Chronicle of Bioresource Management 2022, 6(3):066-071

Chronicle of Bioresource Management
An International E-magazine

September, 2022 *Popular Article*

LiDAR Sensor: Applications in Agriculture

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Citation: Debangshi, 2022. LiDAR Sensor: Applications in Agriculture. Chronicle of Bioresource Management 6(3), 066-071.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

Keywords:

3D Modelling, LiDAR, Phenomics, Sustainable, Urbanisation

Article History

Article ID: CBM121
Received on 08th August 2022
Received in revised form on 25th August 2022
Accepted in final form on 04th September 2022

Abstract

Agriculture is one of the oldest and primitive occupations. However, this sector is currently facing number of challenges, including population growth, high production costs, urbanisation and environmental degradation. According to the Food and Agriculture Organization (FAO), by 2050, we need to produce 60% more food to feed a world population of 9.3 billion. As a result, there is an urgent need for some sustainable, resource-efficient technologies to combat these issues, among which, LiDAR sensor is one of better options. LiDAR, which stands for Light Detection and Ranging, is a remote sensing method that measure variable distances of the Earth by using light in the form of a pulsed laser. LiDAR can smartly improve the agriculture system with 3D modelling, yield forecasting, soil type determination and phenomics study. Even in difficult weather and lighting conditions, it provides precise 3D measurement. Thus, this technology is preparing the agricultural sector for the future.

1. Introduction

Precision agriculture (PA) is a farm management method that employs information technology (IT) to ensure that crops and soil receive exactly what they need for optimum health and productivity. The goal of PA is to ensure profitability, sustainability and protection of the environment. But what is the right amount, when, where and how it should be given? For making such decisions it is necessary to collect, store and process crop field data at a subfield level and 3D level (Weiss and Biber, 2011). Among the different solutions at farm level, LiDAR is one of the most effective. It is a remote sensing technique that uses visible or near-infrared laser energy to measure the distance between a sensor and an object (generally on earth). LiDAR sensors are versatile and mobile. LiDAR technology can be used to generate 3D digital models of farms as well as accurate maps of natural resources. For example, it can be used to map the water flow, water catchment area, location of tree and crop and their accurate plant population, water flow direction at the base of each tree (Howard, 2015). Farms are not uniform and there is always some natural variability in soil, moisture levels and microclimate

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due to landscape features. LiDAR can be used to observe, measure and map out the variations in slope, aspect and elevation (Howard, 2015). As illustrated in the figure 1, the 3D maps of the farmland include the shape and size of the farmland in a layered function, which can help farmers analyse the suitability of land for a particular crop, different managemental practices and the best time to plant. This could also be used to identify potential agricultural production zones in an area where production is likely to be higher than the rest of the land.

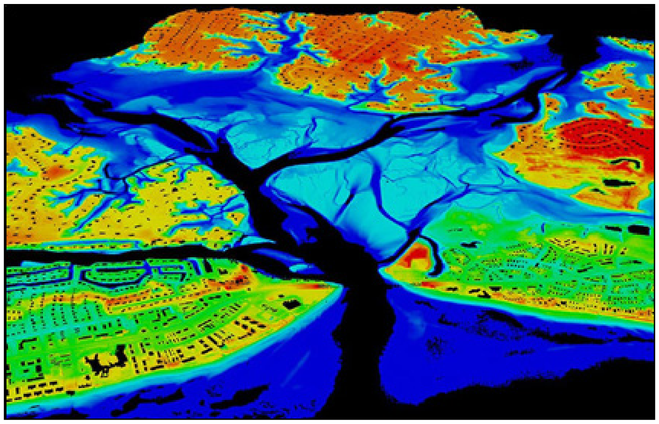

Figure 1: 3D imaging of the field

2. Types of LiDAR

2.1. Based on Mode

• *Pulse-based, or linear-mode,* systems that emit a pulse of laser energy and measure the time it takes for that energy to travel to a target, bounce off the target and return to the sensor. Pulse-based systems are very common and mostly used.

• *Phase-based LiDAR systems measure distance via interferometry*, that is, by using the phase of a modulated laser beam to calculate a distance as a fraction of the modulated signal's wavelength. Phase-based systems is very precise.

• *Geiger-mode, or photon-counting*, systems use extremely sensitive detectors that can be triggered by a single photon.

2.2. Based on Scanning Place

• *Ground LiDAR system (GLS):* scanning with a stationary LiDAR sensor, usually mounted on a tripod.

• *Airborne LiDAR scanning (ALS):* scanning with a LiDAR scanner mounted to a fixed-wing or rotor aircraft (Figure 2).

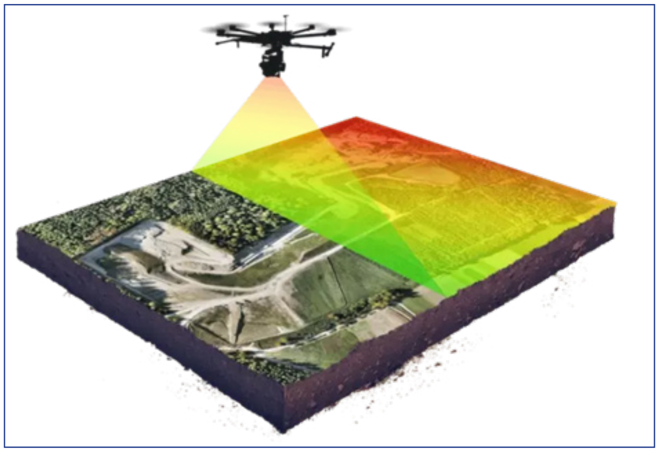

Figure 2: Drone equipped with a LiDAR sensor

• *Mobile LiDAR scanning (MLS):* scanning from a ground-based vehicle, such as a car, tractor.

• *Unmanned LiDAR scanning (ULS):* scanning with drones or other unmanned vehicles.

3. Working Principle of LiDAR Sensor

A LiDAR sensor consists primarily of a laser, a scanner and a specialised GPS receiver. The most common platforms for collecting LiDAR data over large areas are planes, drones, and helicopters. There are two types of LiDAR: topographic and bathymetric. Topographic LiDAR typically maps the land with a near-infrared laser, whereas bathymetric LiDAR measures seafloor and riverbed elevations with water-penetrating green light. A typical LiDAR sensor sends out pulsed electromagnetic beam into its environment. These pulses reflect off nearby objects and return to the sensor. The sensor calculates the distance travelled by using the time it takes for each pulse to return to the sensor. Repeating this process millions of times per second creates a precise, real-time 3D map of the environment. This 3D map is called a "point cloud". An onboard computer can utilize the LiDAR point cloud for safe navigation and different variable rate technologies (VRTs) used in agriculture. The process is similar to how sonar or radar detect objects, which rely on bouncing a sound or radio wave off an object and measuring the time it takes to return in order to understand how far away the object is, or what its dimensions are. With LiDAR, a high-powered laser shoots precise pulses at a target, and measures the pulse that bounces back in order to collect data about the target. To create an understanding of an object in three dimensions, LiDAR sensors measure:

✓ *Time*—how long it takes for the pulse to return.

✓ *Intensity*—the return strength of the laser pulse.

✓ *Angle of the reflection*—the ways the surface being measured change as indicated by the angle of reflection.

After collecting these data points, specialized 3D mapping software processes this information along with GPS (Global Positioning System) data and INS (Inertial Navigation System) data to create detailed and precise 3D models of a targeted area or object. The 3D models are then sent to the farmers' community for easier their managemental work.

4. Advantages of LiDAR Sensor in Agriculture

LiDAR technology is one of the most advanced and most accurate technologies in the GIS system. It used in several sectors; one such sector is agriculture. LiDAR is used extensively for various reasons in the agricultural sector. Below are some of its uses in this field.

4.1. 3D Modelling of Crop Field

LiDAR technology can develop 3D models of farmland and come up with accurate maps of the natural resources around that particular area. As shown in the figure 3, electronic measurements of canopy characteristics, greenness, chlorophyll content, soil map, water 3D map appear to be the most accurate method of providing reliable and objective information regarding management of crops. This information will then be used either in real time to instantaneously modify the working parameters of agronomic applications. In all cases, LiDAR appears to be the most accurate procedure for canopy measurements. The 3D modelling of the crops is important for a number of different aspects such as; application of pesticides or irrigation systems. The aspect of canopy characterization is also important in horticulture to improve pesticide application. In field crops, GLS was applied to discriminate maize plants from weeds and soil for a targeted application of herbicides (Andujar et al., 2013). Sensing of the nitrogen status of wheat plants by GLS was used for improved application of nitrogen fertilizers (Eitel et al., 2011). In another approach, GLS can estimate crop density of wheat that could be used to automatically adjust the speed of a combine harvester for a constant intake of biomass.

4.2. Phenomics study

Plant phenomics is a new avenue for linking plant genomics and environmental studies, thereby improving plant breeding and management. Remote sensing techniques have improved "high-throughput plant phenotyping". However, the accuracy, efficiency, and applicability of three-dimensional (3D) phenotyping are still challenging, especially in field environments. Light detection and ranging (LiDAR) provide a powerful new tool for 3D phenotyping with the rapid development of facilities and algorithms. Numerous efforts have been devoted to studying static and dynamic changes of structural and functional phenotypes using LiDAR in agriculture (Jin et al., 2021). These progresses also improve 3D plant modelling across different spatial–temporal scales and disciplines, providing easier and less expensive association with genes and analysis of environmental practices and affords new insights into breeding and management (Figure 4).

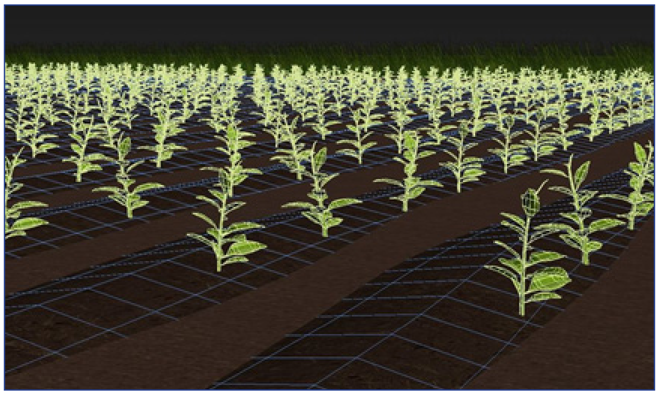

Figure 3: 3D modelling of crop field by LiDAR sensor

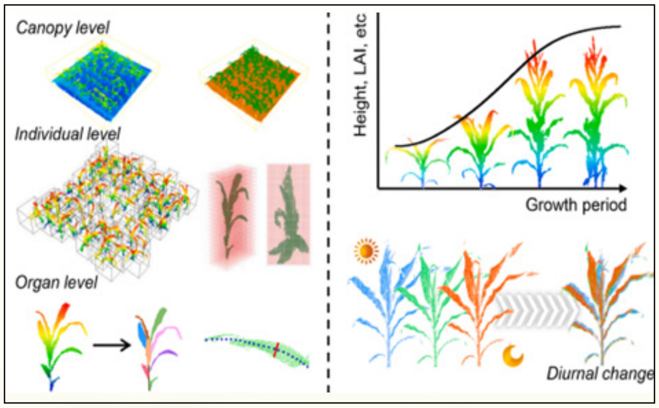

Figure 4: Applications of LiDAR in agricultural phenotyping

4.3. Determination of soil type and soil analysis

LiDAR technology can also be used to collect data that can identify the exact soil type of that particular farmland.

This information is important to the farmer because it helps the farmer to know which type of crops can be grown on that farm and the fertilizer requirements. It can help in the 5R' stewardship (right time, right dose, right amount, right place, right method). LiDAR sensor can help in Experts and farmers to use the LiDAR technology to analyse soil content and soil type to determine its suitability for crop production (Figure 5). LiDAR data can also be used to map a farmland and come up with the exact design and map of the land. This data will also include the shape and terrain of the farmland. According to study a 2D mean profile view of the soil is constructed to compare the digital LiDAR. From the experiments it was concluded; The geometric variations of soil texture, water content and flow, slope, fertility in the direction of the soil are observed more clearly by increasing the resolution from 2D measurements to 3D scans (Foldager et al., 2019). Thus, the results indicated the importance of applying a non-contact method for accurate soil surface measurements.

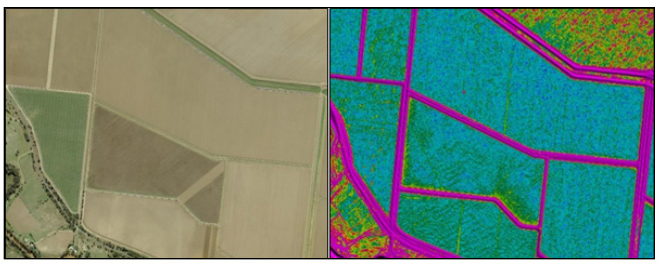

Figure 5: Soil type analysis by LiDAR sensor through laser sensing

4.4. LiDAR in agriculture for smart crop management

Traditionally, maps of cultivated fields are generated via manual digitization of the fields through satellite or aerial imagery. These images are then assigned for different crop types by manual ground surveys. However, this method is time-consuming, expensive and prone to human error. As illustrated in the Figure 6, automated remote sensing methods, such as using airborne LiDARs, are cost-effective alternatives. The data collected using LiDAR can be combined with machine learning algorithms for automating the crop classification. LiDAR can also be used to estimate the crop quality and measuring against the standards to carry out crop analysis and determine the suitability of the crop to thrive in a particular area. By using LiDAR in agricultural, farmers would be able to understand the current choice of agricultural soil, which crops are appropriate for farming in the current stage, other environmental information of farmland, through

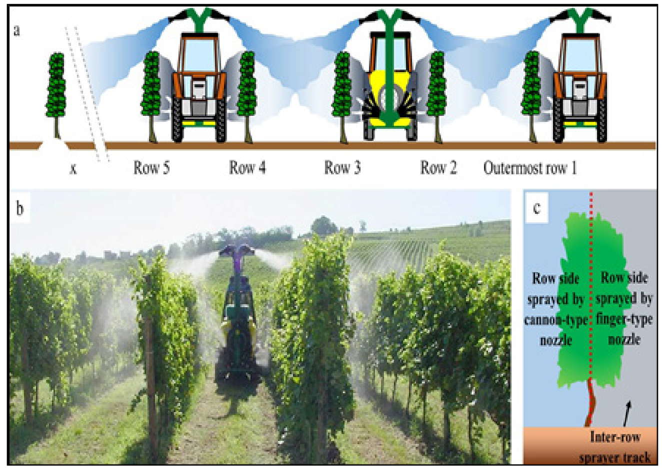

Figure 6: Variable rate technology using LiDAR sensor

intelligent analysis and better management and also helps in determining the extent to which crops have been damaged and help farmers to devise a recovery strategy.

4.5. Yield forecasting

LiDAR data has been used to forecast expected farm yields as shown in the Figure 7. Yield monitoring and crop geometric characterization provide information about field variability in yield, allowing farmers to make faster and better harvesting decisions. Farmers can detect fruit maturation using LiDAR technology. LiDAR sensors can estimate the yield by just scanning the field and assist farmers for increasing yield. Matsushita et al. (2021) found that LiDAR technology can help in rice yield prediction using drone-based LiDAR sensor. Five relevant vegetation indices, the normalized difference vegetation index (NDVI), normalized difference water index (NDWI), rice growth vegetation index (RGVI),

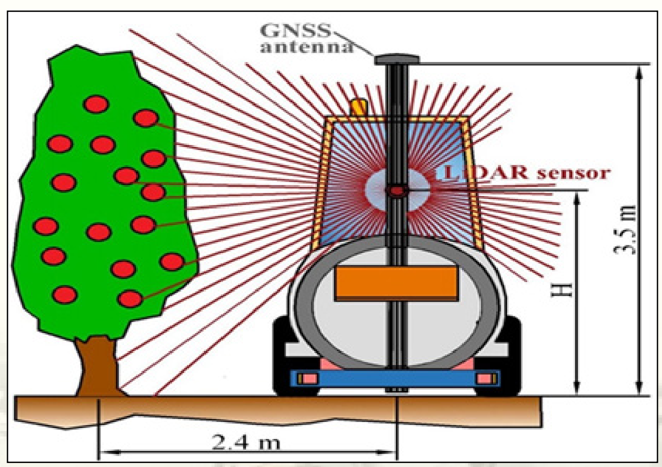

Figure 7: Fruit detection, yield prediction by LiDAR

moisture stress index (MSI), and leaf area index (LAI), were used to develop several empirical yield prediction models for rice production.

4.6. Prevention of Soil Erosion

LiDAR data can be used to quantify soil loss, specifically the GLS point cloud is employed to measure properties of surface properties (roughness) in the runoff zone which are impossible to measure in the field through 2D mapping and modelling of a given farmland. By getting the exact terrain of the farm and knowing the contours of a farm, farmers are able to come up with preventive measures to reduce or eliminate soil erosion (Haas et al., 2012).

4.7. Applications of LiDAR in Forestry.

LiDAR can be used to map the forests by measuring the vertical structures of the canopy, its density. These models help us understand the complex forest structures and generate accurate forest inventory (Figure 8). LiDAR can be used to monitor the fire patterns in the forests making the fire department aware of the next possible forest fire. Precision Forestry, targeted to specific forest areas could help us increase the productivity of the site in terms of the quality of the tree and the overall yield. Ground LiDAR system is highly potential in deriving forest inventory variables (DBH and tree height) and structural characteristics like volume in greater accuracy. The results confirm that GLS can provide a non-destructive, high-resolution and precise determination of forest inventory parameters (Ghimire et al., 2017).

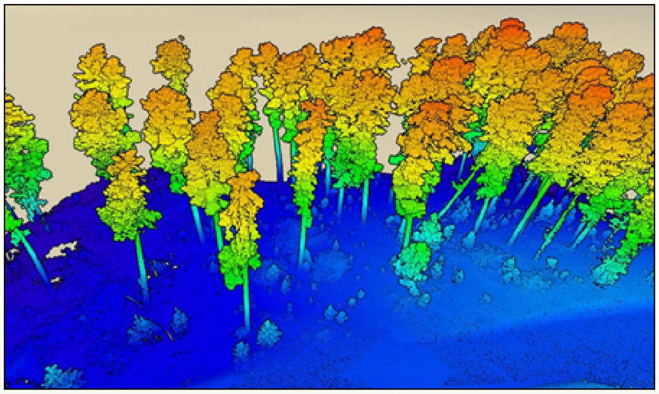

Figure 8: LiDAR image showing forest profile

4.8. Crop Damage

LiDAR technology can be used to determine the extent to which crops in an area have been damaged and the cause of the damage. This can help farmers come up with mechanisms to prevent the damage and hence increase yields.

5. Bottlenecks of LiDAR Sensor

• LiDAR is expensive; both initial costs and maintenance costs.

• LiDAR is power hungry; needing more power than other sensors.

• LiDAR is a technology that collects very huge datasets that require a high level of analysis and interpretation

• Unreliable for water depth and turbulent breaking waves

• Elevation errors due to inability to penetrate very dense forests

6. Conclusion

The use of new sensor technology in agriculture, such as LiDAR, can significantly increase yields and assist farmers in making better use of land. The use of these technologies represents an important step in preparing the industry for the future. 3D laser sensors seem to be the most promising and reliable systems for autonomous agricultural robots to sense the environment, with the added benefit of working in a variety of weather conditions.

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