Distance Measurements Prevent Collisions

LiDAR Systems for the Recognition of Obstacles

For vehicles to drive autonomously or unmanned aerial vehicles to fly alone, they must be able to recognize obstacles in order to avoid them. Monitoring surroundings using LiDAR systems has many advantages: These systems are not only inexpensive, but they can also measure distances of up to 100 meters. LiDAR is short for light detection and ranging.

During measurement, pulsed laser diodes (PLDs) are used as emitters and avalanche photodiodes (APDs) as receivers; this measurement principle is based on optical time-of-flight (ToF) measurements.

Optical ToF Measurements

The principle of optical ToF measurement can be easily explained: A PLD sends a single short light pulse; ideally, this light propagates undisturbed along the shortest path through the air until it detects an obstacle. At the obstacle, light is reflected and the pulse returned to be detected by an APD. The electronics that connect APDs and PLDs measure the time Δt between sending and receiving the returned light pulse. Because the propagation speed of light is already known, the distance l of an obstacle can be easily calculated from measured time.

Basic Physical Principles

Light propagates in a vacuum at light speed c. Measurements in a vacuum yield the following value for c:

$$c = 299{,}792{,}458 \text{ meters/second}$$

In the physical sense, a vacuum is space without matter; therefore, it has an optical density of $n = 1$.
The smallest dust particles found in the air change this optical density, which is known as the refractive index n. The wavelength and phase speed are smaller than in a vacuum; therefore, the speed of light propagation also changes: $c_{air} = c/n_{air}$
Calculation example
Imagine for a minute that a light pulse is detected at $\Delta t = 500\ ns$. The obstacle has a distance of l, the measured time refers to the two-way (back and forth) path of light (i.e., $2*l$).

The distance can be measured in your head if you allow for the following approximate values:

$$c = 300{,}000{,}000 \text{ m/s} = 3*10^8 \text{ m/s}$$

$$n = 1$$

The following equation applies:

$$\Delta t = 2*l*n/c = 500 \text{ ns} = 5*10^{-7} \text{ s}$$

$$l = 0.5 * (c * \Delta t) / n$$

The distance can be calculated as:

$$l = 0.5* (3*10^8 \text{ m/s} * 5*10^{-7} \text{ s})/1$$

$$l = 0.5*3*5*10^1 \text{ m} = 75 \text{ m}$$

It is impressive to realize just how small the intervals are that are required for measurements at short distances; these intervals extend into the picosecond range, which is the trillionth part of a second.

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Challenges in operating Pulsed Laser Diodes for LiDAR applications

Applications of Pulsed Laser Diodes or PLDs are expanding into high precision distance measurement systems. The old challenges of energizing the devices become ever more significant. In order to achieve the distance resolution managed by modern time-of-flight ranging systems, shorter and shorter pulses need to be generated. The wavelength of choice for the majority of safety scanning applications is 905 nm. The primary advantages of this wavelength are cost and efficiency provided by the triple junction epitaxial designs. No matter what wavelength of the PLD is chosen, the switching of the drive current of very high speeds remains critical to achieving the range and distance resolution. Because PLDs are current activated, the inductance in the driver circuitry is the limiting factor to generating fast rise times and short pulse widths. The screen circuitry may not provide connection short enough to reduce inductance in the drive current path, so a trend towards hybridization of the PLD and driver often offer the best solution. To do so, requiring the critical components namely PLD, charge capacitor and switching element to be assembled in very close proximity to one another. Typically, all the components are packaged and connected inside 1 to 2 mm envelope. This configuration lends itself well to scaling of multi-PLD arrays, where the PLD chips can be place in very close proximity to each other with high alignment precision. Such an arrangement enables scanning systems, with fewer moving mechanical parts and lower overall production cost. Some PLD vendors, such as Laser Components, are now offering hybrid solutions, which achieve sub 2ns pulse widths and tens of Watts of peak optical power. With persistent and growing market demand for smarter and more capable LiDAR sensors, a reasonable cost innovation by PLD manufacturers will continue to play an important supporting role in the successful implementation of scanning LiDAR systems of increasing complexity.

The detection side of the system

From the detection point of view, any electro-optical system using time-of-flight concept has to use detectors that have high sensitivity, low noise, and cost. Silicon Avalanche Photodiodes (APDs), are meeting all those specs by utilizing the internal gain mechanism in a way that they are amplifying very weak signals coming from the targets. In that way making detectors very highly sensitive to weak signals, at the same time keeping the noise low. In order to have that gain process internal, these devices are using very high fields and inherently very fast. For example, typical Si APDs have a response time of less than 500 pico seconds, which is sufficient to meet any present and in the future pulse demands on the laser in the system. Packaging aspects of the Si APDs is very important from the system point of view, particularly in complex systems like LiDAR. In some instances, manufacturers prefer to buy just the chips, but advances in Surface Mount Packaging are allowing a very small form factor needed for this complex system and are incorporating Si APDS into the frames or printed circuit boards (PCBs) platforms encapsulated by the optical resin and in such a way protecting the device as well as allowing the manufacturer to build automatic equipment in order to place those components into systems. The application of the bandpass filter, which is eliminating interferences from surrounding light and increasing the detector performance. Future trends seen with laser sources as well asd Si APDs are moving from single components to arrays. Either linear or 2D configurations. Such as component will significantly improve systems in terms of reliability by removing most of moving parts, as well as lowering the cost, because the overall system size is allowed to shrink. ■

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