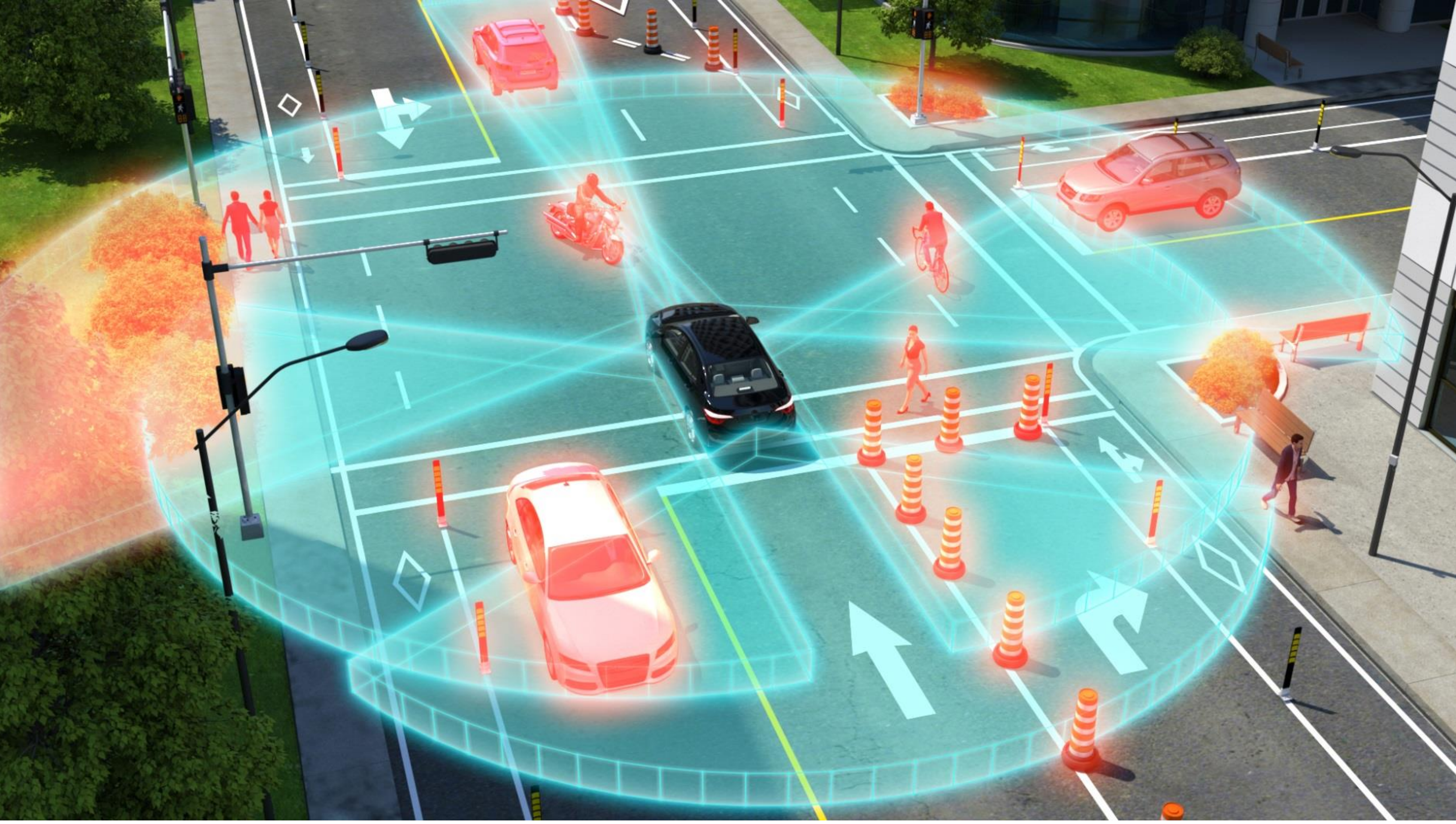


LEDDAR OPTICAL TIME-OF-FLIGHT SENSING TECHNOLOGY:

A NEW APPROACH TO DETECTION AND RANGING

Leddar® optical time-of-flight sensing technology, originally discovered by the National Optics Institute (INO) in Quebec City and developed and commercialized by LeddarTech, is a unique LiDAR technology in the field of optical sensing. Combining fast, high-resolution analog-to-digital conversion and innovative signal processing, Leddar light processing brings the benefits of time-domain processing to optical time-of-flight sensing.

This white paper will give a high-level overview of the Leddar optical time-of-flight sensing technology and its advantages compared with competing technologies. It will then describe architectural choices for sensors incorporating Leddar technology as well as the benefits that such sensors provide.

LeddarTech®
MASTERING LIDAR SENSOR TECHNOLOGY

LEDDAR OPTICAL TIME-OF-FLIGHT SENSING TECHNOLOGY: A NEW APPROACH TO DETECTION AND RANGING

By Pierre Olivier, Vice President, Engineering and Manufacturing, LeddarTech Inc.

Detection and Ranging

Remote sensing consists of acquiring information about a specific object in the vicinity of a sensor without making physical contact with the object. Countless applications such as automotive driver assistance systems and autonomous driving, drone and robot collision avoidance and navigation, traffic management and level sensing exist thanks to this technique.

Multiple technology options are available for remote sensing; we can divide them into three broad applications:

- Presence or proximity detection, where the absence or presence of an object in a general area is the only information that is required (e.g., for security applications). This is the simplest form of remote sensing;
- Speed measurement, where the exact position of an object does not need to be known but where its accurate speed is required (e.g., for law enforcement applications); and
- Detection and ranging, where the position of an object relative to the sensor needs to be precisely and accurately determined.

This paper will concentrate on technologies capable of providing a detection and ranging functionality, as it is the most complex of the three applications. From the position information, presence and speed can be retrieved so technologies capable of detection and ranging can be universally applied to all remote sensing applications.

Although it is possible to obtain distance information with passive technologies, such as stereo triangulation of camera images, these passive technologies are usually very constrained in capability. For instance, stereo triangulation requires well-defined edges for the matching algorithms to work. Therefore, the most commonly used technologies for measuring the position of an object involve sending energy towards the object to be measured, collecting the echo signal, and analyzing this echo signal to determine the position of one or several objects located in the sensor's field of view. Since energy is intentionally emitted towards the object to be measured, we will refer to these technologies as being "active."

Of these, some technologies rely on the geometric location of the return echo to infer position information. For instance, structured lighting involves projecting an array of dots towards the object to be measured, and analyzing the geometric dispersion of the dots on the object using a camera and image analysis.

Other technologies rely on the time characteristic of the return echo to determine the position of the object to be measured. These are generally known as “time-of-flight measurement” technologies.

Although the implementation differs, time-of-flight measurement can be accomplished with radio waves (radar), sound or ultrasonic waves (sonar), or light waves (lidar).

Figure 1 is a visual representation of the different remote sensing technologies currently available. In the next section we will cover light-based, or optical, time-of-flight measurement technologies in more detail.

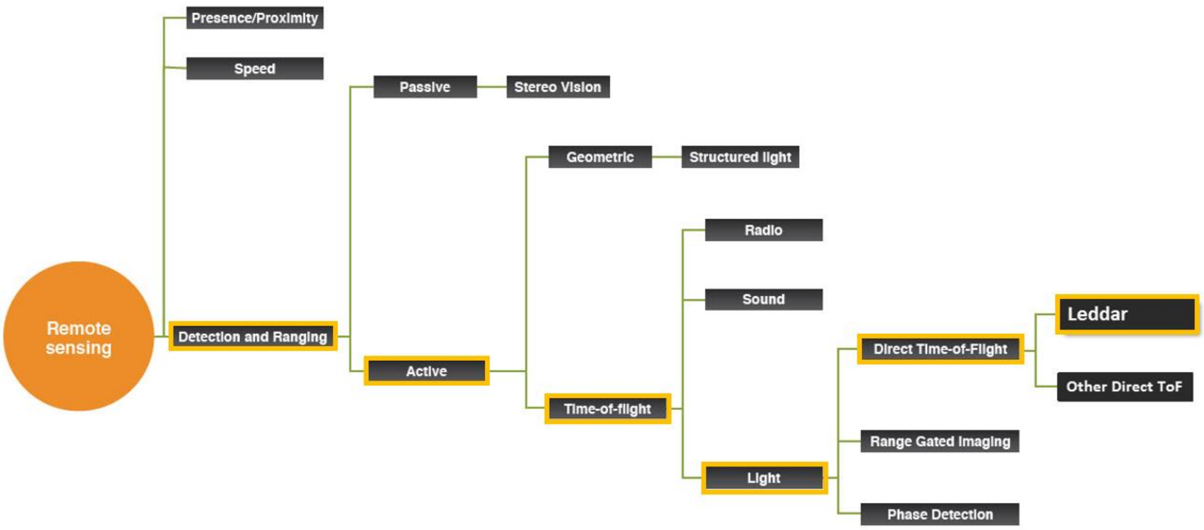


Figure 1 – Remote Sensing Technologies Taxonomy

Optical Time-of-Flight Measurement

Optical time-of-flight measurement computes the distance to a target from the round-trip time of flight between a sensor and an object. Since the speed of light in air changes very little over normal temperature and pressure extremes, and its order of magnitude is faster than the speed of objects to be measured, optical time-of-flight measurement is one of the most reliable ways to accurately measure distance to objects in a contactless fashion.

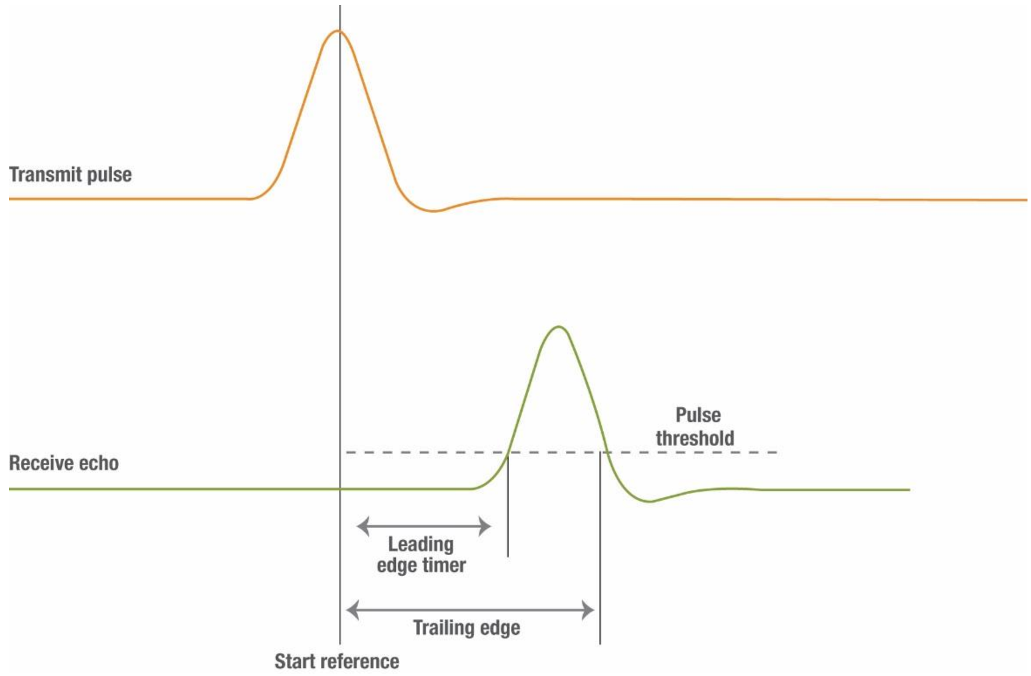
Conventional optical time-of-flight sensors fall into three broad categories: direct time-of-flight, range-gated imaging, and phase detection. Leddar is a new and unique technology for performing time-of-flight measurement. This section will describe the operating principle for each measurement technology.

Direct Time-of-Flight

In the direct time-of-flight measurement method, a discrete pulse is emitted and one or several timers are used to measure the time difference between the emitted pulse and the return echo, based on threshold detection. This time difference can be directly converted to a distance, based on the following equation:

$$d = \frac{C * t}{2}$$

C is the speed of light, which is 299,792,458 m/s in a vacuum. The division by 2 accounts for the fact that light has to travel from the sensor to the object and then back to the sensor.

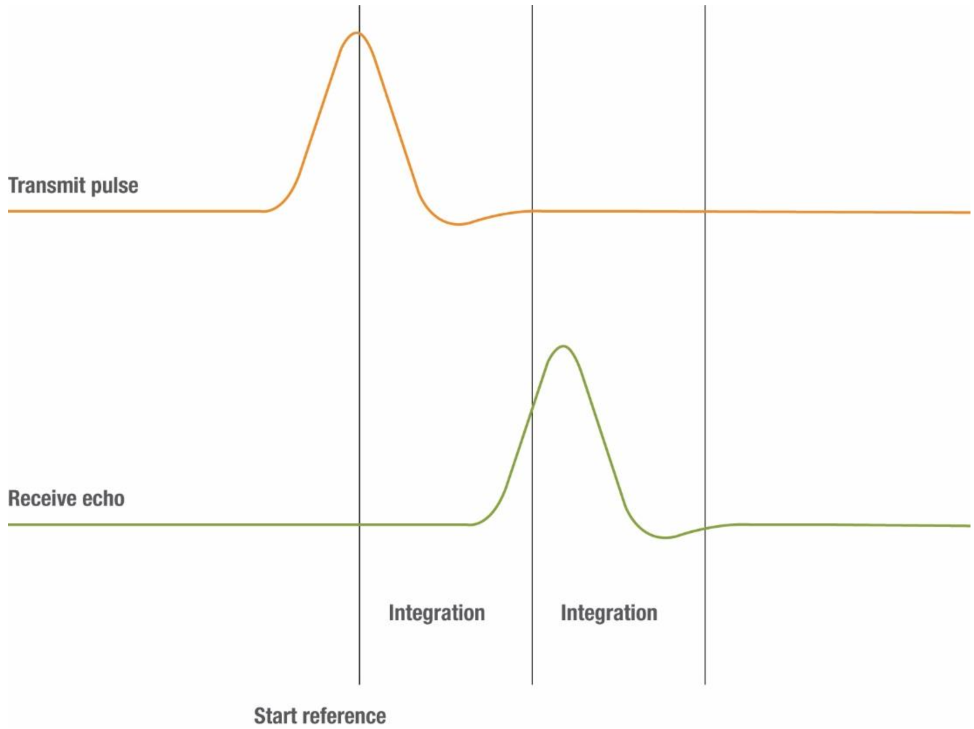


The difficulty in implementing the direct time-of-flight measurement method resides in the time intervals to be measured. In order to resolve a distance to centimeter-level accuracy, the required accuracy for the timers is 67 ps. Implemented in digital logic, this would require a 15 GHz clock speed, which is obviously not practical. Therefore, various time-to-digital conversion methods are typically used.

Both edges of the pulse are commonly used to maintain accuracy independently of varying echo amplitude.

Range-gated Imaging

Whereas direct time-of-flight relies on measurements made on the immediate value of the received signal, range-gated imaging uses signal integration methods, typically with CCD or CMOS imagers.



By measuring the energy received in successive integration intervals, it is possible to extrapolate the distance between the sensor and the measured object, based on the ratio of energy received in the different intervals.

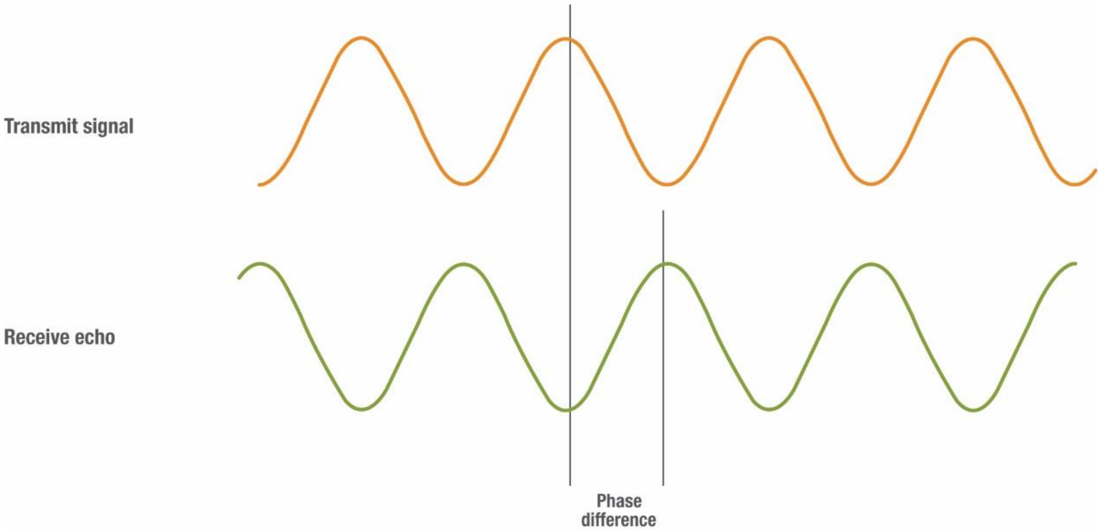
The difficulty with range-gated imaging is that CCD and CMOS imagers have a limited dynamic range; therefore, strong ambient light can easily cause saturation and impair measurement. Furthermore, since neither the emitted and received pulses are perfect rectangle pulses, nor is the sensor perfectly linear, compensation is required and accuracy is ultimately limited.

Phase Difference Measurement

In contrast to the previous two methods, phase difference measurement relies on a modulated light source and evaluates the phase difference between the transmit signal and the receive echo. This phase difference can be converted to a distance, using the following formula:

$$d = \frac{C * \emptyset}{4 * \pi * f}$$

C is the speed of light, Ø is the phase difference in radians, and f is the modulation frequency.



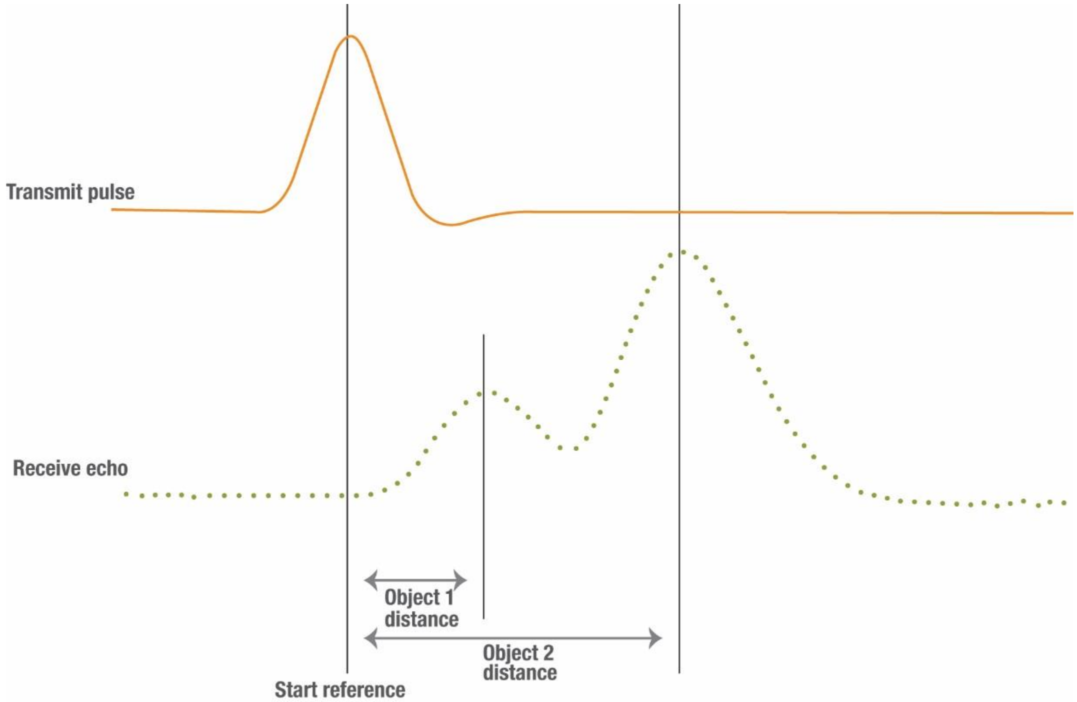
Correlation methods are typically used to measure the phase difference of the receive echo respective to the transmit signal as well as recover the propagation delay and therefore the distance to the object to be measured.

Of course, a phase difference greater than 2 π is not resolvable; for instance, 3 π or 5 π will be measured as a π radian phase difference. Therefore, depending on the chosen modulation frequency, an artefacting phenomenon will occur where far-away objects will appear to be much closer than in reality.

Leddar Optical Time-of-flight Technology

Leddar optical time-of-flight sensing technology is based on direct time-of-flight measurement; however, rather than working directly on the analog signal, Leddar light processing starts by sampling the receive echo for the complete detection range of the sensor. Through patented methods, Leddar iteratively expands the sampling rate and resolution of this sampled signal. Finally, it analyzes the resulting discrete-time signal and recovers the distance for every object.

As opposed to the preceding methods, Leddar light processing can extract the distance for every object found in the field of view.



Where the preceding methods implement detection and ranging mostly through hardware, Leddar light processing utilizes complex algorithms implemented in software. This characteristic is the key to the flexibility and performance of the technology.

Through signal processing, Leddar is capable of computing an accurate distance for an object with a very weak echo. Using various advanced filters, it is also able to detect objects in the presence of nuisance signals, such as that returned by dust, snow or raindrops.

Finally, as opposed to the preceding methods, Leddar light processing can extract the distance for every object found in the field of view.

Therefore, the key advantages of Leddar technology are high sensitivity, immunity to noise, and powerful data extraction capabilities. Sensors integrating Leddar technology will be able to turn these advantages into measurable benefits, as will be discussed later in the document.

At the heart of Leddar technology is a library of signal processing functions covering four distinct stages of processing as presented in Figure 2.

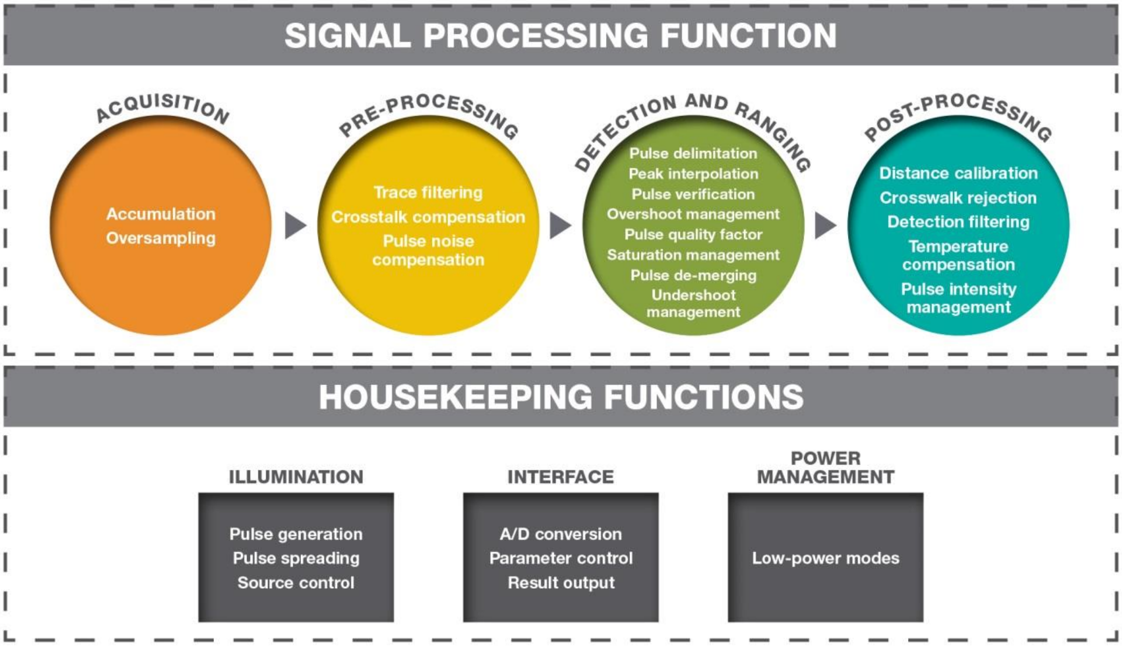


Figure 2- Leddar Light Processing Functional Blocks

The Leddar Sensor

Leddar is the root technology enabling the development and production of high-efficiency sensor modules. Sensors incorporating Leddar optical time-of-flight technology provide three key benefits compared to competing products: a high range-to-power ratio, target detection in low-visibility conditions, and the ability to resolve multiple targets. Before discussing these benefits in more detail, let’s review the key components of a Leddar-based sensor.

LeddarCore

Implemented in standard submicron CMOS processes, Leddar becomes an ultra-low-power sensor core (i.e., the LeddarCore) that will maximize the performance of any optical time-of-flight sensor. When combined with a photodetector, a pulsed light source and optics, it forms a complete sensor system that can easily be integrated into a small footprint at low cost (figure 3)

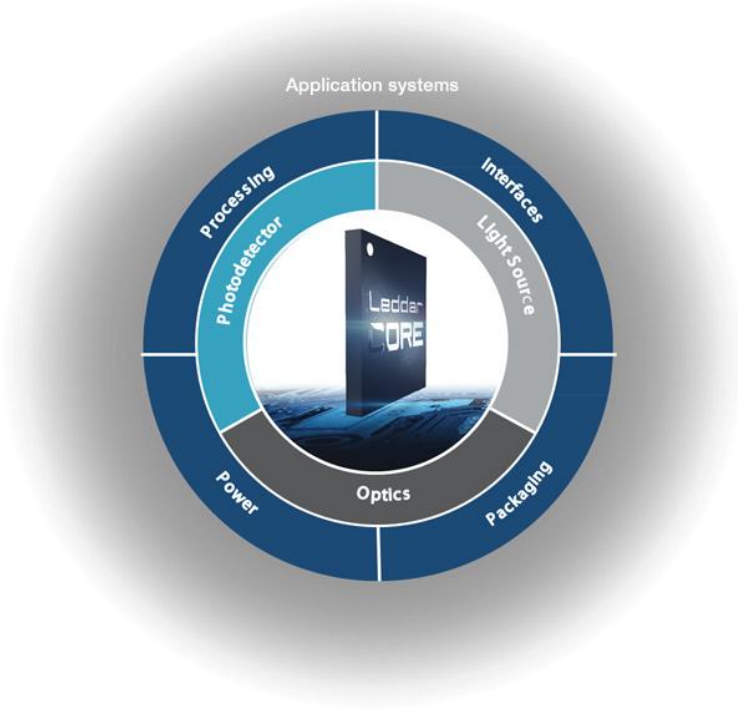


Figure 3 – Main Components of a Leddar Sensor

Photodetector

The photodetector is the component responsible for converting light pulses into an electrical signal that can be read by the Leddar Core. Therefore, its function is key to any Leddar sensor, which can leverage various types of detectors including PIN photodiodes and APDs.

PIN Photodiode

Leddar technology can be used with low-cost silicon PIN photodiodes, achieving a long detection range and immunity to ambient light conditions.

The main benefit of PIN photodiodes is that the rise and fall times are very rapid (typically 10 ns or less); therefore, they are well-suited for receiving short light pulses on the order of 25 ns. Furthermore, they exhibit a very high linearity, enabling very small signals to be detected even in the presence of strong incident light.

Multi-element arrays, either one- or two-dimensional, can be used to build 2D or 3D sensors with fast, parallel measurement and no moving parts. These sensors can be used in applications requiring rapid and accurate presence, position, or speed information.

APD

Avalanche photodiodes can also be used. They share most of their characteristics with PIN photodiodes; however, with the use of a high reverse bias voltage (typically up to 300 V), they exhibit a current gain (typically 100 or more), enabling very weak signals to be detected.

However, one of their main drawbacks is that this gain is highly dependent on temperature and bias voltage; and that bias voltage also significantly affects the dark current. Therefore, the bias voltage normally has to be adjusted depending on temperature.

Other Photodetectors

Although Leddar technology has been originally developed for use with PIN or avalanche photodiodes, other types of photodetectors with sufficient bandwidth may also be used.

Light Source

Whereas the photodetector detects the return echo, it is the light source that is responsible for initially emitting the transmit pulse. It is therefore equally critical to the Leddar sensor.

Leddar technology can be used with visible or infrared light sources. Any light source that can generate sufficiently fast pulses can be utilized, including LEDs, lasers, or VCSELs.

LEDs

LEDs constitute an ideal light source for many Leddar-based applications. Moreover, the growth in LED illumination has driven the development of a large quantity of commercial light shaping components, such as collimators and reflectors. Furthermore, LEDs are inexpensive, available in various wavelengths, easy to assemble on printed circuit boards, and highly reliable. It is also easy to design eye-safe solutions around LEDs.

For many applications, Leddar technology can make use of a LED source that is already used for illumination or signaling. The short measurement pulses of Leddar (typically less than 50 ns) can be made imperceptible to the human eye.

Leddar is not limited to single-wavelength LEDs; white LEDs can also be used, which is particularly attractive for many smart lighting and automotive applications.

The short measurement pulses and very low duty cycle required by Leddar light processing also mean that in most cases, no specific thermal management needs to be implemented.

Lasers

Pulsed laser diodes are well-suited for long-range, narrow-beam applications. They are a good choice for delivering a maximum light intensity and can be collimated with small optics.

One drawback of pulsed laser diodes is that they have very low allowable duty cycles, limiting the measurement rate.

The cost per watt of laser diodes is also significantly higher than for LEDs. For high-power applications, however, the footprint and the number of optical and electronic components required can be much smaller with a laser diode than with an equivalent number of LEDs.

Finally, the regulatory environment for laser products is more complex than for LED-based products; therefore, product approval and distribution for these products will be more expensive.

VCSEL

VCSELs are a type of laser diode that emit light perpendicularly to the top surface of the wafer. They can therefore be produced at much lower cost than conventional, edge-emitting laser diodes. They can also be built into arrays. Therefore, they can achieve performance comparable to edge-emitting laser diodes at a cost approaching LEDs.

Aside from that, the other comments on lasers stated above also apply to VCSELs.

Optics

Since Leddar is an optical technology, the field of view of a Leddar sensor can be easily tailored by selection of the source and reception optics.

Solutions ranging from a collimated beam to a 180-degree field of view can therefore be easily designed using simple aspheric lenses.

More complex solutions can also be engineered to address specific requirements. For instance, it may be desirable for an automotive driver assistance sensor to have a longer detection range or higher resolution for the zone directly in front of the vehicle than for the sides. This is a scenario that is easily accomplishable with Leddar technology.

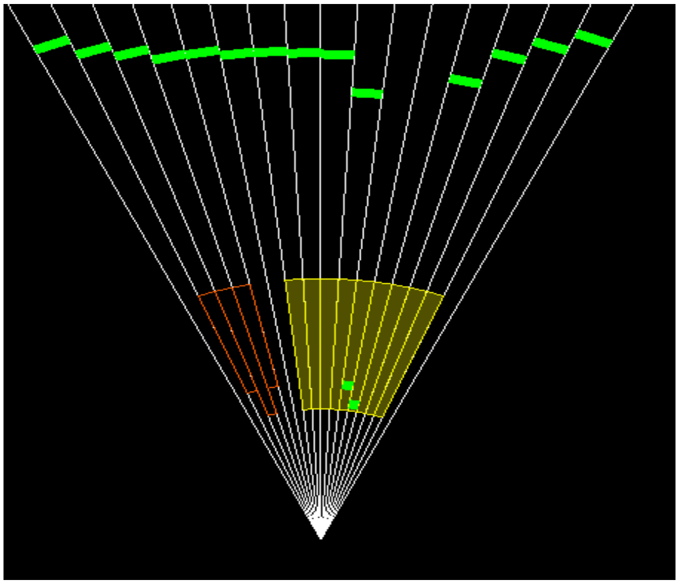


Figure 4 – Example of wide beam and different detection zones produced by a multi-element platform

Benefits of Leddar Technology

The first benefit of Leddar optical time-of-flight sensing technology is its **high range-to-power ratio**. What this means is that, compared with other optical time-of-flight technologies, it can detect at a farther range with an equivalent amount of light.

This benefit can be leveraged in many different ways, depending on the target application. Compared to a sensor integrating another optical time-of-flight technology, a sensor integrating Leddar technology can:

- Have a longer detection range with an equivalent light output; or
- Have a similar detection range with a lower light output.

Another way to leverage the high range-to-power ratio of Leddar is by using a diffuse light source instead of a collimated source. In this case, each detection element can cover a large area. Simple optics can then be employed to customize the emission and reception patterns for specific applications.

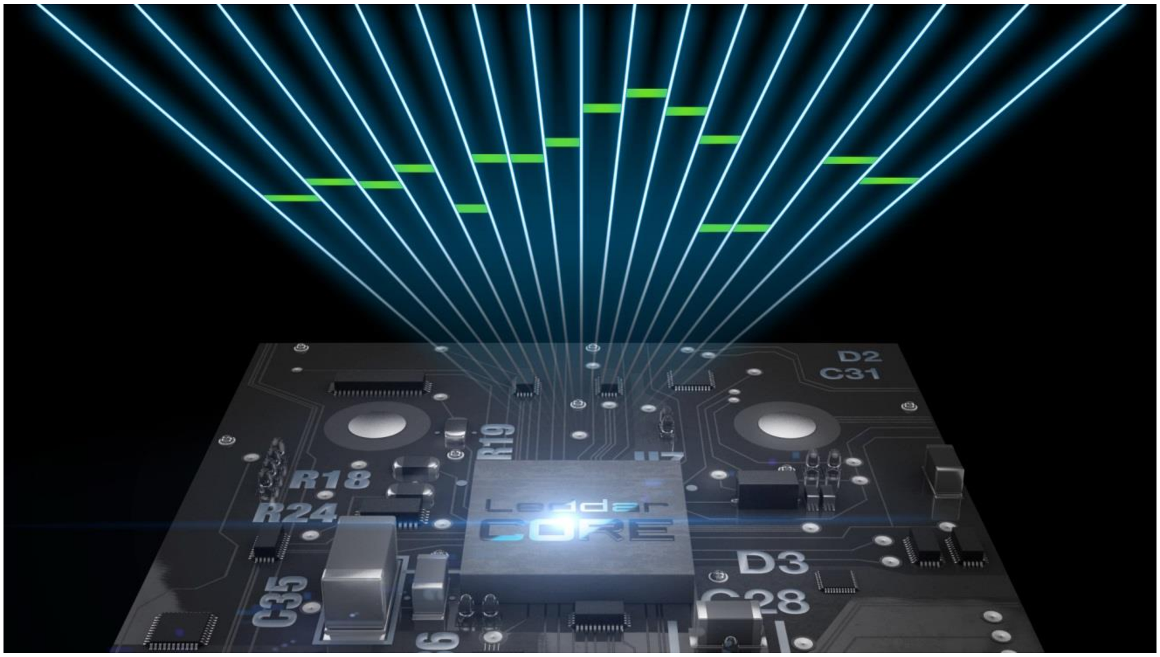
The second benefit of Leddar technology is its **capability to detect targets in low-visibility conditions**. Since each measurement is formed from hundreds or even thousands of discrete light pulses, the likelihood that the technology is able to obtain reliable measurements under environmental conditions such as rain, snow, for or dust is very high. This is particularly true when using a diffuse light source.

Finally, the third benefit of Leddar technology is its **ability to resolve multiple targets with a single detector element**. Once again, this benefit can be fully exploited with a diffuse light source, where a small object may not fully occupy the field of view, and where the distance to background objects can be simultaneously measured. Detecting multiple targets at once can represent significant added value and increased versatility for many applications. Even a single-element sensor can provide a high degree of spatial awareness.

The low-power characteristics of the technology make it suitable for mobile or portable applications. Leddar technology is applicable to sensors starting from one detection element—and ranging up to thousands or even millions such elements.

Conclusion

Backed by a decade of focused R&D, Leddar technology has reached a high level of maturity and has already been deployed in commercial solutions. With its novel, highly efficient approach to optical time-of-flight sensing, Leddar technology helps developers and integrators meet the key LiDAR sensor requirements sought after for ultrahigh-volume deployments: small size, low cost, low power consumption, reliability, robustness, and adaptability. With its unique characteristics, Leddar opens up an array of new possibilities in detection and ranging, and contributes to increasing efficiency, productivity, safety, or quality of life in a variety of industrial, commercial, and consumer applications.



More information about Leddar technology and Leddar sensor IC and modules can be found at leddartech.com

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