Lecture 07. Fundamentals of Lidar Remote Sensing (5)

- Basic Lidar Architecture
- Configurations vs. Arrangements
- A real example: Arecibo K Doppler Lidar
- Transceiver with HOE
- Lidar Classifications
- Summary
Physical Picture of Lidar Equation

\[ \beta(\lambda, \lambda_L, \theta, R) \cdot \Delta R \]
Interaction between radiation and objects

\[ T(\lambda_L, R) \]
Radiation Propagation Through Medium

\[ T(\lambda, R) \]
Signal Propagation Through Medium

\[ \eta(\lambda, \lambda_L)G(R) \]

Transmitter (Radiation Source)

Receiver (Detector)

System Control & Data Acquisition

Data Analysis & Interpretation
Basic Architecture of LIDAR

Transmitter
(Light Source)

Receiver
(Light Collection & Detection)

Data Acquisition & Control System
Function of Transmitter

- A transmitter is to provide laser pulses that meet certain requirements depending on application needs (e.g., wavelength, frequency accuracy, bandwidth, pulse duration time, pulse energy, repetition rate, divergence angle, etc).

- Usually, transmitter consists of lasers, collimating optics, diagnostic equipment, and wavelength control system.

- For sophisticated lidars with spectral analysis capabilities, the lidar transmitter is usually the most challenging part. The properties of the lidar transmitter determine the performance of the lidar system.

- Most modern lidars use ns pulsed lasers, while some uses cw lasers with bistatic configuration or pulse coding.
Function of Receiver

- A receiver is to collect and detect returned photon signals while compressing background noise.
- Usually, it consists of telescopes, filters, collimating optics, photon detectors, discriminators, etc.
- The bandwidth of the filters determines whether the receiver can spectrally distinguish the returned photons.
Function of Data Acquisition and Control System

- Data acquisition and control system are to record returned data and corresponding time-of-flight, provide system control and coordination to transmitter and receiver.

- Usually, it consists of multi-channel scaler which has very precise clock so can record time precisely, discriminator, computer and software.

- This part has become more and more important to modern lidars. Recording every single pulse return has been done by several groups, enabling various data acquisition modes.
LIDAR Configurations: Bistatic vs. Monostatic

- Bistatic configuration involves a considerable separation of the transmitter and receiver to achieve spatial resolution in optical probing study.

- Monostatic configuration has the transmitter and receiver locating at the same location, so that in effect one has a single-ended system. The precise determination of range is enabled by the nanosecond pulsed lasers via time of flight (TOF).

- A monostatic lidar can have either coaxial or biaxial arrangement.
Basic Configurations of LIDAR Bistatic and Monostatic

Bistatic Configuration

Monostatic Configuration

\[ R = c \cdot \Delta t / 2 \]
Coaxial vs. Biaxial Arrangements

- In a coaxial system, the axis of the laser beam is coincident with the axis of the receiver optics.
- In the biaxial arrangement, the laser beam only enters the field of view of the receiver optics beyond some predetermined range.
- Biaxial arrangement helps avoiding near-field backscattered radiation saturating photo-detector.
- The near-field backscattering problem in a coaxial system can be overcome by either gating of the photo-detector or use of a fast shutter or chopper.
Biaxial Arrangement

Lidar Transmitter

Lasers

Frequency Reference

Wavelength Frequency Control

Frequency Shift/Modulation Device

Energy/Power Meter

Fast Photo Diode
Temporal Detection

Spatial Beam Profiler

Spectrum Analyzer

Data Acquisition and System Control
Computer + Trigger Box
Control/Triggering/Monitoring

Beam Expander

Field Stop Chopper

Collimating Optics

Filters

Photo Detector

Amplifier

Discriminator

Multi-Channel Scalers
**Coaxial Arrangement**

**Lidar Transmitter**

- Lasers
  - Frequency Reference
  - Wavelength Frequency Control
- Frequency Shift/Modulation Device
  - Energy/Power Meter
  - Fast Photo Diode Temporal Detection
  - Spatial Beam Profiler
  - Spectrum Analyzer
- Data Acquisition and System Control
  - Computer + Trigger Box
  - Control/Triggering/Monitoring
- Trigger
- Beam Expander
- Field Stop Chopper
- Collimating Optics
- Filters
- Photo Detector
- Amplifier
- Discriminator
- Multi-Channel Scalers
“Fancy” Architecture of LIDAR

Transceiver
(Light Source
Light Collection
Lidar Detection)

Data Acquisition
& Control System

Transceiver with holographic optical element (HOE)

Courtesy to Geary Schwemmer
Example: Arecibo K Doppler Lidar


[Friedman and Chu, JGR, 2007]
Lidar Transmitter

- A pulsed alexandrite ring laser injection seeded by an external cavity diode laser
- Seed laser frequency is locked to K D1a Doppler-free feature
- Twin dual-pass acousto-optic modulators shift seed laser to two wing frequencies
- Diagnostic equipment: CCD beam profiler, fast photo diode, spectrum analyzer, and oscilloscopes, monitor the spatial, temporal, and spectral features of the lasers to ensure fidelity operation.
Lidar Receiver

- A Cassegrain optical telescope
  80-cm in diameter

- An optical fiber
  couples signals to receiver chain

- A rotating chopper
  blocks lower atmosphere return
to avoid saturating photo detector

- Coupling/collimating optics

- An interference filter and a Faraday filter
  compress bkg while transmits signals

- A photomultiplier tube (PMT)
detects photons in photon counting mode
DAQ and Control System

- **Amplifier**
  to amplify PMT signal

- **Discriminator**
  to judge whether it is real photon signal

- **Multichannel scaler**
  to record data along time bins

- **Computer with DAQ card and code**
  to control system and record data

- **Trigger control**
  to coordinate the entire system

- **Pulse build-up time monitor**
  to preclude signals from bad pulses
Alexandrite-Laser-Based K Doppler Lidar Transmitter

Credit and courtesy to Dr. Jonathan Friedman
Arecibo 80-cm Telescope

Courtesy to Dr. Jonathan Friedman
Rawdata Profile of K Lidar

Linear Scale

Log Scale
Classifications of Lidar

There are several different classifications on lidars e.g., based on the physical process; (Mie, Rayleigh, Raman, Res. Fluorescence, ...)
based on the platform; (Groundbased, Airborne, Spaceborne, ...)
based on the detection region; (Atmosphere, Ocean, Solid Earth, Space, ...)
based on the emphasis of signal type; (Ranging, Scattering, ...)
based on the topics to detect; (Aerosol, Constituent, Temp, Wind, Target, ...)

... ...
<table>
<thead>
<tr>
<th>Physical Process</th>
<th>Device</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic Scattering by Aerosols and Clouds</td>
<td>Mie Lidar</td>
<td>Aerosols, Clouds: Geometry, Thickness</td>
</tr>
<tr>
<td>Absorption by Atoms and Molecules</td>
<td>DIAL</td>
<td>Gaseous Pollutants</td>
</tr>
<tr>
<td>Inelastic Scattering</td>
<td>Rayleigh Lidar</td>
<td>Ozone</td>
</tr>
<tr>
<td>Elastic Scattering by Air Molecules</td>
<td>Raman Lidar</td>
<td>Humidity (H₂O)</td>
</tr>
<tr>
<td>Resonance Scattering/Fluorescence by Atoms</td>
<td>Resonance Fluorescence Lidar</td>
<td>Aerosols, Clouds: Optical Density</td>
</tr>
<tr>
<td>Doppler Shift</td>
<td>Wind Lidar</td>
<td>Temperature in Lower Atmosphere</td>
</tr>
<tr>
<td>Laser Induced Fluorescence</td>
<td>Fluorescence Lidar</td>
<td>Stratos &amp; Mesos Density &amp; Temp</td>
</tr>
<tr>
<td>Reflection from Surfaces</td>
<td>Target Lidar Laser Altimeter</td>
<td>Temperature, Wind Density, Clouds in Mid-Upper Atmos</td>
</tr>
</tbody>
</table>

Classification on Platform

Spaceborne lidar

Satellite, Space Shuttle, Space Station

Airborne lidar

Jet, Propeller Airplanes, Unmanned Aerial Vehicle (UAV), Kite

Ground-based lidar

Stationary, Containerized moved with truck

Shipborne lidar

Icebreaker, Ships

Submarine lidar

Submarine
Detection Regions

Atmosphere lidar

Hydrosphere lidar

Solid Earth lidar

Target lidar

Various types
From various platforms

Various types
From various platforms

Airborne or Spaceborne
Laser altimeter

Various type
With or without
Imaging function
Emphasis on Signal Type

Scattering Lidar

Besides time delay, more interested in signal strength, spectra, etc

Ranging/Profiling Lidar

Mainly concern Time delay between transmission and reception
Various Topics

- Aerosol/Cloud lidar
- Constituent lidar
- Temperature lidar
- Wind lidar
- Target lidar

... ... ... ...
Lidar Classifications on Challenge

Middle and Upper Atmosphere Lidar
- Long range – weak signal
- Accurate knowledge about atoms
- Accurate knowledge of transmitter
- Accurate knowledge of receiver
- Demanding requirements on lasers

Lower Atmosphere Lidar
- Many factors involved together
- Aerosols play a key role, also add the difficulty to lower atmosphere

Target lidar
- Precise determination of altitude is a great challenge, as many factors are involved.
Summary

- Basic lidar architecture includes transmitter, receiver and data acquisition and control system. Each has special functions. There are bistatic and monostatic configurations, and coaxial and biaxial arrangements.

- We use a real lidar – the Arecibo K Doppler lidar – as an example to examine the basic concepts of lidar picture and lidar architecture.

- High level lidar systems are sophisticated, mainly on the transmitter (laser) aspect. But receiver and DAQ also strongly affect system performance.

- Lidar classifications may have many different categories, depending on what we want to emphasize.