Ways to increase efficiency of lidar scan system of three-dimensional objects

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ABSTRACT

This article discusses the main methods of scanning three-dimensional objects and the features of using lidars as devices for this purpose; it is a comparative analysis of different types of optical, acoustic, and laser devices. Areas of the use of these technologies have been considered. The principle of laser scanning operations is also described in detail, as is the operations of radiating and reading devices. Information is recorded by the system about an object as well as additional parameters. The classification of the returned signal and additional attributes that the sensor takes into account are considered. Based on this information, a mobile system has been developed that optimizes the use of lidars and allows one to use similar systems that work with mobile applications.

Keywords: laser, cloud of points, API, lidar, radar, scanning, 3D modeling

1. Introduction

Modern 3D scanners are high-tech devices – the primary purpose of which is to create three-dimensional models of various physical objects. 3D scanners allow one to measure linear dimensions with high accuracy, determine any object's geometric shape, and then create a three-dimensional digital model. Then, one can perform any manipulations and calculations in computer programs with this 3D model.

In industry, one of the main areas of the application of 3D scanners is reverse engineering. When designing almost any industrial product (from a car to a toothbrush), one must usually create a lot of iterations until an optimal shape is achieved. In industry, various types of 3D scanners are also used to control the quality and other parameters of finished products. In science, 3D scanners are used in archeology and paleontology, for example, to reproduce the forms of various ancient objects and the appearance of fossils. 3D scanners help to create accurate models of any works of art: sculptures, statuettes, jewelry, and other products as well as paintings in their original frames. In medicine, 3D scanners are used to obtain the parameters of the body of a particular patient in the design of orthopedic shoes, corsets, prostheses, and various individual medical devices. 3D-scanning – technologies are widely used in the cinematography, animation, and gaming industries. The 3D scanning of premises and buildings is an important stage of interior design. The resulting three-dimensional models are the bases for the construction of utilities, the design of buildings and premises, the selection and placement of furniture and equipment, VR technology (National Ocean Service 2021).

2. Review and analysis of research

Different types of radar are used to perform such work: optical, acoustic, and laser. High-precision projects require the use of the last, which in turn are expensive and complex systems. Many optical 3D scanners allow one to obtain data not only on the location of points but also on their colors, which differs favorably from laser 3D scanners. However, optical scanners on a tripod are difficult to use for studying large objects, such as vehicles and large parts in mechanical engineering. Another disadvantage of "optics" is that it does not cope well with copies of black and shiny objects and requires the use of special sprays or other equipment.

2.1. Principle of operation of laser radars

Laser systems make it possible to obtain a high-precision digital copy; they are not vulnerable to the parameters and coverage of an object. The measurements are performed by calculating the return times of laser beams and their wavelengths; this creates accurate, high quality, and three-dimensional maps of any environment they scan. The formed map of an area helps in its characterization and research, which significantly distinguishes this technology against the background of more classic scanning methods.

Laser radar has a long-wavelength optical range ($\lambda \leq 1.5$ μm) and a laser as a source of radiation. Its principle of operation: laser radiation is directed to an object, reflected from the object, and returned to the receiver. Then, the distance to the object is determined in the device. With lidar with a movable mirror in which a 360° viewing angle can be obtained, one can obtain a cloud of environmental points to create a 3D map or digitize architectural objects. Special software creates a three-dimensional image that reproduces the shape around the lidar system with a precise location in space. (Fig. 1).

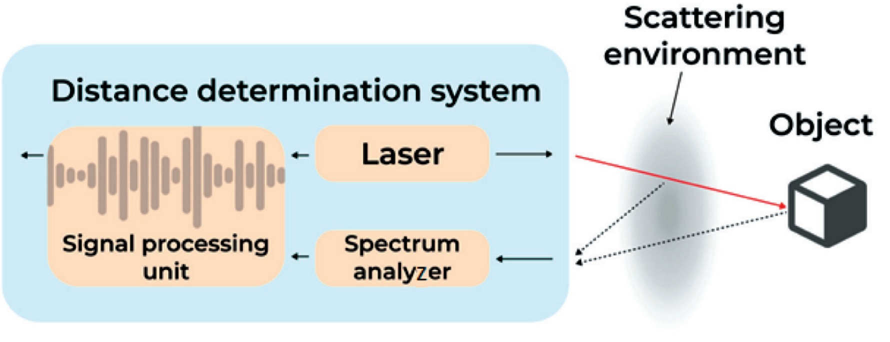

Fig. 1. Lidar scheme

2.2. Principle of operation of optical 3D-scanners

The principle of operation of optical 3D-scanners is simple – the scanning process is to illuminate objects created by a projector with structured light and capture reflected light from certain angles. The scanning object is illuminated with a light strip or pattern – a reference monochrome pattern. By processing the reflected signal and calculating the locations of the points on its surface based on the difference between the projected and reflected image, the computer obtains the necessary information for building a 3D model (Heritage, Large 2009).

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Color information is very important; sometimes color changes can diagnose deviations in the properties of a part. It is also necessary for the further reproduction of the appearance of the object, which is critical if not about technical details but about historical objects or works of art.

3. Three factors that distinguish lidars from each other

3.1. Beam control technology

Most leading lidars use one of four methods for directing laser beams in different directions:

1) A rotating lidar in which a certain number of lasers are placed vertically. The design rotates at a speed of several revolutions per second. The advantages of this approach are 360° coverage; however, such designs are expensive and unreliable.
2) A mechanical scanning lidar uses a mirror to redirect a single laser beam in different directions. Some companies use an approach called a “microelectromechanical system” (MEMS) to control the mirror (Zdobytskyi et al. 2020).
3) An active phased array antenna uses a number of emitters that are capable of changing the direction of the laser beam, thus adjusting the relative phase of the signal between adjacent transmitters.
4) A flash-based lidar highlights an entire area at once; existing technologies use one wide-angle laser. The technology has difficulties with long distances, as only a small part of the laser light reaches any point.

3.2. Distance measurement

A lidar measures the time it takes for light to reach and reflect off an object. There are three easy ways to do this:

1) Travel time: the lidar sends a short pulse and measures how long it takes to fix the return of the pulse.
2) Lidar of continuous radiation with frequency modulation: this sends a continuous beam of light, the frequency of which constantly changes over time. The beam is divided in two; one of these is sent to the outside world, and then merges with the other

upon its return. Since the frequency of the beam source changes continuously, the difference in the path of the two rays is expressed through the difference of their frequencies. The result is a picture of interference, the frequency of which is a function of time on the road (and, consequently, from a distance). This path may seem unreasonably complicated, but it has a couple of advantages. This lidar is resistant to interference from other lidars or from the Sun. This lidar can also use a Doppler offset to measure the speeds of objects, not just the distances to them.

3) Lidar of continuous radiation with amplitude modulation: this can be considered as a compromise between the two previous options. A lidar, like a simple sensor that measures time on the road, sends a signal and then measures the time it took it to reflect and return; however, when simple systems send a single pulse, lidar sends a complex circuit (a pseudo-random flow of digital zeros and ones). Proponents of the approach say that this option is more resistant to interference.

3.3. Laser wavelength

This choice is important for two reasons; one of these is eye safety. The fluid inside an eye is transparent to light with wavelengths of 850 nm and 905 nm, which allows light to reach the retina. If a laser is too powerful, it can cause irreparable damage; on the other hand, the eye is opaque to radiation with a wavelength of 1550 nm, which allows such lidars to work at higher power without damaging the retina. Increasing the power allows one to increase the range.

So, why not use lasers with a wavelength of 1550 nm in lidars? Detectors that operate at 850 nm and 905 nm can be created on the basis of inexpensive and common silicon technologies. To create a lidar with a wavelength of 1550 nm, one must use exotic and expensive materials such as gallium, indium, or arsenide.

Even though 1550 nm lasers can operate at higher power without posing a threat to the eye, such power levels can lead to other problems. And, of course, higher-power lasers consume more energy (Neoge, Mehendale 2020).

3.4. Lidar classification of points

Each lidar point can be assigned a classification that determines the type of object that reflects a laser pulse. Lidar points can be divided into several categories, including bare ground or ground, a canopy top, and water. Different classes are defined by using numeric integer codes in LAS files.

When the classification is based on lidar data, points may fall into more than one classification category. Classification flags are used to provide additional descriptions or classifications of lidar points. With LAS Version 1.0, a lidar point cannot support two assigned classification attributes at the same time. For example, it may be necessary to extract a result that is returned from water from the final dataset, but it should still remain and be managed as a collected lidar point in the LAS file. Using LAS Version 1.0, this point will not be established as water and will be excluded from the analysis.

Later versions (LAS 1.1 and later) have used class flags to solve this problem. Classification flags have been added to the LAS standard to flagpoles with additional information to traditional classification. Synthetic flags, key point flags, hidden flags, and overlaps can be set for each lidar point. These flags can be set along with their classification codes. For example, a water record may have a classification code for water as well as a prohibited flag. This point will remain in the dataset but be hidden from any additional analysis of the LAS files.

Laser pulses that are emitted by a system of lidars are reflected from objects on both the surface of the Earth and above its surface: vegetation, buildings, bridges, etc. One radiated laser pulse can be returned to a lidar sensor as one or more returns. Any radiated laser pulse that encounters several reflective surfaces as it moves toward the ground is broken into as many reflective surfaces, as there are reflective surfaces (McManamon 2020).

The first laser pulse that returns is the most significant return and will be associated with the highest object in a landscape, such as the top of a tree or the top of a building. The first return can also represent land; in such a case, only one return will be detected by the lidar system. Multiple rotations can detect the height of several objects within the laser imprint of the output laser pulse. Intermediate returns are typically used for vegetation structures, and the last returns are used for bare-land relief models. The last return will not always be from a land return; for example, consider a case where a pulse hits a thick branch on the way to the ground and does not actually reach the ground. In this case, the last departure is not from the ground but from the branch that reflected the entire laser pulse (Tab. 1).

Table 1
Data classification

Classification value	**Meaning**
0	Never classified
1	Not intended
2	Earth
3	Low vegetation
4	Average vegetation
5	High vegetation
6	Building

Table 1 cont.

7	Low point
8	Reserved
9	Reserved
10	Water
11	Railway
12	Road surface
13	Reserved
14	Reserved
15	Wire – shield (shield)
16	Wire – conductor (phase)
17	Transmission tower
18	Wire connector (insulator)
19–63	Deck of bridge
64–255	High noise level

Additional information is stored with each position value's x, y, and z points. For each registered laser pulse, the following lidar point attributes are stored: intensity (Fig. 2), number of revolutions, number of revolutions, point classification values, points at the edge of a flight line, RGB values (red, green, and blue), GPS time, scan angle, and scan direction. The following table describes the attributes that can be assigned to each lidar point (Tab. 2).

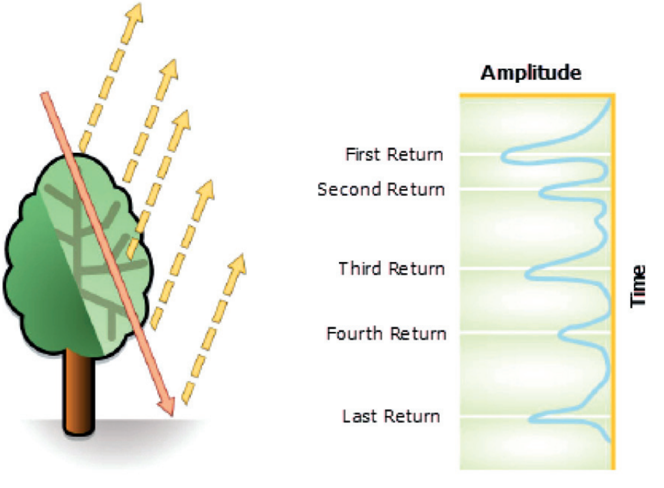

Fig. 2. Returning signal

Table 2
Lidar attributes

Attribute lidar	Description
Intensity	The reverse force of the laser pulse that generated the lidar point
Return number	An emitted laser pulse can have up to five revolutions depending on the characteristics from which it is reflected and the capabilities of the laser scanner that is used to collect the data. The first return will be marked as return number one, the second as return number two, and so on
Number of returns	The number of returns is the total number of returns for a given pulse. For example, a laser data point can return two (return number) in a total of five returns
Point classification	Each lidar point that can be further processed may have a classi-fication that determines the type of object that reflected the laser pulse. Lidar points can be divided into several categories, including bare ground or ground, canopy tops, and water. Different classes are defined using numeric integer codes in LAS files
GPS time	The GPS timestamp at which the laser point was emitted from an aircraft. The time is specified in GPS seconds of the week
Scanning angle	The scan angle is a value in degrees from –90° to +90°. At 0°, the laser pulse is directly below the aircraft at the highest point. At –90°, the laser pulse is on the left side of the aircraft, while at +90°, it is on the right side of the aircraft in the direction of flight. Most lidar systems currently have values that are below ±30°
Scanning direction	The scanning direction is the direction in which the laser scanning mirror moved during the output laser pulse. A value of 1 is the positive direction of the scan, and a value of 0 is the negative direction of the scan. A positive value indicates that the scanner moved from left to right on the track direction, and a negative value indicates the opposite

4. Lidar and API system

With the development of technology in the modern world, the lidar as the system has begun to be used in various fields, which allows it to comprehensively solve many issues that are related to scanning objects. To qualitatively improve the use of the lidar of the systems, the priority is to ensure their availability in a wide range of industries.

Although the basic idea is simple, the details complicate things very quickly. Lidars face the challenge of making decisions based on the following three basic principles: the method of multi-directional laser direction, measuring the duration of a signal in the forward and reverse directions, and the spectrum of light that was used.

Due to the use of a significant number of lasers, we obtain an array of significant data points.

Since one of the key points of the above technologies involves the analysis and processing of large amounts of data, the study considers one of the options for optimizing this process; namely, the remote processing of data that contains information about coordinates GPS positions, etc. This approach will simplify a mobile system and increase its usability in the case of interacting through a mobile application.

A lidar system consists of components that are responsible for determining distance, positioning, and orientation as well as a database, emitter, and receiver. The distance-determination system consists of a laser and a spectrum analyzer. The laser creates and sends a light flux through the emitter, which in turn is returned to the receiver. The laser also sends a signal to the database to create a timestamp; this is used to compare with the information that is provided by the receiver. The receiver transmits the reflected signal to the spectrum analyzer; together with the wavelength, time of receiving the signal, and its angle, information from this unit is transferred to a database (where it is grouped and compared). The database also contains information from the GPS system about location, position, and acceleration when moving the system.

All of this data is stored in a database; based on this, a detailed cloud of surface points of any complexity is created. It is advantageous to use cloud services to create a cloud of data; they simplify the system and, in combination with the use of a mobile application, significantly increase the convenience.

Cloud storage is a model of storing data on a computer in which digital data is stored in logical pools; this physical storage covers several servers (usually in several places). The physical environment usually belongs to the hosting companies that manage it. These cloud storage providers are responsible for maintaining and accessing available information as well as for the physical environment. Users can purchase the ability to store data from cloud storage service providers.

Cloud storage services can be accessed through a web service interface (API) or applications that use an API; thus, the system receives many benefits. It is more profitable to use cloud capacity than to keep one's own. Cloud storage gives users instant access to a wide range of resources and applications that are hosted on another organization's infrastructure through a web service interface. Cloud storage makes it possible to have a backup of data, as companies that provide similar services have two or three different back-up servers that are located in different places around the world. In this way, the data is reliably protected from loss.

The use of API significantly increases the convenience of the system. A user can access the results through a mobile application for instant viewing anywhere and anytime. One can also work on an object in detail via a personal computer using the power of the server; all one needs is access to the Internet (Fig. 3).

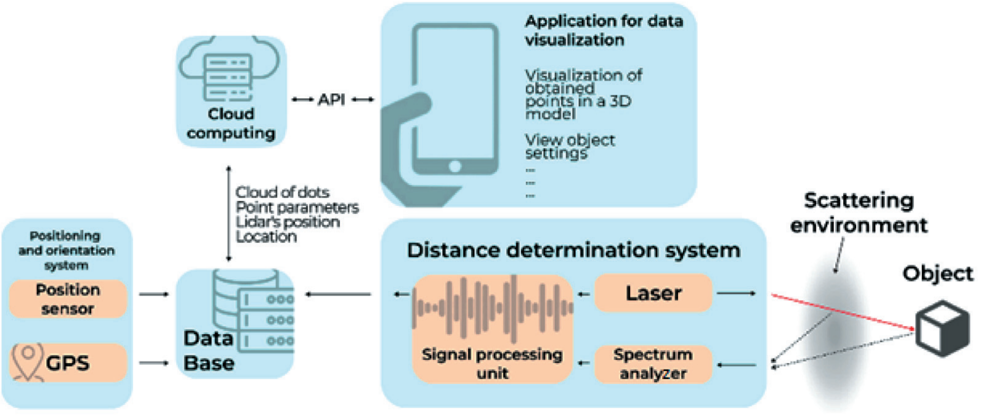

Fig. 3. Block diagram of technical implementation of lidars using cloud technologies

5. Conclusions

The implementation of such a system has a number of significant advantages over cloud storage. Moreover, it provides users with instant access to a wide range of resources and applications that are hosted in another organization's infrastructure via the interface of the web service. The use of an API significantly increases the usability of the system, as the user is provided with the necessary access to the results via a mobile application for instant viewing at any convenient time.

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