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A STUDY ON LIDAR SYSTEMS: STRUCTURAL FRAMEWORK, FUNCTIONING, APPLICATIONS WITH A SPECIAL EMPHASIS ON AUTONOMOUS VEHICLES

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ABSTRACT

Ever since the invention of the laser in 1960, LIDAR has made a path-breaking progress. More and more LIDAR technologies have been developed over these last 60 years or so. This study highlights the application of LIDAR technology to industries including construction, automotive, military operations, farming, forestry and oceanography. It discusses the structural framework around which the LIDAR is built and the technologies that it uses to function. The study discusses the importance of LIDAR to autonomous and semi- autonomous vehicles. However, the cost effectiveness of these sensors needs to be established. There is also discussion about more and more companies coming up with a combination of VCSEL lasers and SPAD detectors which are popular due to their ease on design complexity and cost. However, they may only thrive if they are able to improve their efficiency in terms of range. The study covers the challenges and opportunities faced by LIDAR technology along with tools to curb them. These will help to protect customers' data privacy and lead to new product development in the future. The entire study has been conducted while keeping in mind the fast-paced growth and market projections over the next couple of years.

KEYWORDS: LIDAR technology, LIDAR applications, Autonomous Vehicles, Semi-autonomous Vehicles, LIDAR market, VCSEL lasers, SPAD detectors.

INTRODUCTION

According to Grand View Research, the global LiDAR services market size was valued at USD 985.4 million in 2018 and is expected to register a CAGR of 14.5% from 2019 to 2025. With

LiDAR technology having an eminent remote sensing tool, it is gaining a lot of popularity among the mapping community and land surveyors worldwide.

LiDAR technology has vast application in the unreachable, secluded territories, and forests. This technology has made studying these areas possible. Light energy is used from the laser which then helps to take account of the distances on the ground and underneath the ground.

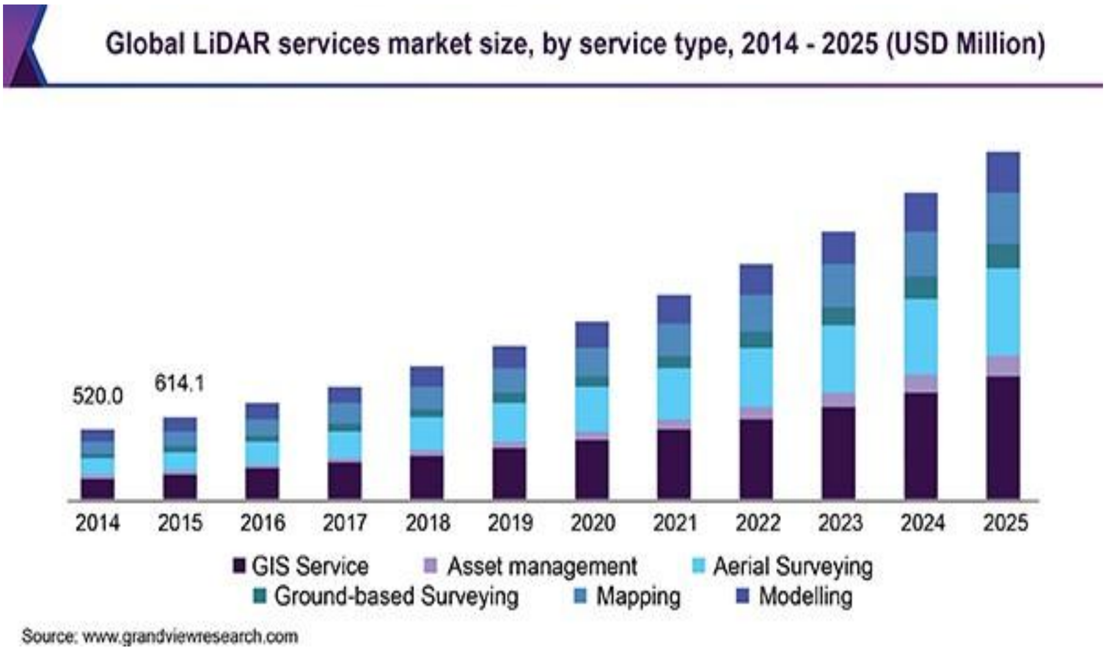

Figure 1: Market Projection for LIDAR services.

LIDAR stands for Light Detection and Ranging. In this technology, light is used in the form of a pulsed laser to measure distances between the sensors and objects around it. The time taken by the echo to return with respect to the speed of light is then used to estimate the distance from that object. LIDAR is a type of remote sensing technology that measure ranges (variable distances). Multiplying this time interval by the speed of light results in a measurement of the round-trip distance travelled, and dividing that figure by two yields the distance between the sensor and the target.[1]

Laser light is sent out in LIDAR and is measured for the time taken for it to reverse. Since light travels at a constant speed, the round- trip time can be translated into a precise distance estimate. Repeat this process across a two- dimensional grid and the result is a three-dimensional “point cloud” showing the location of objects around a room, street, or other location.[2]

The first three- dimensional lidar sensor was introduced by Velodyne with a unit cost of around \$75,000. It mounted 64 individually packaged lasers in a column on a spinning gimbal. Each laser came with a corresponding detector. Velodyne's initial LIDAR units were very expensive due to the need for these lasers to align with the detector which made the overall design very complex. More recently, a number of companies have experimented with using small mirrors to "steer" a laser beam in a scanning pattern. This design requires only a single laser instead of 64. But it still involves at least one moving part.[2]

However, LIDAR has become cheaper and accurate owing to break- through progress in IMU (Inertial Measuring Unit), lasers, and other technologies. Around the advent of the 21st century, efficient and accurate terrain- mapping tools have been developed based on this airborne remote sensing technology. This development has spawned innovative solutions to difficult mapping problems, including several new applications which were nearly impossible earlier in the absence of data like LiDAR.[3]

LiDAR mapping is an active method of generating precise and directly georeferenced spatial information about the shape and surface characteristics of the Earth.[4]

The aim of this research work is to study the existing LIDAR systems, their structural framework and functioning, LIDAR applications and challenges and opportunities in LIDAR. This area of technology is gaining a lot of momentum and hence a review of all these aspects of LIDAR helps to gain a better understanding of how well this technology can support the cause of mankind and its survival.

STRUCTURAL FRAMEWORK & FUNCTIONING OF LIDAR TECHNOLOGY

According to MOSAIC Mapping Systems Inc. (2001) LiDAR is the integration of three technologies into a single system capable of acquiring data to produce accurate digital elevation models (DEMs). These technologies are; Lasers, the Global Positioning System (GPS), and Inertial Navigation Systems (INS). Combined, they allow the positioning of the footprint of a laser beam as it hits an object, to a high degree of accuracy.[5]

STRUCTURAL COMPONENTS OF LIDAR

1. LASER

- The laser light bounces from the lidar and hits different objects all around it (360- degree vision) and then comes back to the lidar. The detection is done with the help of another component of the system which is known as the sensor.

- Lidar can also be compared with sonar which uses sound waves instead of light waves. However, lidar is preferred because light travels much faster than sound, so the response time of a lidar system is much quicker than a sonar system.
- Due to the response time, lidar is preferred in autonomous vehicles as anything unexpected can happen on the road and it is better to have a faster response time.

Key differences among lidar sensors are related to the laser's wavelength, power, pulse duration and repetition rate, beam size and divergence angle, the specifics of the scanning mechanism (if any), and the information recorded for each reflected pulse.[6] Also, there are various components or features which require co-operation:

1) Frequency – normally the frequency of the light emitted by the laser is between 50,000 – 200,000 Hz (pulses per second)
2) Wavelength – The wavelength of the laser is dependent on the purpose for which the lidar system is being used. Specifically, for autonomous machinery, the wavelength used is 905nm and 1550 nm. These lie in the near- infrared – infrared region.

Figure 2: An image of a laser.

3) Safety (prevention of visual impairment) – At the beginning, 905 nm lasers were used because they were much cheaper and readily available. However, the 1550nm lasers are safer for the human eye.

2. SCANNER

- The scanner receives the returning pulse from the object of which the light bounces off.
- The speed at which the images are formulated by the lidar system is dependent on the speed at which the scanner receives the images.

- A scanner works by measuring the amount of time it takes for the light ray to return. It works on a very basic system. The speed of light is 299792458 m/s. Supposing that the light ray hits a car and comes back in one second. Therefore, the distance between that car and the lidar sensor will be 299792458m.

Hence, the time is used to determine the distance between different objects and the lidar sensor. Formula for distance = (speed of light x time taken) / 2

In this the total is divided by 2 because the amount of time taken is the time taken for the pulse and return both. But we need the time for only the return.

Figure 3: Example of a Velodyne lidar system.

3. GPS (Global Positioning System) and IMU (Inertial Navigation Management Unit)

- The GPS system has a very simple role in the lidar system. It records the X, Y, Z coordinates. This locates the position of the scanner and the location of the various objects around it.
- The IMU measures the inertial balance of the scanner relative to the ground to make the measurements even more precise and make sure there is no deviation in the results due to the orientation of the scanning device. This unit is more useful in airborne measurement units such as planes or drones.
- The IMU measures the roll, pitch and yaw of the aerial measuring unit which works alongside the GPS system to successfully know the correct position of every single light pulse.

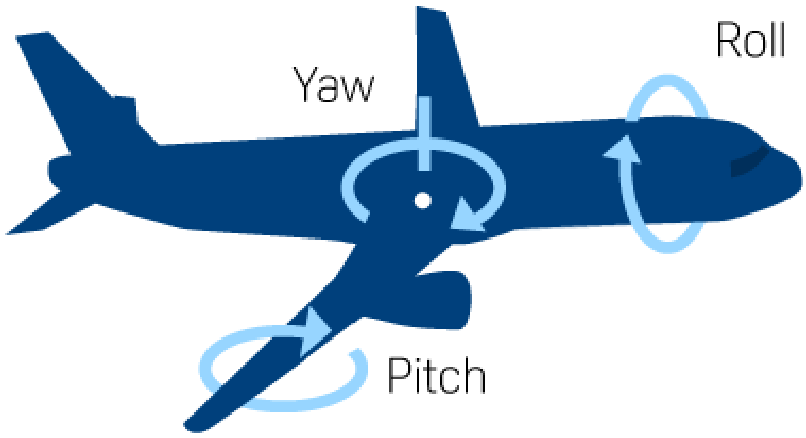

Figure 4: The variations in a plane.

4. HIGH PRECISION CLOCK

- The function of a clock is to measure the amount of time it takes for the pulse to return. This is very important as it is required to make precise recordings to know the exact distance between the sensor and the object.

FUNCTIONING OF LIDAR TECHNOLOGY

According to Lohani & Ghosh (2017), the functioning of LiDAR technology has been proposed as follows:

An airborne LiDAR system consists of:

(i) An airborne platform is used to fly a LiDAR sensor over the area to be studied;

(ii) LiDAR sensor is used to generate short width laser pulses (of the order of a few nano-seconds), transmit them towards the ground, scan the ground beneath while firing pulses, receive the return signal (i.e., return waveform), measure the time of travel of the return pulse (most significant return, first return, last return, or multiple returns), associate each return pulse with Global Navigation Satellite System (GNSS) time and the scan angle at which the pulse was transmitted;

(iii) GNSS receiver works along with a ground based GNSS base station receiver and observes the position of the aircraft at each epoch of GNSS observation (1 Hz or 2 Hz);

(iv) Inertial Measuring Unit (IMU) sensor, which observes the accelerations and orientations of the aircraft at a much higher frequency than that of GNSS epoch (say 400 Hz);

(v) Onboard computer, which timestamps different data produced by the above sensors using the GNSS time and archives raw data.

It is a common practice to also fly a medium format digital camera (60MP to 100MP) along with LiDAR sensor as it provides colour information of the terrain.[3]

APPLICATIONS OF LIDAR TECHNOLOGY

According to MOSAIC Mapping Systems Inc. (2001), LiDAR (Light Detection and Ranging) is popularly used as a technology to make high-resolution maps, with applications in geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing, atmospheric physics, airborne laser swath mapping (ALSM), laser altimetry, and contour mapping.[5] Some of these LIDAR applications have been discussed as follows:

- Topographic Applications: Because of its accuracy in mapping surface features, lidar is useful in creating maps topographical. Mapping of topographic features is the largest and fastest growing area of application for lidar remote sensing, because of its use in commercial land surveys.[7] Ecologists are also interested in topography (and bathymetry), which often has a strong influence on the structure, composition, and function of ecological systems.[6] LIDAR's ability to map the ground in tree-covered areas like the Central American rainforest has proven particularly effective for archaeologists, who have discovered thousands of Mayan buildings covered by vegetation.
- Prediction of forest structure: Forests can be studied with lidar and the profile of the multiple returns can be used to determine what kinds of trees are present. Lidar data also have been used to predict biophysical characteristics of plant communities, most notably forests.[8]
- Oceanography: Lidar can also be used to determine ocean depths in shallow areas near land by using two lasers, one that transmits at near-infrared wavelengths that reflect off the water's surface and the other at optical wavelengths that reflect off the ocean bottom.
- Range-finding and map-making in space exploration. In the year 1971, for example, Lidar was used to map the surface of the moon.
- Detection of obstacle and avoidance of collision in autonomous vehicles, such as driverless cars.
- Biological agent detection and autonomous flight for military operations. The Airborne Laser Mine Detection System (ALMDS) for counter-mine warfare by Areté Associates.[9]
- Determining the most effective use of fertilizers for efficiency of farming. The farmers can improve their field output by focussing on the most fertile fragments of their land.
- Atmospheric Remote Sensing and Meteorology: Lidar technology is used to measure

profile of clouds, winds, aerosols and capturing various other atmospheric components.

- Predicting the energy yield for wind power: Doppler lidars with different measurement capabilities are widely adopted by the wind energy industry.[10][11]
- Surveying and calculating ore volumes for minerals.
- Construction Projects: to support large engineering projects and to monitor in great detail infrastructures of all sorts, from bridges to buildings and urban canyons.[12]
- According to Wang & Menenti (2021), the successful lidar operations of NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations[13] and Ice, Cloud, and land Elevation Satellite[14] and ESA's Aeolus wind satellite[15] highlight a new era of lidar developments and applications.[16]

VARIOUS AUTONOMOUS OR SEMI- AUTONOMOUS VEHICLES USING LIDAR

There are various machines in which lidar technology can be applied. Light Detection and Ranging (LiDAR) based mobile mapping technology draws lot of practitioners' attentions, and has been recognized as an efficient and economic method for gathering various types of roadway asset data.[17]

One of its main application is in cars. In cars, lidar is basically the eye of the car. In fact, in any autonomous vehicle, lidar acts as the eye of the machine providing it with a 360- degree vision.

- In any autonomous vehicle, the main objective is to prevent making contact with the objects around it; along with reaching its destination. Lidar helps with this by making a digital map of the car's surrounding which then helps the car to prevent making contact with the objects around it. This is lidar's role in autonomous vehicles.
- Lidar has various applications in the robotics industry as-well and many companies have realised that the 3D data obtained by the lidar sensor can prove useful for any purpose. Several companies have already started to utilise automated robots that utilise lidars.

According to an article published in the ***ars TECHNICA*** (October, 2020); companies are using the combination of VCSEL (vertical cavity surface-emitting lasers) lasers and SPAD (single-photon avalanche diodes) detectors to build much more powerful lidar for the automotive market. The reason is that they both can be developed by using conventional semiconductor fabrication techniques. Thus, they benefit from economies of scale and can get cheaper and viable. The two companies working on high-end VCSEL-based LIDAR are Ouster and Ibeo. These companies are coming up with new affordable and cost- effective models to meet the high future demand from the automotive industry. LIDAR can effectively detect stationary objects, thus improve vehicles' Advanced Driver Assistance Systems (ADAS). So far, lidar was considered too expensive to be used by the vehicle. However, its safety benefits clubbed with vendors promising it at a low cost over the coming years will enable its growth. Ouster is planning to have its ES2 sensor ready for automotive consumption by 2024. Ibeo has tied up with Great Wall Motors of China to begin mass production of IbeoNext in 2022.

Car manufacturer Volvo is aiming to produce cars fitted with Luminar lidar by 2022. Luminar's lidar has boasted a longer range as much as 250 metres as it uses lasers at a wavelength of 1550 nm (far outside the visible light range). Luminar's lidar offers a wider field of view than Ouster's. However, it is still priced way above the lidar models based on VCSEL and SPAD technology.

The way forward is for Ouster, Ibeo and Sense to improve the performance of the VCSEL and SPAD combination of lidars to be able to increase their range to 200 metres. This clubbed with their low cost and simplicity of design may make the market moving in their favour for mass consumption.[18]

CHALLENGES & OPPORTUNITIES IN LIDAR TECHNOLOGY

The role of lidar technology will be gaining momentum in the future. Although there are still a lot of challenges for lidar technology applications and advancements; they come with their own set of opportunities. The market has faced some challenges owing to data and privacy issues associated with LiDAR services. The inefficiency of LiDAR services and lack of appropriate customer awareness are factors restraining the growth of the market. New Product Development in the application of LIDAR technology also needs to work around the issues of privacy and identity protection. The following areas and solutions focus on the challenges and opportunities for advancing lidar applications in times to come.

- The data of customers' needs to be handled with utmost confidentiality. Companies should maintain customer databases with security login ID's and limited access to in-house employees and systems.
- The customers' can be made aware of the data privacy policies being adopted by the companies selling LIDAR.
- LIDAR companies can tie- up with the vehicle manufacturers to produce the customised LIDAR devices which may be most appropriate for their vehicles.

- LIDAR can find immense scope in coastline management, forest management, pollution modelling, precision forestry, wind farms and agriculture.
- LIDAR services can be adopted in drone operations, project management, data processing, and determining GPS control points.
- Services like international LIDAR survey can be used to collect data for photogrammetry, mapping, and other geospatial projects. The rising adoption of such services in various industries including automotive, construction, and transportation is expected to deliver high growth opportunities.
- The growing use of 3D imaging technology for robotics and medical imaging is expected to grow by many folds.

SUGGESTIONS AND CONCLUSION

Lidar has the most efficient features of 360-degree visibility and depth information. 360-degree view allows us to view in all directions simultaneously which means that we know where all the objects around are placed. Depth information basically helps us to predict the distance between those objects and you. A LIDAR sensor continually fires off beams of laser light, and then measures how long it takes for the light to return to the sensor.

We can conclude that there are several ups and downs to using lidar in our cars. Yet, it shows a very positive future in the autonomous vehicles industry even though some development may be required. Development in Lidar and autonomous vehicles is a big opportunity available in the automotive industry. Companies which encash this opportunity will be the ones to profit the most from this situation and also be able to survive the best in the long term.

As lidars became higher resolution, they started defining objects around them and can tell the difference between a man walking and a bicycle, not tell them to be one and the same thing. Python programming can help us derive a map of the surroundings of the vehicle using which the vehicle can make decisions regarding the path along which it should go. Velodyne is the pioneer company and in charge of making lidar sensors.

There are several competitors in the marketplace, but they are all providing a similar solution. So, each company needs to find its own USP (Unique Selling Proposition). Companies may use post- processing of data, i.e., faster speed at which data is interpreted; better algorithms which also increase the speed at which data is interpreted. So, the ultimate goal should always be to optimise the amount of time it takes to interpret the data. Companies can create models by using real- life situations which can further improve the validity, utility and reliability of these devices. In order to achieve this, utmost confidentiality needs to be maintained while using customer databases. Also, the protocols for data privacy need to be adhered to very strictly. By developing USP's around these features, the service providers can find their niche and their goals can be achieved.

A few companies already create and promote these sensors, and another few start- ups are solely working on Lidar production. Hence, major spots have already been occupied in the industry. Post- assessment and post- analysis of data can come in very useful in this process. So, one needs to act swiftly, if they want to get in it and make a footprint. This industry is already very dynamic, and one would rather have to promptly identify their positioning and build up further considering all this carefully.

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