is largely provided by the differential kinematic use of GPS technologies. Finding or setting up a GPS base station should be thoroughly inspected and co-initialized with the airborne GPS. At intervals of 0.5 seconds, the airborne GPS antenna's position (x, y, and z) is determined. 95 kilometres or less should separate the ground station from the project site. This will guarantee that the GPS satellite signals being recorded by the aeroplane and the ground station are identical. The data are retrieved and processed after each mission.

Kinematic GPS post-processing software is used to process GPS data from both the aircraft and the ground station(s).

- **Laser scanner system:** The laser scanner system is the most important component of LiDAR which consists of 1) laser source- LASER (Light Amplification by Stimulated Emission of Radiation) has a monochromatic and directional characteristic thus laser controls the way photons are released. LiDAR laser systems are capable of emitting tens of thousands of laser pulses each second, 2) the laser detector - The laser detector is co-mounted with the laser. It is used to recognize the laser light that is reflected off the target and returned to the aircraft. 3) scanning mechanism - electronics system, and real-time processing capability to measure the timing of pulses and returns. 4) Electrons timing- measurement of time is an important task in LiDAR for acquiring astonishing accuracy. The laser light pulses were projected at a rate of 4000 to 100000 per second. At the speed of light, each pulse may reflect up to five return pulses. 5) Computing power-LiDAR generates a large amount of data in a really quick period thus it is important to record and process LiDAR data. Think about how each LiDAR return is assigned a number, its range is computed, the look angle is established, and then the GPS and IMU data must be taken into account. In the end, geographic X, Y, and Z coordinates are created using the LiDAR range and look angle information.

- **Inertial Navigation System (INS):** Another important component of the LiDAR is the Inertial Navigation System (INS). The GPS tracks the precise location of the aeroplane in space, while the INS monitors the rotations of the aircraft in its three dimensions (pitch, roll, and yaw). Accelerometers are used by the INS to monitor variations in movement rates. They must use the GPS to update their position data every 0.5 seconds because the INS can easily lose track of its location.

IV. ACCURACY OF LiDAR MEASUREMENTS

LiDAR is an emerging technology. Its capacity to deliver x, y, and z-elevation information as accurately as conventional in situ surveying and photogrammetry is therefore viewed with a healthy degree of scepticism. Fortunately, there exist standards for accuracy assessment that may be employed to give a fair evaluation of the accuracy of goods obtained from LiDAR.

NSSDA Horizontal and Vertical Accuracy Assessment

It is conventional to identify in situ x, y, and z checkpoints throughout the study region using a higher precision technique, such as total station surveying or differential GPS, to the accuracy of a LiDAR-derived digital surface model (DSM) or bare-Earth digital terrain model (DTM). The LiDAR-derived DSM or DTM then contains the location of each in situ checkpoint [25].

The closest LiDAR-derived data is then compared to the location and elevation data associated with each in-place checkpoint. This is done at various checkpoints. The results are then used to calculate the horizontal and vertical accuracy of LiDAR-derived data, which is expressed as the root mean squared error (RMSE). The Geospatial Position Accuracy Standards Part 3: National Standard for Spatial Data Accuracy was published in 1998 by the

Federal Geographic Data Committee (FGDC) (NSSDA) [8]. This standard superseded both the Office of Management and Budget's 1947 National Map Accuracy Standards (NMAS) and the American Society for Photogrammetry and Remote Sensing's (ASPRS) 1990 ASPRS Accuracy Standards for Large Scale Maps. The FGDC's Geospatial Accuracy Standard for horizontal and vertical accuracy of spatial products is based on the calculation of RMSE. where,

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \Delta^2}{n}}$$

and Δ is the difference between an in-situ checkpoint measurement and a measurement derived from remote sensing at the same location. The standard recommends using at least 20 checkpoints, i.e., n > 20. The checkpoints should be significantly more accurate than the remote sensing-derived product under consideration. [23].

At the 95% confidence level, horizontal accuracy (i.e., circular standard error) is assessed using

$$\text{Horizontal} = 2.4477 \times 0.5 \times (RMSEx + RMSEy)$$

Vertical accuracy at the 95% confidence level is calculated using

$$\text{Vertical} = 1.96 \times RMSEz$$

The equations assume that x and z have normally distributed error distributions. FEMA based its flood-hazard mapping partners on these criteria and provides detailed accuracy assessment procedures. [12,29].

V. ADVANTAGES OF LiDAR REMOTE SENSING

1. Data collection can be done promptly and accurately. The sample density is higher with surface data.
2. For some applications, such as the identification of floodplains, the increased sample density improves the findings.
3. Collect elevation data in a deep forest, where photogrammetry is hindered by the thick canopy cover and cannot disclose the true ground surface.
4. When compared to conventional photogrammetric methods, LiDAR uses an active lighting sensor and can be collected at any time of day or night.
5. Similar to how a side-looking radar has no geometric aberrations, so does LiDAR.
6. Other data sources can be merged with LiDAR.

VI. MAJOR APPLICATIONS OF LIDAR

1. **Agriculture:** In agriculture, LiDAR is widely used for anything from crop mapping and classification to viability studies.

- **Crop categorization:** LiDAR technology has also made it considerably simpler to classify crops according to their traits and determine the ideal locations for planting them. A crop could do well in one part of the farm but poorly in another [32].

- **3D modelling:** LiDAR technology is critical in developing precise maps of natural resources as well as 3D representations of agricultural land. With this information, the farmer may determine the farm's precise topography, as well as its water catchment area and erosion flow [16].

- **Determination of soil type:** LiDAR technology can also be used to obtain information that specifies the precise type of soil that a particular plot of agricultural land contains. The farmer has to know this information to determine what crops can be grown on his or her property and how much fertilizers should be used. LiDAR is also used by soil scientists to manage soil, control erosion, and measure surface roughness.

- **Precision agriculture:** LiDAR data is critical for precision farming. Planning a specific agricultural site to boost output through enhancing overall yields is known as precision agriculture [11,18].

- **Land use and land cover mapping:** LiDAR data has the potential to precisely construct and map farmland to map it out. LiDAR data can be utilised for agricultural farm planning and management. The farmer can use this technology to determine the optimal time to sow a crop and whether a certain piece of land is suitable for it. Experts have been able to split the land for different uses by using the data to reveal the patterns of the land through the use of LiDAR technology. These could include things like irrigation, the amount of water necessary for irrigation, or how frequently a crop should be grown on certain farmland each year [19].

- **Yield forecasting:** A farm's yields can be predicted using LiDAR data. Based on the returns earned of the yields at the end of the season, the data produced by this technology assist farmers in determining the suitability of a specific crop on a given plot of land [7,31].

- **Crop damage and crop analysis:** The level of crop damage and the source of the damage can both be determined using LiDAR technology. Farmers may be able to develop techniques to stop the damage and hence boost yields as a result of this. LiDAR can also be used to do general crop analysis and assess a crop's compatibility with a given environment. This can be achieved by estimating crop quality and comparing it to ideal criteria [21].

- **Water resource management:** Using GIS software, watershed areas may be established and delineation can be streamlined using DEMs produced by LiDAR. By doing so, they can determine the watershed for a specific body of water and forecast the possibility of flooding. From that, flood modellers can identify places at risk of flooding before it occurs [3,21].

2. **Forestry:** LiDAR specializes in displaying the height and structure of trees in forests. A precise vertical profile can be obtained by knowing the height of the tree and the height of the ground. But terrestrial LiDAR produces accurate three-dimensional representations if users really want a 3D vegetation structure [6,28].

   - **Micro-topography:** LiDAR technology to determine the surface elevation values. In comparison to LiDAR, other conventional methods like photogrammetry are not as accurate. LiDAR gathers this information by precisely striking the item with laser pulses; it is unaffected by forest growth or canopy [1].

   - **Forest mapping, planning and management:** For forest planning and management, LiDAR technology can be used to estimate the density of the forest canopy and determine the vertical structures of the canopy [4,17]. To accurately describe a location's terrain and determine if it is suitable to grow a forest there, LiDAR data is crucial. The information obtained using this technology will provide specifics about the topography, like the height of the land and the calibre of the soil, to assess its viability for having a forest [17].

   - **Forest fire management:** LiDAR tool is being used by fire departments all across the world to manage forest fires track the patterns of forest fires, alert the fire service to the next potential forest fire and even allow them to take preventative action [1,14].

   - **Precision forestry:** Precision forestry is the design of a particular forest site to maximise the site's productivity in terms of tree quality and overall production. To accomplish this, LiDAR data aids in prioritizing the area and delivers precise data about a certain spot [13,24].

   - **Pollution modelling:** The LiDAR system's short wavelength operates in the ultraviolet-visible spectrum or close to the infrared. To compare the object size to the wavelength, it can be used. Any carbon dioxide, sulphur, and methane pollution will be picked up by the LiDAR. Accurate information on the forest, including the amount of carbon it absorbs, can be obtained using LiDAR technology. LiDAR technology can identify and map the contaminants that are present within and surrounding the forest, and assist scientists and forest professionals in the removal of pollutants and maintaining the health of the forest. Accurate information on the forest, including the amount of carbon it absorbs, can be obtained using LiDAR technology [2,20].

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