LIGHT DETETCION AND RANGING (LiDAR)

LiDAR, or light detection and ranging, is a popular remote sensing method used for measuring the exact distance of an object. LiDAR technology is similar to the RADAR which was first successfully used in 1940's for military and defence application where electromagnetic waves were used to determine the location and velocity of distant objects by analysing changes to the reflected signal.
Even though RADAR technology came into in 1940's, LiDAR technology came into existence only in 1960's after the invention of Lasers. As the technology advanced, it quickly became apparent that the higher the frequency (bandwidth) of the Radar signal, the more information the signal could carry, and therefore result in finer resolution. It is for this reason that engineers started developing laser-based radar systems for defence application. LIDAR was originally understood as laser radar, but is nowadays taken as an acronym meaning light detection and ranging, which is somewhat more general.

Basic Operation Principles
LiDAR can be compared to special class of optical transceivers modules which transmit light to a target and receive the reflected light from the target for analysis. There are 2 modes of operation viz. Pulsed Lidar and Coherent Lidar.
Pulsed laser measurements operate similar to AM radios in which the pulse amplitude and timing are used to determine distance, whereas Coherent Lidar measurements are similar to FM radio operation in which the transmitting laser frequency is modulated and the reflected laser beam's frequency is compared through coherent mixing of the transmitted frequency and reflected laser signals.

Pulsed LiDAR
Laser pulses (few nanosecond) are sent in a certain direction in the form of a laser beam, and these pulses eventually hit some target which reflects or scatters light back towards the source, the detected time delay of that light can be used to determine the distance of the object (time-of-flight method). By doing many such measurements while scanning the direction of the beam, one can acquire information for 3D images (3D laser scanning). The image data can be collected with some kind of computer (e.g. realized with a microprocessor), which can then display them on a screen. The larger pulse energy needs to be sufficient intense depending on the target distance and intensity of reflected beam. Due to eye safety concerns, the maximum output power of lasers is limited and regulated in certain applications. The detection system should be very sensitive and fast to doing the reliable measurements.

Coherent LiDAR or Doppler LiDAR
Coherent LIDAR is based on optical heterodyne detection where the reflected/returned light is mixed with a "local oscillator" based on light from the laser used for sending out light. The heterodyne detection greatly improves the sensitivity hence it work over a larger distance even with common detection systems.

The sent-out light is frequently a single-frequency signal with a linear up-chirp during some time interval. Since the frequency difference between the returning light and the light emitted at the same time grows with the propagation time, a measurement of the beat note frequency allows one to measure the distance from which the reflection originated – without using short laser pulses.

The recorded beat frequency is also modified by longitudinal motion of the target, or more precisely the relative velocity between LIDAR device and detected object. Motion of the target along the beam direction leads to a change in the light's frequency via the Doppler shift: motion towards the lidar brings about a compression of the wave and an increase in its frequency (a "blue shift"), while movement away stretches the wave reducing its frequency (a red shift). This frequency shift is measured accurately by mixing the return signal with a portion of the original beam, and sensing the resulting beats at the difference frequency on a photodetector. Devices which utilize the Doppler effect for velocity measurements are called coherent Doppler LIDAR.

By mixing the reflected signal with an optical local oscillator, the full field can be detected in a Doppler laser measurement, including both phase and amplitude, as compared to pulse laser measurements, where only the intensity (amplitude) of the reflected laser signal is measured. Measuring the phase of the return signal through Doppler shift enables the simultaneous measurement of velocity and range.

Due to the principle of optical heterodyne detection, coherent LiDAR can be substantially more sensitive and can therefore offer a larger measurement range and/or enable the use of lower laser powers. Particularly when using semiconductor lasers, the much lower required peak power is advantageous. On the other hand, there is the requirement of carefully controlled single-frequency sweeps; in that respect, the demands on the laser are higher.

Applications:
The frequency shift can be used to measure the velocity of solid objects like airplanes, automobiles, or baseballs, but it is also widely used to track winds and aerosols. One of the most common uses of Doppler lidar is for determining wind speed and direction in wind farms, so the blade angle can be adjusted to optimize the efficiency without overloading the turbine. Another typical example is for aviation safety where abrupt changes in windspeeds can be detrimental to air traffic, particularly in crowded airports.

Laser Eye Safety
Due to eye safety concerns, the maximum output power of lasers is limited and regulated. This impacts selection of laser wavelength, its operating mode (pulsed or continuous) and drives the selection of detection method.

Lasers operating in shorter wavelengths in near-infrared (NIR) regions have lower output power/energy limits due to the fact that human eye focuses shorter NIR wavelengths onto retina thus concentrating the laser radiation onto a small point. Longer laser wavelengths in NIR however are absorbed in the cornea and have higher output power/energy limits. For example in a 1 nsec laser pulse, laser safety limit for 1550 nm is 1,000,000 times higher than a laser operating at 905 nm. Similarly, for the continuous laser operating mode, Class-1 laser safety limit is 10x higher for 1550 nm than 905 nm operating. Thus operating in 1550 nm wavelength range is preferred for long reach applications due to eye safety considerations.

Why Coherent Lidar?
Coherent lidar devices use low phase noise laser sources (narrow linewidth lasers) and relatively low speed receivers that are already in high volume production in the industry. In addition to providing long range distance measurements, being able simultaneously measure speed and distance at the same time has been advertised as the key advantages of the initial

systems despite the size and cost. Finally, coherent lidar technology is inherently more accurate in measuring distance.

Coherent detection by far is the simplest and most sensitive technique for lidar receivers while being practically immune to interference from ambient light sources and other lidars. CW LiDAR systems possess advantage of reduced complexity, and their performance can tailored closely to the industry’s requirements.

While a wide variety of single frequency lasers have been used in Doppler LiDAR research, the industry as a whole has adopted single frequency fiber lasers at the ideal light source.
Most fiber lasers are erbium (Er) doped and lase at approximately 1550 nm, which corresponds to the peak absorption band of water making them eye-safe which is critical for the deployment of any practical lidar system.