APPLICATION OF LiDAR IN MARINE TECHNOLOGY

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Abstract

Since the 1960s, there has been LiDAR (Light Detection and Ranging) technology.Technology development has made LiDAR a well-liked sensor nowadays. Automation,agriculture, archaeology ,marine, and the quantification of various atmospheric components are all fields where LiDARs are presently utilised. This seminar include LiDAR's operation as well as its types, development, and various applications with respect to marine field. LiDAR measurements can be used to create 3D digital representations of the area in front of the sensor as well as distance calculations from various objects in space and draw the 3D digital representation of the area in front of LiDAR. LiDAR mapping is a well known technique for quickly generating precise geo-referenced spatial data about the Earth's shape and surface features. LiDAR mapping systems and their underlying technology have recently progressed, allowing scientists and mapping professionals to investigate natural and built environments at sizes never before feasible, with greater accuracy, precision, and cost effectively provide the best aspects of the culture of human civilization.

1. Introduction

LiDAR (light detection and ranging) uses the technique of projecting laser light onto the target and detecting the re-emitted light to identify variations in wave-length and arrival time. Being physically present in an environment and taking manual measurements is not always possible. LiDAR enters the scene when it comes to these measurements. Calculating the laser return timings and their wavelengths is how the measurement is done. It produces an accurate, detailed, and occasionally even three-dimensional map of the environment that it scans. The created map of the area in question aids in characterising and analysing it. A scanner, laser, and sometimes a specialised GPS receiver are the main components of a standard LiDAR system. Optics and

photodetectors are additional key components for data gathering and analysis. Typically, a le with the extension ".las" is where the LiDAR data is kept. American Society of Photogrammetry and Remote Sensing (ASPRS) supports this format (AS-PRS). LasTools recently created a brand-new format with the extension ".laz." The format ".laz" is a heavily compressed version of ".las." A file with the extension ".tif" is used to store the output data that are created from the scanned data. Scientists and mappers frequently utilise this technique to investigate a particular environment of interest. Most airborne, mobile, and terrestrial applications use these LiDAR measurements. LiDAR has proven useful in a variety of industries, including agriculture, where LiDAR robots sow seeds, detect weeds, and distribute fertiliser automatically, making it simpler to grow crops, fruits, and vegetables efficiently. In archaeology, LiDAR can be used to identify the topography of an archaeological site, analyse the forest canopy, and discover the features of the ground that were previously impossible to detect. In order to easily navigate across the path utilising laser beams, autonomous cars employ LiDAR to detect and avoid obstructions. In order to determine surface pressure, greenhouse gas emissions, photosynthesis, res, and humidity, LiDAR can be used to quantify various atmospheric components, monitor winds, analyse aerosols, and collect data on rain clouds.

Lidar mapping is a recognised technique for producing accurate and immediately georeferenced spatial data regarding the properties of the Earth's surface and shape. Scientists and mapping specialists can now explore natural and constructed surroundings on a variety of sizes with greater accuracy, precision, and flexibility than ever before because to recent developments in lidar mapping systems and their supporting technologies. The importance and utility of lidar data have been highlighted in numerous national papers published over the previous five years. In order to better understand how they use enhanced elevation data, such as lidar data, over 200 federal, state, municipal, tribal, and nongovernmental entities participated in the National Enhanced Elevation Assessment (NEEA). For summary and benefit-cost analysis, the nearly 400 functional activities that resulted were divided into 27 predetermined business purposes (NDEP, 2012). The applications portion of this document will go into greater detail about a few of these tasks.

2. History Of LiDAR

Our need to find solutions to problems leads to the creation of many inventions. Many people aspired to fly once Orville and Wilbur Wright proved that it was possible. You could fly farther, higher, and more quickly as flying technology advanced. Everything was OK, but there was an issue almost immediately: how to land. You must be aware of how far you are from the ground in order to land (safely). Knowing your relative distance to the ground is essential during landing approach. How then can you determine that distance in circumstances where vision is impaired, particularly in poor lighting or during bad weather like snow?

LIDAR sensors of today employ a laser beam to calculate a distance to an item. After striking an object, the light beam returns to the sensor. The amount of time it takes for this light to return to the LIDAR sensor is tracked by a microcontroller within. The sensor can now calculate and deliver the distance to that item because it is aware that the speed of light is constant. These measurements and computations are made by LIDAR sensors anywhere from 10 to 1000 times per second.

2.1 Early attempts of LiDAR technology

LiDAR and RADAR are linked (Radio Detection and Ranging). Christian Huelsmeyer's employment of an antenna, a receiver, and a transmitter to detect things at sea so that ships could avoid collisions with them in 1904 marked the invention of RADAR. The maximum detection range of early RADAR was 3000 metres. The original idea was to pulse radio waves at the target, then measure the strength of the signal that was reflected back. This was further enhanced by calculating the separation between the object and the transmitter by taking into account both the elevation of the object being detected and the height of the transmitting antenna. When radio waves hit an item, they travel a short distance, which is measured by RADARs. Light is used similarly in LiDAR. EH Synge, who in 1930 used searchlights to investigate the atmosphere, is credited with coming up with the concept of using light and measuring how long it took for the light to return in order to determine distance. Light pulses were employed in 1938 to monitor cloud heights in accordance with the atmosphere. Because laser light has a short wavelength, it offers the benefit of allowing for the detection and measurement of much smaller things. Because it can monitor raindrops and cloud particles, LiDAR is very well-liked by meteorologists. Additionally, because laser light is highly focused, it may be used to see even the smallest things in great clarity at considerable distances.

LiDAR technology continued to evolve as both the federal government saw significant defence applications, such as for targeting, and scientists could now conduct in-depth studies of the atmosphere, such as calculating the quantity of pollution in the air. NASA made an investment in LiDAR to map Mars, Mercury, and the moon during these numerous exploratory missions, making land mapping possible. Even the building and architectural industries could see the benefits of LiDAR. Geology, forest scientists, and oceanographers all came on board. LiDAR started to find widespread use in aircraft applications around 1960. LiDAR was utilised by NASA in the 1970s while it was creating exploration spacecraft. LiDAR is a laser-based remote sensing technique. Applications for LiDAR have expanded to include measuring the characteristics of the atmosphere and ocean water for topographic mapping. LiDAR technology was also used to study ice sheets and forest canopies.

Still, LIDAR didn't become a practical and incredibly accurate instrument for scientists until the GPS (Global Positioning System) became widely accessible and was combined with inertial measurement units (IMUs) in the late 1980s. By the mid-1990s, topographic mapping of the earth's surface was the primary usage for LIDAR scanners, which could generate 2,000 to 25,000 pulses per second. Although outdated compared to modern technologies, this technology helped governments design highways and surveyors and construction firms determine the optimum locations for buildings, particularly in unlevel terrain.

2.2 LiDAR Today

We can now see objects like we've never seen them before thanks to LIDAR technology. LIDAR has a wide range of useful applications, from watershed and river surveys to the assessment of hazards like lava flows, landslides, tsunamis, and floods. It is simpler to build cities, count people and vehicles, monitor climate change, and mine more innovatively and sustainably. We'll look at some well-known LIDAR technology producers below, including Hokuyo, LightWare, and YDLIDAR. All of these companies employ the same fundamental technology in their implementations, but they each focus on a different application. The three of these brands are represented by products from Acroname, and we are happy to direct you in the right direction when it comes to picking the best sensor model for your requirements.

3. Types Of LiDAR

LiDAR comes in two primary varieties: airborne and terrestrial. The downward-pointing architecture of airborne LiDARs allows them to scan solid angles at an average 180 degrees. Terrestrial Li-DARs, on the other hand, primarily carry out the horizontal scan and often cover 360 degrees in 1-D or in 2-D. Typically, airborne LiDAR systems are mounted on an aeroplane or a helicopter. The laser light from the aircraft's LiDAR sensor is directed toward the ground, where it is reflected and returned to the LiDAR sensor's moving airborne counterpart. There are two different kinds of airborne LiDARs: topographic and bathymetric.

For example, topographic LiDARs can be used in forestry, urban planning, landscape ecology, and other fields to examine the surface. Applications involving water penetration use bathymetric LiDARs. They are frequently employed to concurrently examine elevation and water depth. It is used to penetrate water, but it is also used to simultaneously examine height and water depth. It is mostly utilised close to shorelines, banks, and coasts. A terrestrial LiDAR gathers points with exceptional accuracy to enable accurate item identification.

Typically, terrestrial LiDARs are employed for tasks like surveying roads and railroads, maintaining infrastructure, building 3D representations of areas, etc. Additionally, there are two varieties of terrestrial LiDAR: static and mobile. The laser light from the aircraft's LiDAR sensor is directed toward the ground, where it is reflected and returned to the LiDAR sensor's moving airborne counterpart. There are two different kinds of airborne LiDARs: topographic and bathymetric. For example, topographic LiDARs can be used in forestry, urban planning, landscape ecology, and other fields to examine the surface. Applications involving water penetration use bathymetric LiDARs. They are frequently employed to concurrently examine elevation and water depth. The laser light from the aircraft's LiDAR sensor is directed toward the ground, where it is reflected and returned to the LiDAR sensor's moving airborne counterpart. There are two different kinds of airborne LiDARs: topographic and bathymetric. In addition to being utilised for water penetration, it is also used to simultaneously examine both height and water depth. It is mostly utilised close to shorelines, banks, and coasts. A terrestrial LiDAR gathers points with exceptional accuracy to enable accurate item identification.

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On the basis of backscattering, LiDAR can also be divided into three categories. These types include Raman, Mie, and Rayleigh LiDAR. LiDAR can occasionally also be categorised in other ways. The two forms of LiDAR in this classification are coherent and incoherent LiDARs. Incoherent LiDARs are based on amplitude measurement, while coherent LiDARs are based on phase sensitivity.

4. Working Of LiDAR

The reflection of light serves as the LiDAR's guiding design philosophy. This idea involves shining a light beam on a surface and measuring how long it takes for the light to return to its source. The LiDAR system projects laser light onto the target and measures the light that is reflected to determine the variation in wavelength and time of arrival.

It can determine the distance needed to create the target's digital representation based on these data. LiDAR calculates the precise distance very quickly since light moves at such a rapid rate. Continuous wave LiDAR sensors use the phase difference of the return signal to estimate the object's distance and other properties. To generate a point of cloud that reflects the detected item using pulsed waves, we are more concerned with the amplitude of the broadcast and received signals. 2019 (Beland) Forestry measurements frequently employ full-waveform signals, whereas other industries frequently use pulsed signals.

A light source and a receiver or sensor make up the majority of a LiDAR system. The source emits a laser or light beam, which the target deflects and returns to the LiDAR system, where the sensor picks up the pulse.

The LiDAR system estimates the time difference between the laser's emittance and when it is received, taking the speed of light into account, to determine the precise distance of an object. LiDAR can detect an object's location, size, and shape in relation to the LiDAR system on its own. To improve their capabilities, however, LiDAR sensors are frequently combined with a GPS, an IMU sensor, or a camera.

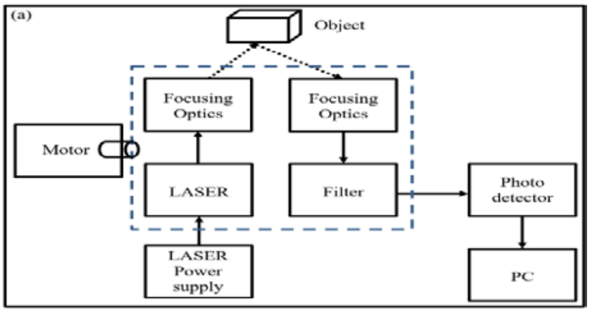

Fig 4.1 Working of LiDAR

5. Applications Of LiDAR

5.1 Autonomous Shipping

The shipping and maritime sectors are sometimes criticised for being extremely conservative and sluggish to adapt, especially to a development as significant as unmanned transport. The maritime industry has recently shown a growing interest in researching the advantages of autonomous maritime boats for freight transportation. This led to a number of exploratory projects, such as the Advanced Autonomous Waterborne Applications Initiative (AAWA), an autonomous system concept from Rolls-Royce Marine in 2016, an autonomous system from Skredderberget in 2018, a Japanese Trans-Pacific test named by Cooper and Matsuda in 2017, the MUNIN research project in 2016, and an autonomous system test location in China named by Jennings in 2018, a start-up firm that converts ancient ships into autonomous vessels was named by Constine in 2018 and the DIMECC "One Sea" Consortium was named by Haikkola in 2017.

Numerous of these initiatives centre on the anticipated advantages of AS, including, among others, improved lifestyles for seafarers, increased maritime shipping capacity, decreased operational costs, decreased manning, increased operational times, decreased fuel consumption, data analytics9, and intercommunication with 5G Networks10. Others, such the ones mentioned by Karlis in 2018, Willumsen in 2018, and Kobyliski in 2018, have shown more scepticism toward the benefits that have been suggested and have highlighted numerous problems that still need to be resolved. An increased technological and ECO progress rate in the maritime shipping sector is another advantage that AS might bring about. This faster rate of improvement is made possible by the increased potential for software upgrades mentioned by Greengard in 2015, the quickly advancing energy technologies for propulsion mentioned by van Biert et al in 2016, and the "Big Data"-driven learning to continuously increase transportation efficiency mentioned by Perera and Mo in 2016.

The evolution of autonomous operations6 depends on a ship's capacity to keep track of its own "health," establish and communicate with its surroundings, and make decisions based on that knowledge. A system of electronic sensors that can provide information to a "electronic brain" and help a ship navigate safely and avoid collisions is needed. Sensor Fusion, Sea State, Meteorology, Control Algorithms, Communication and connectivity6 are the areas of importance. The project AAWA has determined that combining several sensor inputs yields the best results after examining various types of radars, high definition video cameras, thermal imaging, and LIDAR. LIDAR systems (sensors) are high-quality, cutting-edge remote sensing systems that can track environmental parameters. They are crucial not only as a baseline for the environment but also for enhancing the quality and accuracy of measurements, which will be most useful for the accurate knowledge of the surrounding weather and sea conditions in real time, in terms of best trajectory calculation, lowering the risk of cruising6, but also for feeding weather forecasting systems.

Even with the single wavelength LIDAR 4, 5, 6, 7, it is possible to detect and quantify visibility, fog, and several other atmospheric conditions approaching the ship, as well as their estimated time of arrival, making its use cost-effective. Accurate algorithms have been developed in settings that are universally verified to be eye-safe for LIDARs, which have been used for years to detect and quantify atmospheric conditions (1 pp. 203-204), 4, 5, 6, and 7. In this scenario, ships will act as parallel mobile high-performance remote sensing meteorological stations, assisting national meteorological services or other meteorological organisations in their work and, ultimately, the World Meteorological Organization (WMO). By doing this, ships will undoubtedly maximise the accuracy of current weather and sea state measurements and will play the largest role in weather forecasting models. By sending the gathered weather and sea state data from each LIDAR-capable ship to meteorological organisations around the world in real time, a novel type of cooperation can be accomplished. This is also advantageous for the needs of marine units to acquire for future arrangements of cruising in warfare and trade conditions.

Algorithms created in 4, 5, 6, 7, and 8 can also contribute to the detection of hard targets and their separation from waves by measuring the velocity and time of arrival of both hard targets and waves. This increases the safety of the ship from collision and helps it steer clear of terrorist attacks in "operational" open or close seas. In instance, a particular selection of laser beam wavelengths enables the detection of submarines at various depths and/or surfaces. Subsurface - Submarine MUSs approaching, measuring in some depth, the effects for the ship sea current speeds, as well as through the measurement of the sea current energy spectrum, adding to the cost and fuel consumption effectiveness, as well as safe cruising. Even in circumstances where the "naked" eye cannot detect, LIDARs can help with the accurate identification of oil spills and, through that, with the earlier presence and trajectory detection of ships and submarines.

Therefore, LIDARs 6, 7, 8 can achieve extraordinarily high accuracy for the essential measuring parameters of visibility, hard targets detection over and under water, incoming fog - weather conditions - large sea waves, and oil spills. Real-time situational awareness can be provided by LIDAR measurements of wind, temperature, and humidity profiles in three dimensions as well as the directional energy spectra of sea surface waves, surface current air velocity, and speed of the sea surface. For the best route planning, in terms of safe navigation, for fuel consumption and optimization as well as for personnel comfort, it is possible to achieve safe alarm triggering for approaching severe weather conditions detection and forecasting, providing for all important variables for ships in transit. However, AI or AI - Man interaction with best hybrid sensor system availability and algorithmic processing6, 8 is about to "lift" the services offered. Currently, marine environment decision making is solely dependent on the reliability and accuracy of weather and sea state prediction as well as personnel experience. Another area where LIDAR progress may have an impact on shipping is in the management of pollution that ships produce, particularly inside harbours. LIDARs can be installed close to the ship's pipes and on the stern, where the engines produce aerosol, to accurately measure pollution and the efficiency of those engines under various conditions. They can also be used to advise the ship's controller to reduce consumption when necessary through an AI-Man interaction system, which will help the ship be more cost-effective in terms of fuel consumption. Both autonomous and manually operated ships can take advantage of all the aforementioned uses and advantages, and the following will be required :

a). Fluorence and/or Raman LIDARs for accurately measuring oil spill instances, fuel consumption, pollution, the presence of other marine or undersea systems based on their own oil spill traces in the sea, and the possibility of terrorist or other assaults.

b). 3D scanning LIDAR and/or holographic LIDARs with a constrained steady angle-position that continuously monitors the state of the sea for the identification of hard targets, large waves, submarines, MUSs, and approaching low-level weather conditions.

c). Smaller laser proximity sensors that will be used for safe navigation inside harbours and confined spaces and that will be engaged during the mooring phase, ship excursion phase.

d). Importing Satellite Communication (GNSS)-based Navigation Data (Navigation App) into 5G Networks11 (user dependable).

e). Importing weather information from apps and other ships with equivalent systems.

f). After assessing the present weather/sea condition and other inputs, the application of AI algorithms for LIDARs and hybrid system management in total for data and decision-making with an AI system or AI-Man interaction system (user-reliable).

g). Holographic LIDAR or 3D scanning, combined with other anti-UAS technology like microwave radar, can safeguard UASs from potential terrorist or other attacks.

h). "Laser Gun" or "Laser Emitting Device" for the ship's self-defense following tracking and identification of an impending potential threat

I TDL interoperability operating as Regular Networks with Shared Information of All Available Data/Early Warning for Ship Under Attack/Under Emergency from Nearby Ships- Distress Call etc. The aforementioned functions may benefit from 5G Networks11 and satellite communication (GNSS).

j). When satellite communication is not possible due to jamming, interference, or any other reason like malfunction, LIDARs are used as an alternate method of navigation via water depth scanning (where possible) in conjunction with the availability of sea depth maps and the advancement of the latter.

Here is a description of how LIDARs can be used for environmental protection, notably for long-distance trading ships and battleships. This took place so that NATO would be informed and able to function as efficiently as possible. Under the aegis of the new and upcoming ECO requirements, such as pollution control, particularly inside harbours, as well as the threats recently developed, such as UASs and MUSs, LIDARs, and hybrid systems, supposed to feed an AI or AI - Man Machine Interactive Navigation and Protection device, which eventually will affect maritime patrol and control.

5.2 Lidar Sensing Of Wakes

Currently, the ability to detect ship wakes is crucial in a number of fields, such as border security and cargo ship traffic monitoring. Acoustic sensing radar remote sensing ,satellite photography , hyperspectral measurements [and water sample analysis are common approaches for locating the wakes of large ships. The length of the window within which the wake is observable is a crucial aspect of wake diagnostics. After the passage of a large ship, it can take anywhere from a few minutes to hours for conventional approaches (timeof acoustic signal attenuation or wake visibility inthe satellite radar image).

At the same time, due to the rapid relaxation of observed water characteristics in light boat wakes, radar and acoustic detection techniques are of limited use for identifying small, high-speed vessels (below 10 min). Therefore, there is a strong need for novel techniques for remotely sensing the wakes of fast small boats.

Whenever a ship's propeller rotates, a lot of bubbles typically appear in the wake. These could be either cavitation bubbles from water effervescence on the back sides of the propeller blades or air bubbles caught by the movement of the propeller. Cavitation can damage the propeller surface and significantly degrade propeller efficiency . Even the most advanced propellers for high-speed vessels, however, are not immune to the cavitation effect.

At the moment Only at a high propeller rotation velocity, which unavoidably results in cavitation, can the vessel reach the needed high speed. Acoustic measurements and high-speed photography are two established techniques for studying cavitation . The first approach relies on measuring the amplitudes of acoustic waves that result from cavitation bubbles collapsing. The second technique employs stroboscopic illumination for highly precise visual observation of developing bubbles. After the creation of the method for producing cavitation bubbles at the given place, there was a discernible advancement in the research of cavitation using op-tical approaches It made it possible to analyse the development, oscillation, and collapse of cavitation bubbles with a high degree of temporal resolution using a variety of optical techniques. The inability to duplicate the production and evolution of a cavitation bubble at the same position in space made it challenging to research cavitation induced by the rotation of a ship propeller. For a fast rotating propeller, for instance, it is impossible to forecast exactly where a cavitation bubble will form. This is made more difficult by the fact that the propeller creates turbulent flows with complex shapes that can unpredictable break bubbles off and transport them along the flow. Studies on bubble wakes produced by a vessel under natural settings as well as laboratory experiments with model propellers and laser sensing of artificially manufactured gas bubbles have all been done. There, cavitation bubble production was studied solely utilising the elastic scattering signal; no spectral measurements were made. A high-speed boat wake can be detected via distant laser sensing, as we have previously shown in natural tests [20]. We measured the Raman scat-tering (RS) spectra of the water in the boat wake using a Raman scat-tering lidar and found a reduction in the amplitude of the OH valence vibration band. The amplitude of the OH band in the RS spectra reduced when the high-speed boat's propeller stirred up the water and gradually increased again. Calculating the relaxation time over a period of 7 minutes produced a figure of 120 miles.

However, only the first 30 to 50 s showed a decline in the signal of elastic laserbeam scattering. Only the first 1.5 to 2 minutes after the boat wake was identified using acoustic sensors. It was assumed that long-lived bubbles with a diameter smaller than the detecting radiation wavelength were present in the wake to account for the lengthy (tens of minutes) decline in the RS signal (527 nm). Unfortunately, it was unable to measure the length of the RS signal relaxation period in the natural experiment after the high-speed boat propeller was rotated.

6. RADAR Vs LiDAR

6.1 Radar

Radio Detection and Ranging is known as RADAR. Like its name would imply, RADAR operates on a similar concept to LiDAR, with the exception that radio waves are used in place of lasers or other forms of light.

Radars are able to reach greater distances than LiDAR systems because radio waves have a considerably longer wavelength than light waves. Your measurement device's requirements will determine the frequency and kind of radio waves that are utilised.

Table 6.1 RADAR frequency bands (Parker, 2017)

RADAR Band	Frequency (GHz)	Wavelength (cm)
Millimeter	40-100	0.75-0.30
Ka	26.5-40	1.1-0.75
K	18-26.5	1.7-1.1
Ku	12.5-18	2.4-1.7
X	8-12.5	3.75-2.4
C	4-8	7.5-3.75
S	2-4	15-7.5
L	1-2	30-15
UHF	0.3-1	100-30

Although LiDAR and RADAR share the same objectives and guiding concepts, their respective waveforms have brought forth a whole new level of distinction.

Instead of arguing over which system is superior, LiDAR and RADAR systems each have a specific role to play in your system, each with advantages and weaknesses.

- Remote sensing tools like LiDAR and RADAR identify objects by using radio waves and light waves, respectively. They take into account the lag time between the time the waves are transmitted and the time the wave is received after being reflected by the object.

- Compared to RADAR, light waves are more precise and accurate. RADAR sensors, however, are more reliable. It has a longer range and works effectively in adverse weather, when LiDAR frequently fails.
- Comparatively speaking, RADAR systems are less expensive than LiDAR sensors. This may alter, though, as more businesses work to create solid-state LiDARS that are more affordable.

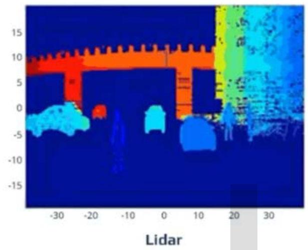

Fig. 6.1 LiDAR

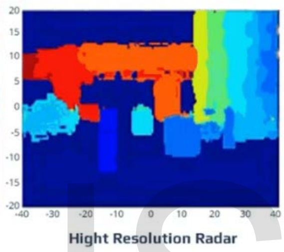

Fig. 6.2 Radar

6.2 Reliability

Although RADAR's accuracy may be considerably better, it is significantly more trustworthy than LiDAR.

LiDAR is susceptible to the medium's own effects because it employs light waves as its medium. For instance, a LiDAR system's performance is impacted by atmospheric moisture. Inclement weather, such as rain, fog, or snowstorms, has an adverse effect on the performance of LiDAR devices.

Additionally, the majority of LiDAR used in autonomous vehicles employs a spinning device to emit laser pulses, necessitating routine maintenance to keep it functioning properly. However, solid-state LiDAR system options have lately expanded, thus this might not be a problem for very long.

In contrast to LiDAR, RADAR employs radio waves that have a significantly larger wavelength and can therefore travel farther.

Additionally, radio waves move with little disruption even in bad weather due to their reduced attenuation. Even with its limited resolution, RADAR is a great alternative to sensors that rely on the optical principle when they are compromised.

6.3 Cost

Due to their exorbitant price, LiDAR sensors have long been out of the reach of the majority of manufacturers.

Velodyne's high-end automotive LiDAR used to cost $75,000 for one vehicle.

But in recent years, the cost of LiDAR systems has significantly decreased as a result of the efforts of numerous businesses.

On CES 2020, Velodyne introduced the Velabit, a solid-state LiDAR with no moving parts that costs $100.

Comparatively speaking, RADAR systems have always been more affordable than LiDAR, with an automotive millimeter-wave RADAR sensor module costing as little as $50.

The high cost of autonomous vehicles is in part due to the cost of LiDAR sensors. The majority, including Waymo, Toyota, and Uber, use LiDAR to detect the environment for their self-driving functionality, however Tesla continues to ignore LiDAR and develop RADAR for its self-driving vehicles.

7. Advantages & Disadvantages Of LiDAR

7.1 Advantages

- **Data can be gathered rapidly and accurately thanks to LiDAR**, an airborne sensing technology that, thanks to its location advantage, enables quick data collection and extremely high precision.
- **The sample density is higher with surface data**. LiDAR provides a substantially higher surface density than other data collection techniques like photogrammetry. For some types of applications, including the delineation of flood plains, this enhances the outcomes.
- **Capable of gathering elevation data in a dense forest:** Due to its great penetrative powers, LiDAR technology is able to get elevation data from a densely populated forest. It can therefore map even heavily forested areas.
- **Has no geometrical distortions:** Unlike other methods of data collecting, LiDAR sensors are unaffected by geometrical distortions like angular landscapes.
- **It can be used with other data sources to simplify the analysis of complex data automatically**. LiDAR technology is a flexible technology that can be combined with other data sources.
- **LiDAR technology relies on fewer people than photogrammetry and surveying because the majority of its operations are automated**. Additionally, this guarantees the efficient use of time, particularly during the phase of data gathering and processing.
- **LiDAR technology can be used to map inaccessible featureless environments**, including high mountains and areas covered in deep snow.
- **It is inexpensive:** Because LiDAR technology is quick and incredibly accurate, it is a less expensive technique of remote sensing in many applications, especially when dealing with large amounts of land.

7.2 Disadvantages

- **High running costs in some applications:** LiDAR can be expensive when used to collect data in limited areas, but being inexpensive when used in large applications.
- **Ineffective in times of heavy rain or low-hanging clouds:** Due to the effects of refraction, LiDAR pulses may be impacted by heavy rains or low-hanging clouds. The information gathered can still be used for analysis, though.
- LiDAR technology suffers from poor performance in regions or circumstances with **high sun angles or significant reflections** because the laser pulses rely on the reflection principle.
- **Unreliable for turbulent breaking waves and water depth:** Since high water depth will impact the pulses' ability to reflect, this method may not provide accurate results when employed on water surfaces or other irregular surfaces.
- LiDAR is a technique that generates **extremely massive datasets** that are challenging to **analyse and that demand a high level of analysis**. The analysis of the data could be time-consuming as a result.
- **Lack of stringent international procedures:** When using LiDAR technology, data collection and analysis are done haphazardly because there are no strict international protocols to guide them.

- **Elevation inaccuracies caused by failure to penetrate extremely dense forests:** In some cases, extensive forest canopies may prevent LiDAR pulses from penetrating, resulting in incomplete data.
- **When a laser beam is strong enough, it may harm the human eye:** LiDAR pulses frequently employ strong laser beams, which can sometimes harm the human eye.
- **Inability to penetrate dense vegetation:** When collecting data, LiDAR pulses may be unable to penetrate dense vegetation, which could result in erroneous data.
- **Need expert data analysis methods:** Due to the size of the data sets and the complexity of the data being gathered, it may be necessary to analyse the data using specialised methodologies, which raises the overall cost.
- **Low working altitude of 500–2000 m:** LiDAR technology cannot operate at altitudes above 2000 m since the pulses will lose their effectiveness at these altitudes.

8. Combined LiDAR-RADAR Remote Sensing

8.1 Initial Result From Crystal-Face

Five remote sensing satellites will make up NASA's "A-train" constellation when it is fully operational. These satellites' equipment will produce a variety of collocated and cotemporal data products, whose synergies should considerably improve our understanding of the Earth's atmosphere. The Aqua satellite, which commands the string of satellites, is where the A-train gets its name [Parkinson, 2003]. The CloudSat [Stephens et al., 2002], CALIPSO [Winker etal., 2002], PARASOL [Deschamps et al., 1994], and Aura [Schoeberl et al., 2001] satellites come after Aqua in that order. These satellites will be in a sun-synchronous orbit of 705 km with a 1:30 pm equatorial crossing time. This constellation of satellites is created to collect supplementary data products and enhance global remote sensing of the atmosphere.

A comprehensive set of instrumentation were deployed during the Cirrus Regional Examine of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE) field mission in July 2002 [Jensen et al., 2004] to study the characteristics and processes of tropical cirrus clouds. One of the aircraft's sensors, the NASA ER-2, produced high-altitude downlooking observations from what can be regarded as close substitutes for the A-train devices. The newly developed Cloud Radar System (CRS) [Li et al., 2003; Racette et al., 2003] is a 94 GHz pulsed polarimetric Doppler radar that gives observations comparable to those of the CloudSat cloud profiling radar (although CloudSat will not haveDoppler capability). Similar observations are provided by the polarization-sensitive lidar aboard CALIPSO, which operates at 532 nm and 1064 nm, as well as the Cloud Physics Lidar (CPL) [McGill et al., 2002, 2003]. The references contain thorough descriptions of each instrument. We see that CPL and CRS both have higher vertical and spatial resolution than the upcoming spaceborne instruments, which is an advantageous attribute for modelling the performance of the spaceborne systems. For cirrus and other cloud studies, ground-based sensors have previously used combined lidar-radar data [e.g., Mace et al., 1998; Comstock et al., 2002]. However, the novel aspect of the high-altitude aeroplane platform is the singular viewpoint and satellite simulation made feasible. Ground-based observations show the value of combining radar and lidar measurements, but the high-altitude view offers a more accurate representation of the CALIPSO-CloudSat data package in the future. The main advantage of using data from ER-2 aircraft sensors is that they are above 94% of the Earth's atmosphere and do not experience atmospheric attenuation like ground-based sensors do.

8.2 Lidar-Radar Observations

Given the disparity in backscatter between the optical and microwave regimes, it is challenging to provide quantitative comparisons of lidar and radar results. Given that neither instrument can directly quantify particle size or form, comparing measurements from basic backscatter lidar and radar is significantly complicated. Thus, as noted in the introduction, there are three degrees of freedom in the air particulates (particle size, particle shape, and concentration) that have a varied impact on each instrument signal. In particular, radar in the Ray-leigh regime is sensitive to equivalent particle diameter to the sixth power, whereas lidar is sensitive to equivalent particle diameter squared. Depolarization measures, which can be produced by both CPL and CRS, can be used to compare the data from lidar and radar, although they are not always accurate because particle size and orientation can change on their own.

8 flight tracks for July 23 comprise of more than 5 million range bins with a vertical resolution of 37.5 m. (8927 profiles with 560 bins per profile ata flight altitude of 21 km). In 21.9 percent of the bins, the radar identified clouds, and in 78.1 percent of the bins, it detected clear air. According to the radar profiles, 10.7% of the radar clear air bins actually contain cloud (or aerosol) that was below the radar detection threshold rather than clear air. The lidar found a layer in 15.3% of the bins, clean air in 52.2 percent, and no signal in 32.5 percent of the bins due to thick cloud covering above. A lower bound for the actual amount of cloud present in areas where the lidar signal was completely attenuated can be calculated from an analysis of the radar data. In this instance, we discover that the lidar signal was completely attenuated for 38.0 percent of the bins where the radar identified clouds.

Examining only the bins designated as being within a layer is another method for evaluating an instrument's detection capacity. Using only the bins inside layers, only the lidar detected 27.6% of the targets, both lidar and radar detected 22.8 percent, and only the radar detected 49.6%. The complimentary nature of the measurements in this example is obvious, and there is some overlap between the equipment.

Convective systems and cirrus anvils were the main topics of interest for CRYSTAL-FACE flights. However, one lengthy trip did not aim for convective systems. Two examples were investigated, one with convective systems and cirrus anvils and one with synoptic cirrus and a sizable amount of clean air, in order to capture some portion of the various meteorological characteristics. The two instances produce quite different results, primarily as a result of differing cloud distributions but also possibly as a result of various features of the ice hydrometeors. It follows that a combination of both sensors, rather than a lidar or a radar, is the optimum device for supplying an accurate picture of atmospheric clouds and aerosols. Future research will integrate the fundamental lidar and radar measurements to produce profiles of microphysical parameters that are crucial to climate models and three-dimensional simulations, such as effective particle diameter and ice water content. The combination of CPL and CRS measurements from CRYSTAL-FACE provides a strong indication of the measurement synergy that exists between these two remote sensing techniques and offers a first look at the combined data output from the upcoming CALIPSO and CloudSat missions.

9. Conclusion

LiDAR and RADAR are nearly identical in theory, with the exception of the waveform employed. Both methods employ a transmitter to send out a wave and a sensor to determine the precise distance to the target by measuring the returned wave.You must choose your measuring unit's requirements and constraints in order to determine which is better for your project. Unlike RADAR, which uses radio waves, LiDAR employs lasers with considerably shorter wavelengths. Due to its increased accuracy and precision, LiDAR is now able to detect smaller objects in greater detail and produce 3D representations based on the high-resolution photographs it produces. On the other hand, RADAR has a lower beginning cost than LiDAR and is far more resilient. Although you don't acquire as many information, it has a greater range than LiDAR and can operate in harsher situations.Alternately, you can use data fusion algorithms to combine RADAR and LiDAR with additional sensors to produce a system with more capabilities. Some of the major application of LiDAR is also studied and the comparison is done accordingly. LiDAR play a main jor role the developing technology like autonomous shipping .Here the combination of LiDAR and RADAR is studied. With the help of this data my proposal is to implement this technology in marine field that is to install it in ship which help us in efficient work application like research , sea mapping etc.

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