UAS-Based LiDAR Mapping

Video A

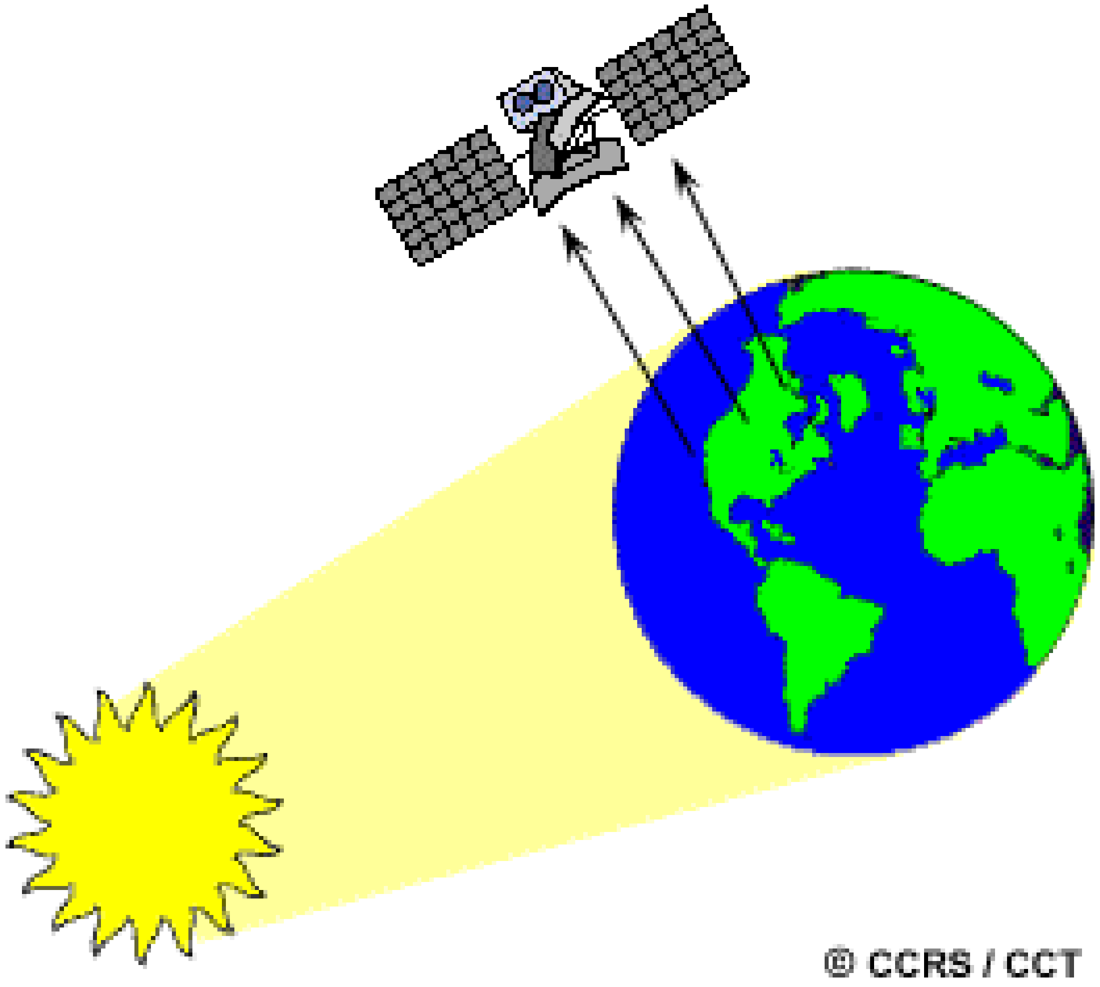
LiDAR Mapping Principles

Overview

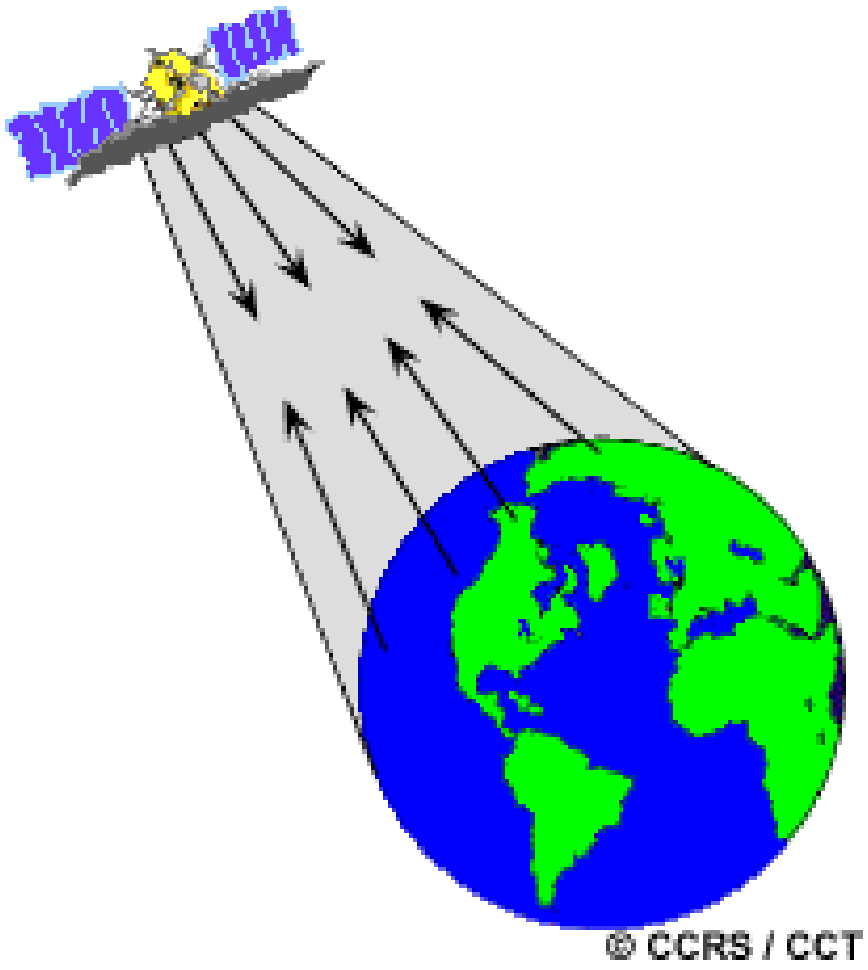
- Passive versus active sensors
- LASER principles
- LiDAR principles

Passive & Active Sensors

Passive Sensing: Photogrammetry



Active Sensing: LiDAR



Source: http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1212

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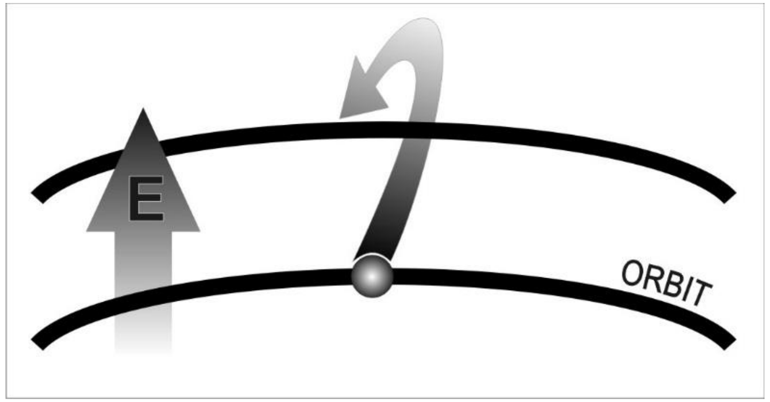
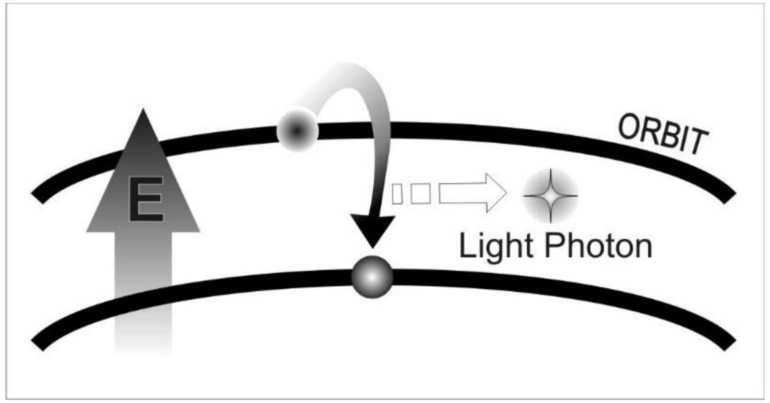
Laser Principles

LASER - **Light Amplification by Stimulated Emission of Radiation**

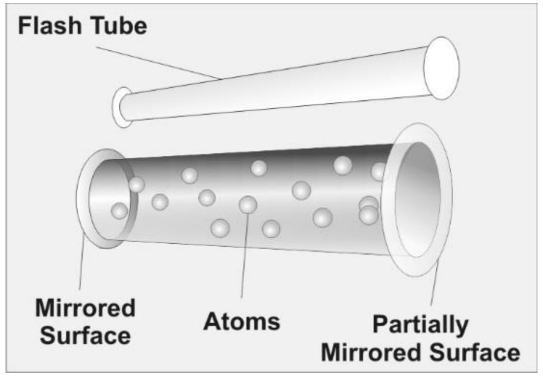


Energy given to an atom in ground state

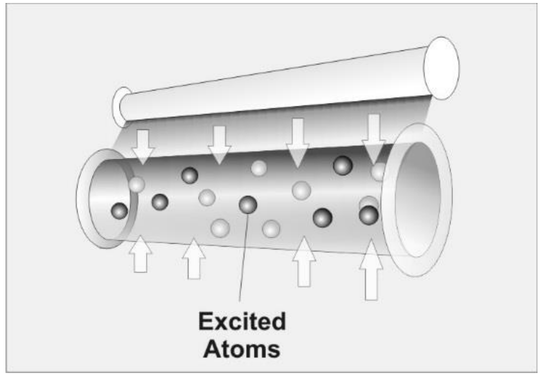


Excited atom returns to ground state by releasing energy

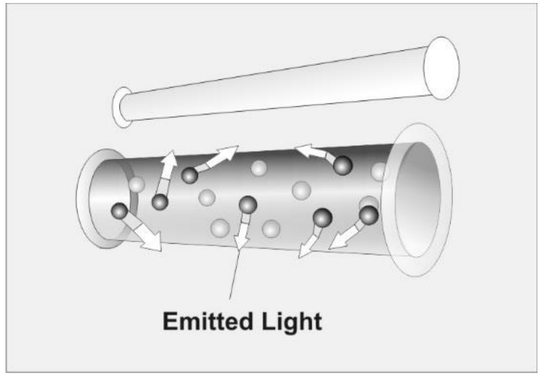
Laser Principles



1. The laser in its non-lasing state

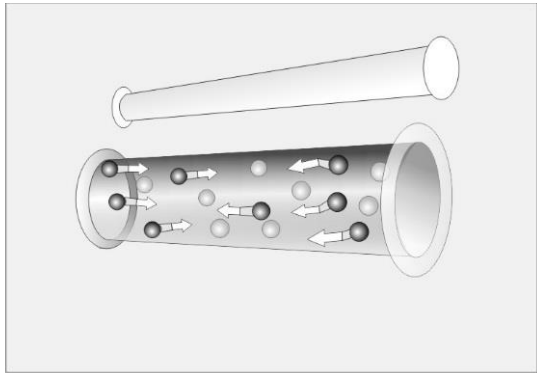


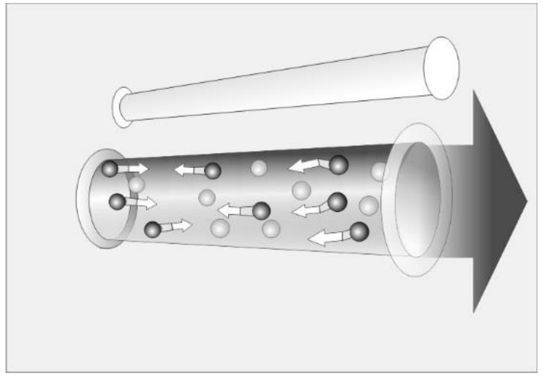
2. The flash tube fires and injects light into the rod. The light excites atoms in the tube.



3. Some of these atoms emit photons.

4. Some of these photons run in a direction parallel to the tube's axis, so they bounce back and forth off the mirrors and they stimulate emission in other atoms.





5. Monochromatic, single-phase, collimated light leaves the tube through the half-silvered mirror -- laser light!

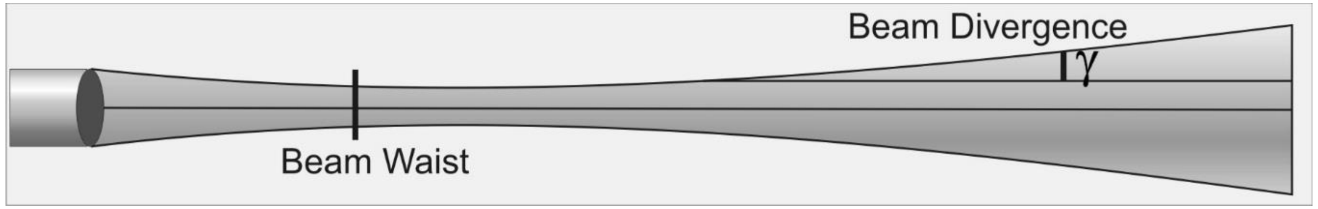
Source: Manual of Geospatial Science and Technology, Second Edition: Edited by J.D. Bossler

Laser Principles

- **Laser light is very different from normal light.**
- **Laser light has the following properties:**
  - **Monochromatic:** It contains one specific wavelength of light (one specific color). The wavelength of light is determined by the amount of energy released when the electron drops to a lower orbit.
    - Laser wavelength 500-1500 nm
    - Typical values 1040 – 1060 nm
  - **Coherent:** It is “organized” -- each photon moves in step with the others.
  - **Directional:** A laser light has a very tight beam and is very strong and concentrated.
    - A flashlight, on the other hand, releases light in many directions, and the light is very weak and diffuse.

Laser Principles

- Beam divergence from 0.2 - 1 mrad.



Source: Manual of Geospatial Science and Technology, Second Edition: Edited by J.D. Bossler

Laser Footprint

Wide Beam (0.8 mrad)	Narrow Beam (0.2 mrad)
• 0.8m diameter at 1,000m • 2.4m diameter at 3,000m	• 0.2m diameter at 1,000m • 0.6m diameter at 3,000m

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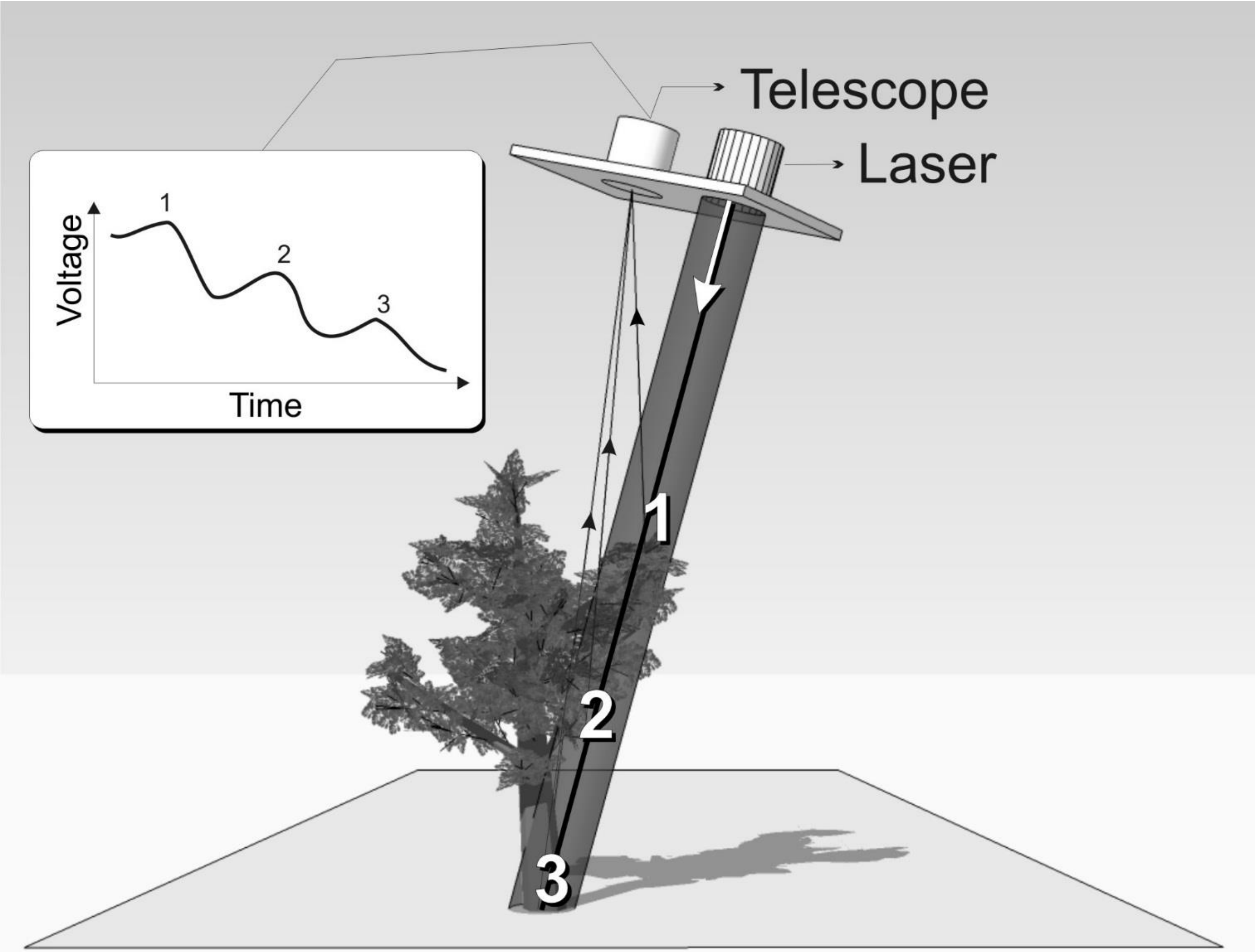
LiDAR Principles: Time of Flight Ranging Principles

- **The LiDAR instrument transmits light out to a target.**
- **The transmitted light interacts with and is changed by the target.**
- **Some of this light is reflected/scattered back to the instrument where it is analyzed.**
- **The time for the light to travel out to the target and back to the LiDAR system is used to determine the range to the target (Time of Flight – TOF).**
  - Some systems directly measure the TOF (Pulse-based systems).
  - Some systems infer TOF using the phase shift between the emitted and reflected signal.
  - Some systems do not measure TOF.
    - They infer the range using a laser and camera combination (triangulation systems).
- **The change in the properties of the light enables some properties of the target to be determined.**
  - Target reflectance in the wavelength of the laser light

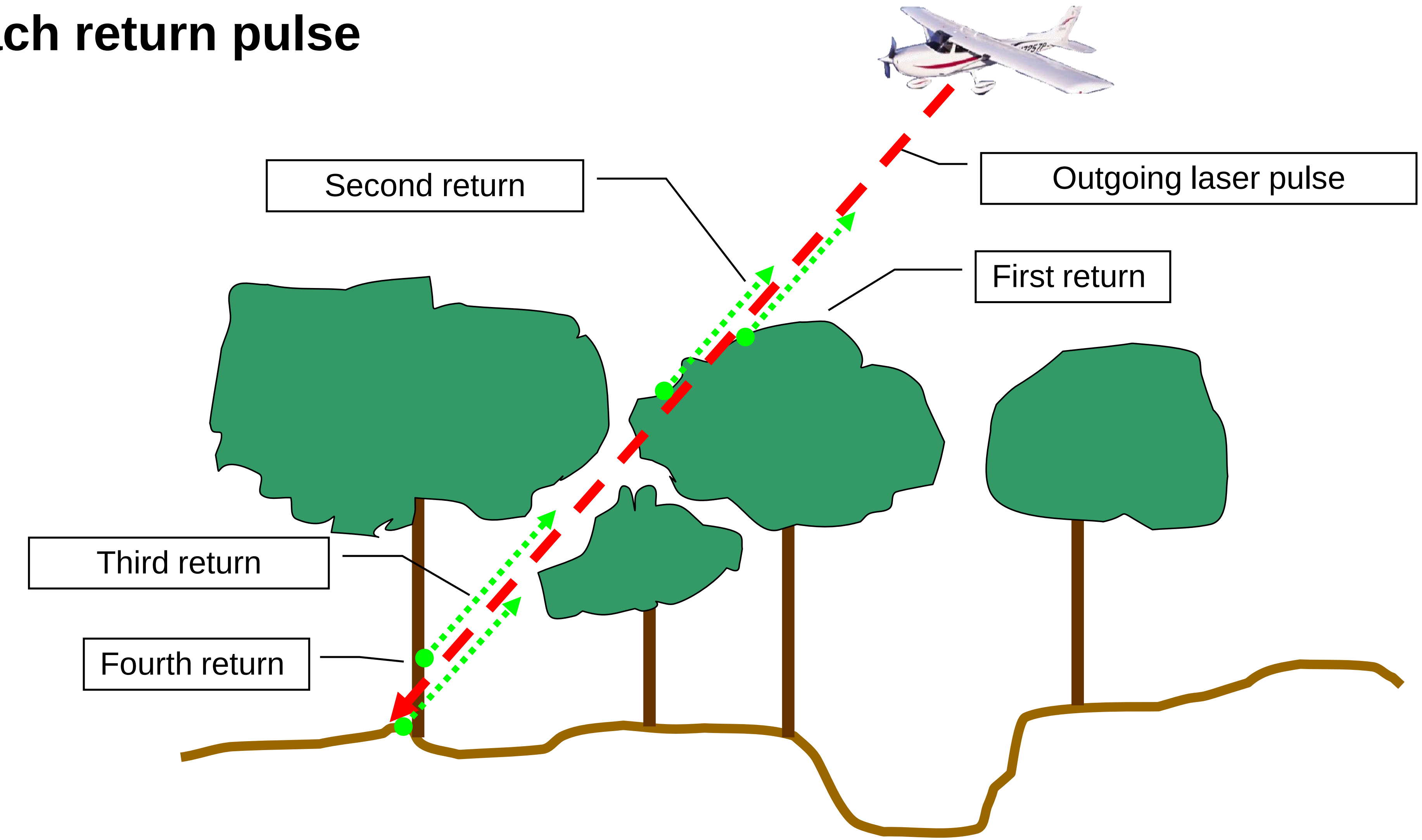
LiDAR Principles: Multi-Return Systems



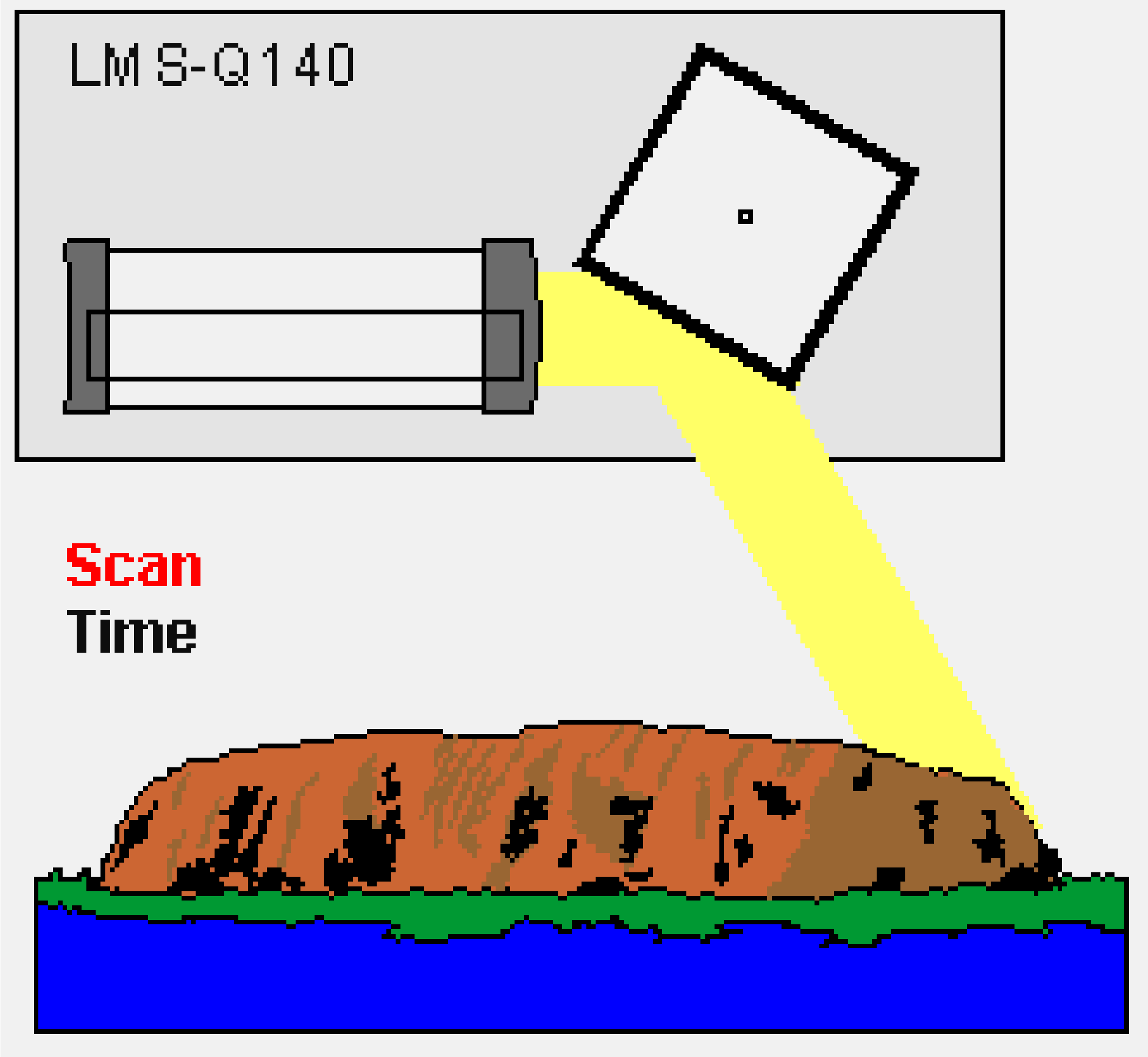
Source: Manual of Geospatial Science and Technology, Second Edition: Edited by J.D. Bossler

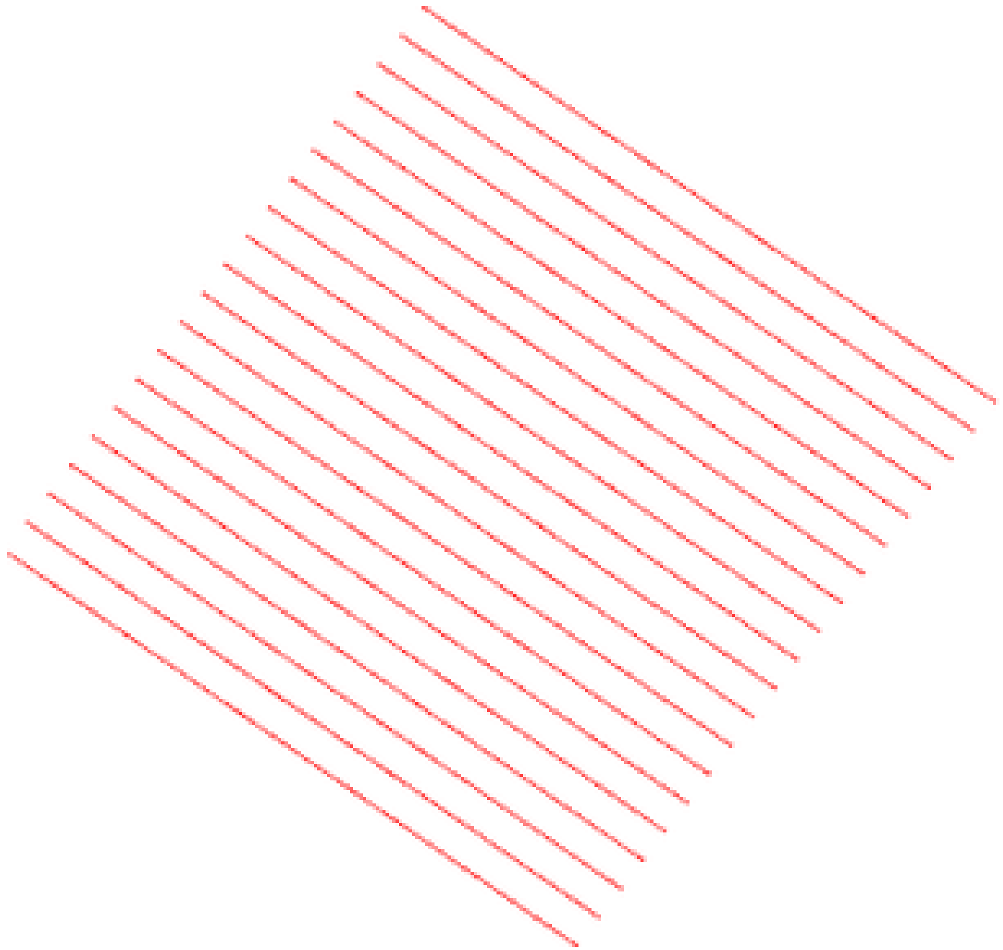
LiDAR Principles: Multi-Return Systems

- Outgoing laser pulse
- One or more return pulses
- Intensity of each return pulse



LiDAR Principles: Scanning Patterns

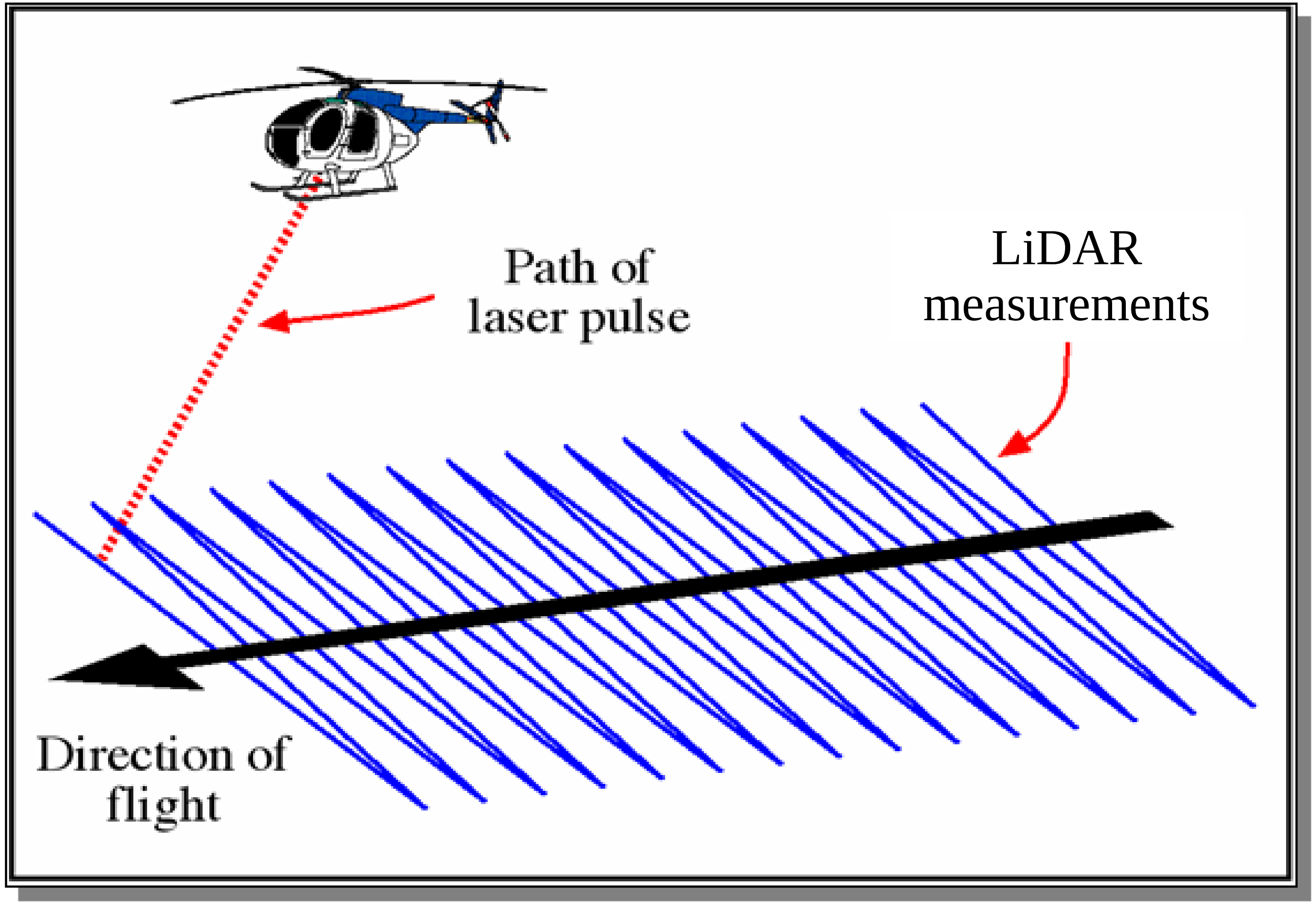




Parallel Scanning Pattern

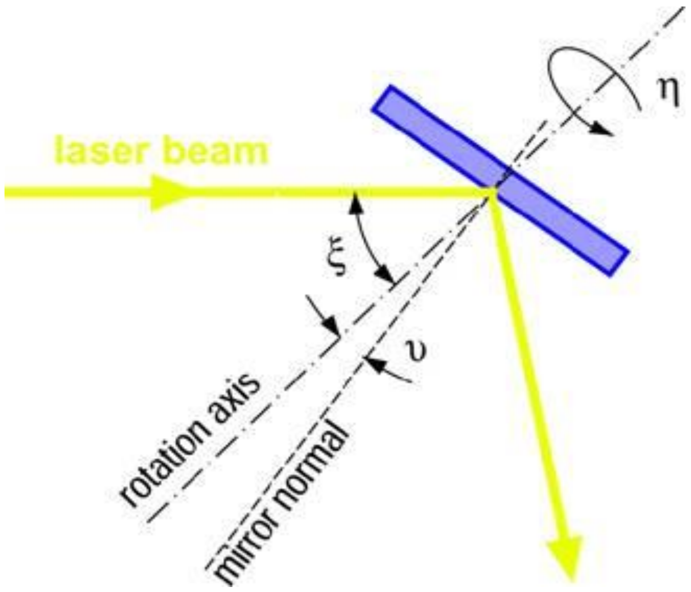
LiDAR Principles: Scanning Patterns

Linear LiDAR Scanners

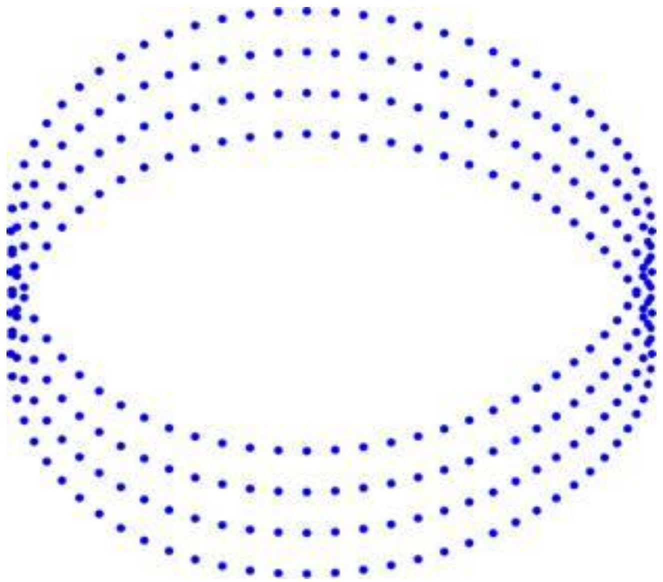


LiDAR Principles: Scanning Patterns

Conical/Elliptical LiDAR Scanners



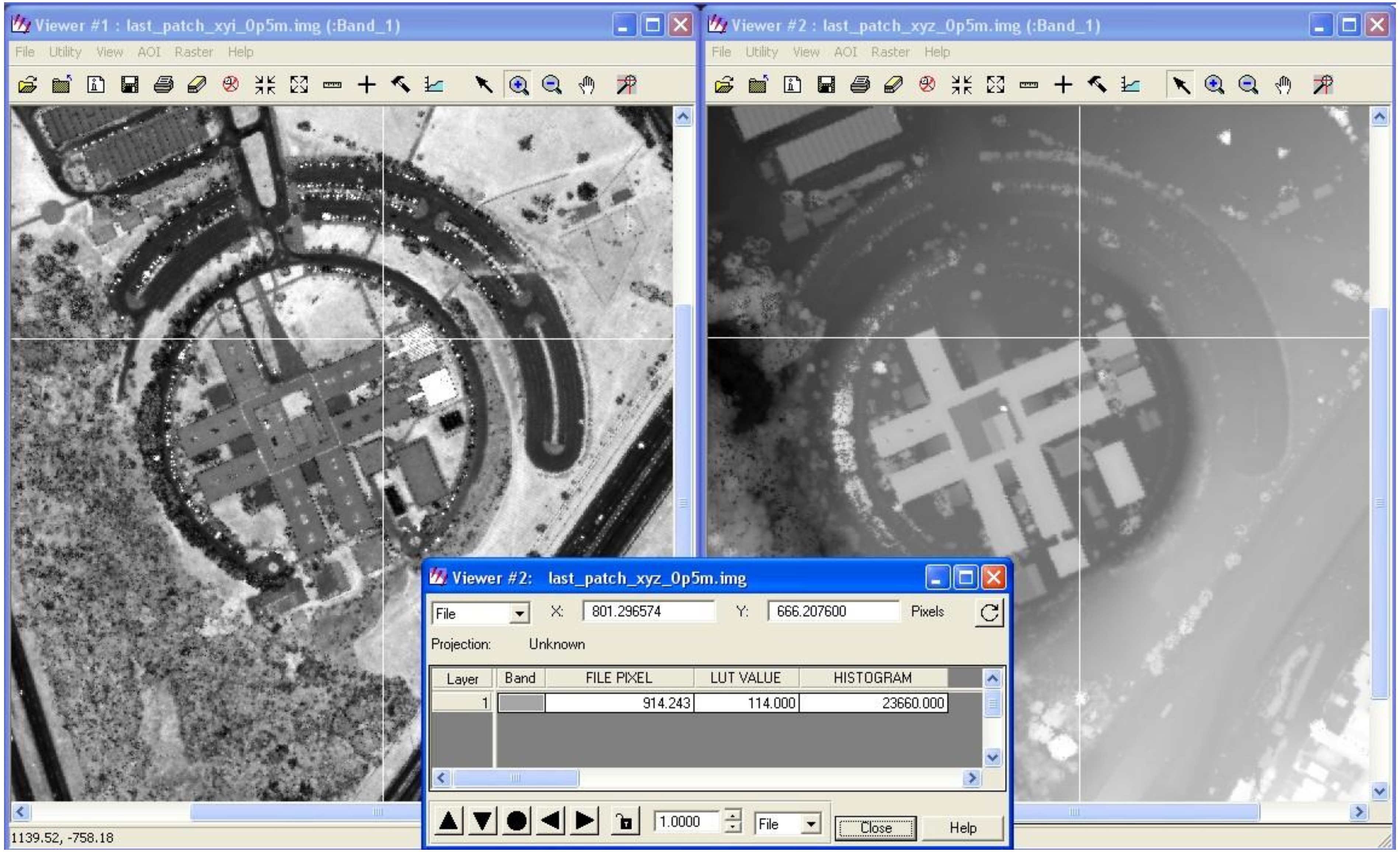
Nutating Mirror



Scanning Pattern

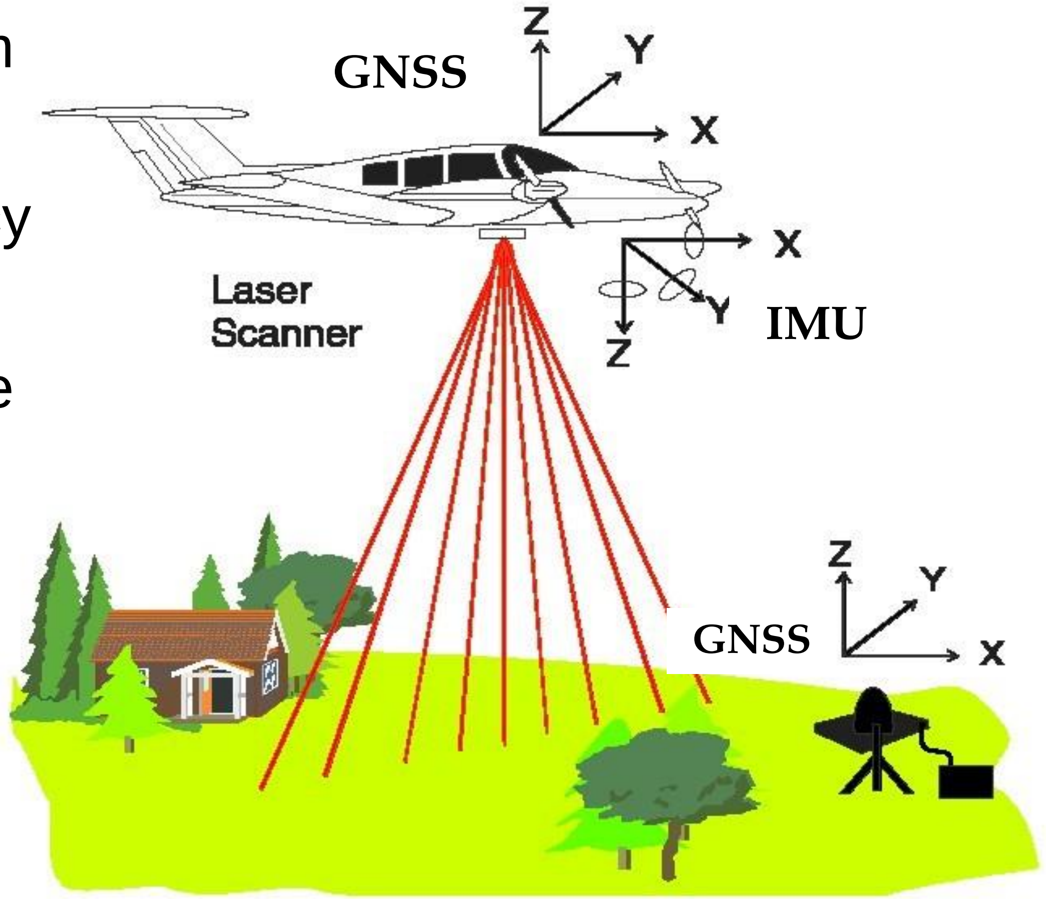
LiDAR Principles: Range and Intensity Data

- **LiDAR produces accurate point cloud coordinates along surfaces in addition to intensity data.**



Airborne Laser Scanning (Airborne LiDAR)

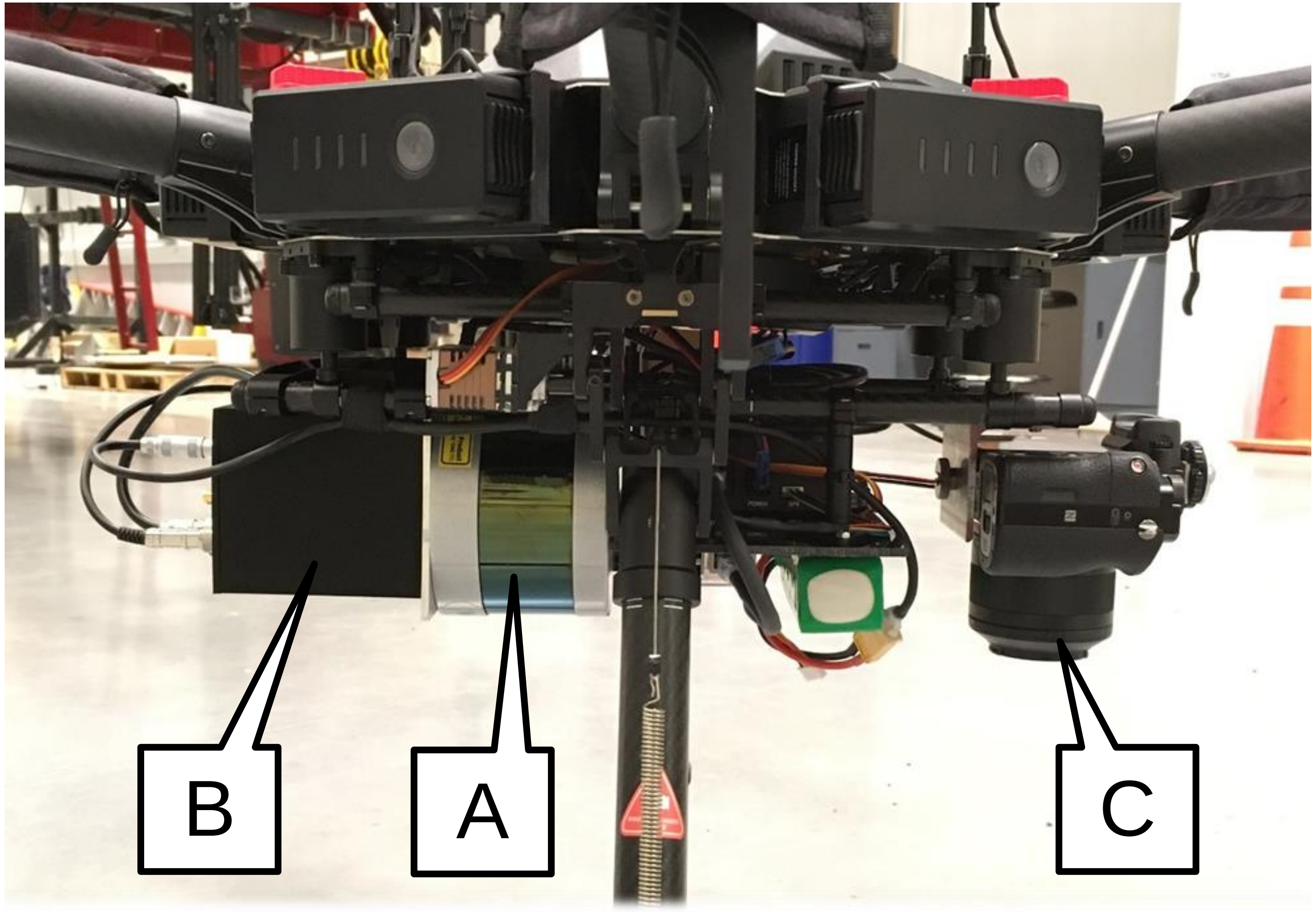
- **Three Measurement Systems**
  - Global Navigation Satellite System (GNSS)
  - Inertial Measurement Unit/Inertial Navigation System (IMU/INS)
  - Laser scanner emits laser beams with high frequency and collects the reflections
  - GNSS/INS defines the position and orientation of the platform relative to a global coordinate system.
  - GNSS/INS allows for the transformation from the LiDAR unit coordinate system to a global coordinate system.



Airborne Laser Scanning (Airborne LiDAR)

Airborne Laser Scanning (Airborne LiDAR)

- **UAV-based LiDAR**

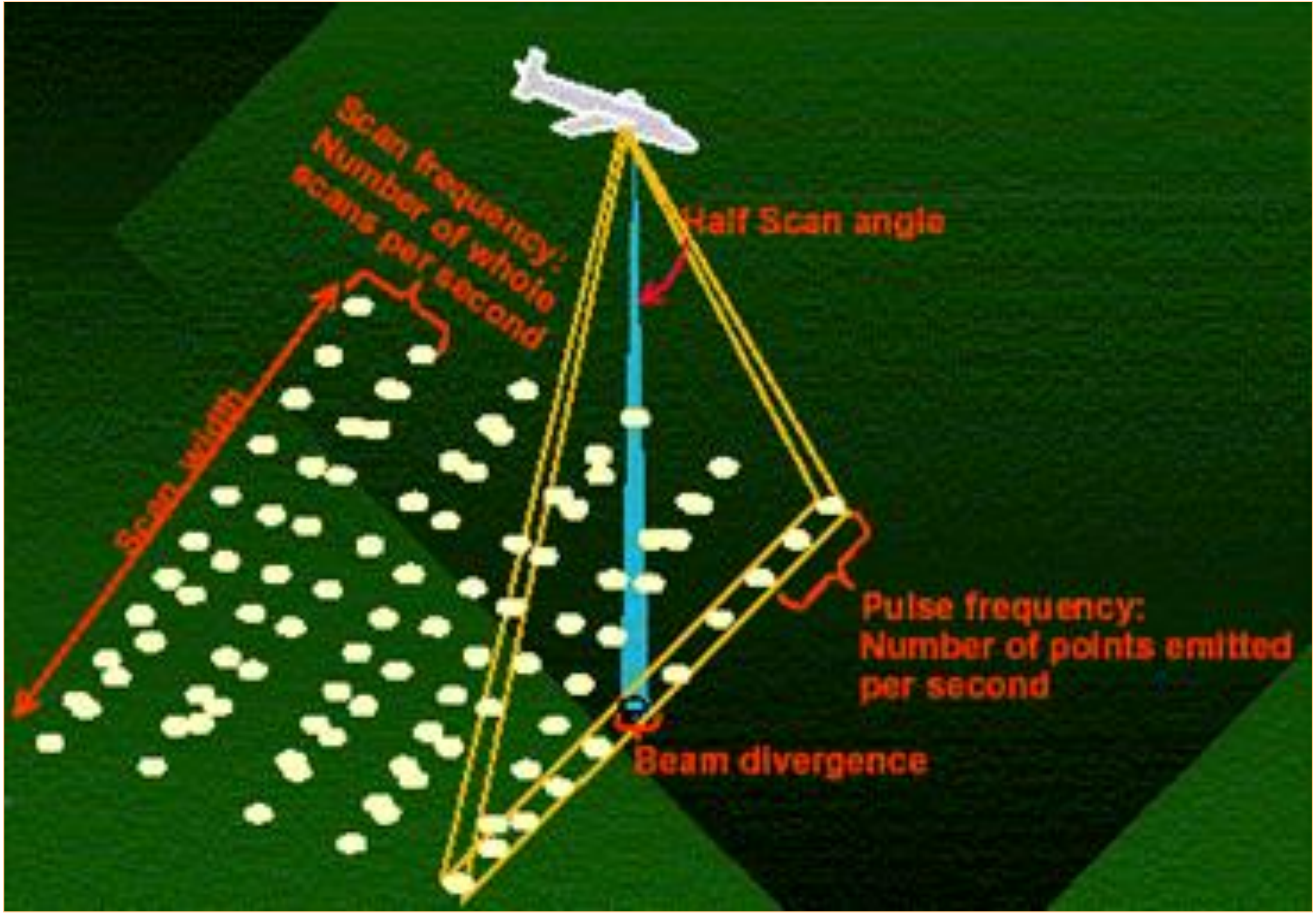


A
Velodyne VLP-32C

B
Applanix APX-15v3

C
Sony Alpha 7RIII

LiDAR Principles: Specifications



LiDAR Principles: Specifications

- **Scan Rate/Frequency:**
  - Number of scanned swaths per second
- **Pulse Rate/Frequency:**
  - Number of transmitted pulses per second
- **Ground Spacing:**
  - The distance between the footprints of two adjacent laser pulses
- **Other specifications include:**
  - Wavelength, scan angle, scan pattern, beam divergence, operating altitude,….

LiDAR Principles: Specifications

Specification	Typical values
Laser wavelength	1.064 µm
Pulse repetition rate	50 – 500 kHz
Pulse energy	100s µJ
Pulse width	< 10 ns
Beam divergence	0.25 – 2 mrad
Scan angle (full angle)	40º – 75º
Scan rate	25 – 90Hz
Scan pattern	Zig-zag; parallel; elliptical; sinusoidal
GNSS frequency	1 – 10 Hz
INS frequency	200 – 300 Hz
Operating altitude	80 – 3,500 m (6,000m max)
Footprint	0.25 – 2m @ 1,000m AGL
Multiple elevation capture	1 – 4 (Full waveform)
Ground spacing	0.5 – 2m
Vertical accuracy	< 5 – 30 cm (1,000 –3,000 m altitude AGL); 1 σ
Horizontal accuracy	1/5,500 – 1/2000 x altitude (m AGL); 1 σ

Specifications of Typical LiDAR Systems

LiDAR Principles

- **Some restrictions**
  - Restricted platforms: with few space-borne systems
    - Ground-based and airborne systems are more common.
  - Flying height:
    - Restricted by laser power, sensitivity of sensor, unambiguous maximum pulse rate
    - 2,000 m or less, it recently reached 6,000 m with unknown accuracies.
    - Minimum height restricted by safety
  - Flying speed restricted by scan rate and point density requirements as well as GNSS/INS

LiDAR Principles

- **Compared to photogrammetric systems, LiDAR systems are <u>not transparent</u>.**
  - Still a provided service
    - Raw measurements are not always accessible.
  - No single system to process the data
  - No interoperability between available systems
  - No standards for calibration, strip adjustment, number and distribution of control points …
  - High initial cost

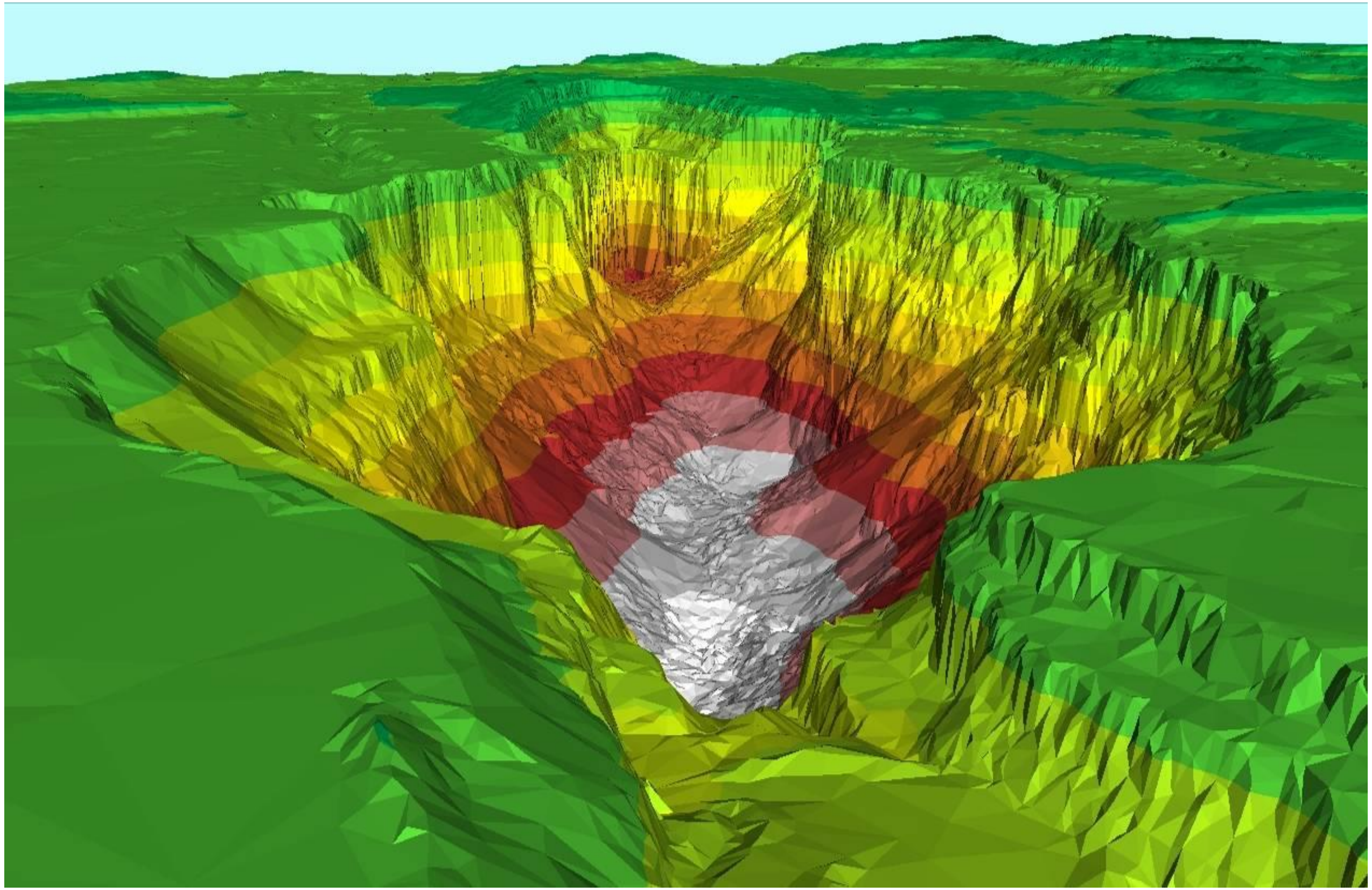
Why Use LiDAR?

- **Fast and Accurate**
  - 10’s – 100’s km^2/hour; 5 cm $RMSE_z$ on hard surfaces possible
- **Flexible Collection:**
  - Maps through canopy
    - Ground measurement is possible.
  - Independent of sun angle
  - Day or night
  - Light rain is tolerated.
  - Mapping of surfaces with very little/no texture or poor definition; ice/snow surfaces, sand, wetlands, ...

Why Use LiDAR?

- **High Resolution 3D Surface:**
  - Dense point clouds; Millions of points/km^2
- **Diverse Data Products:**
  - Full-feature,
  - Bare Earth,
  - Contours,
  - Building Footprints,
  - Land Usage,
  - Transportation/Utility Corridors, and
  - Many more …

Volumetric Calculations



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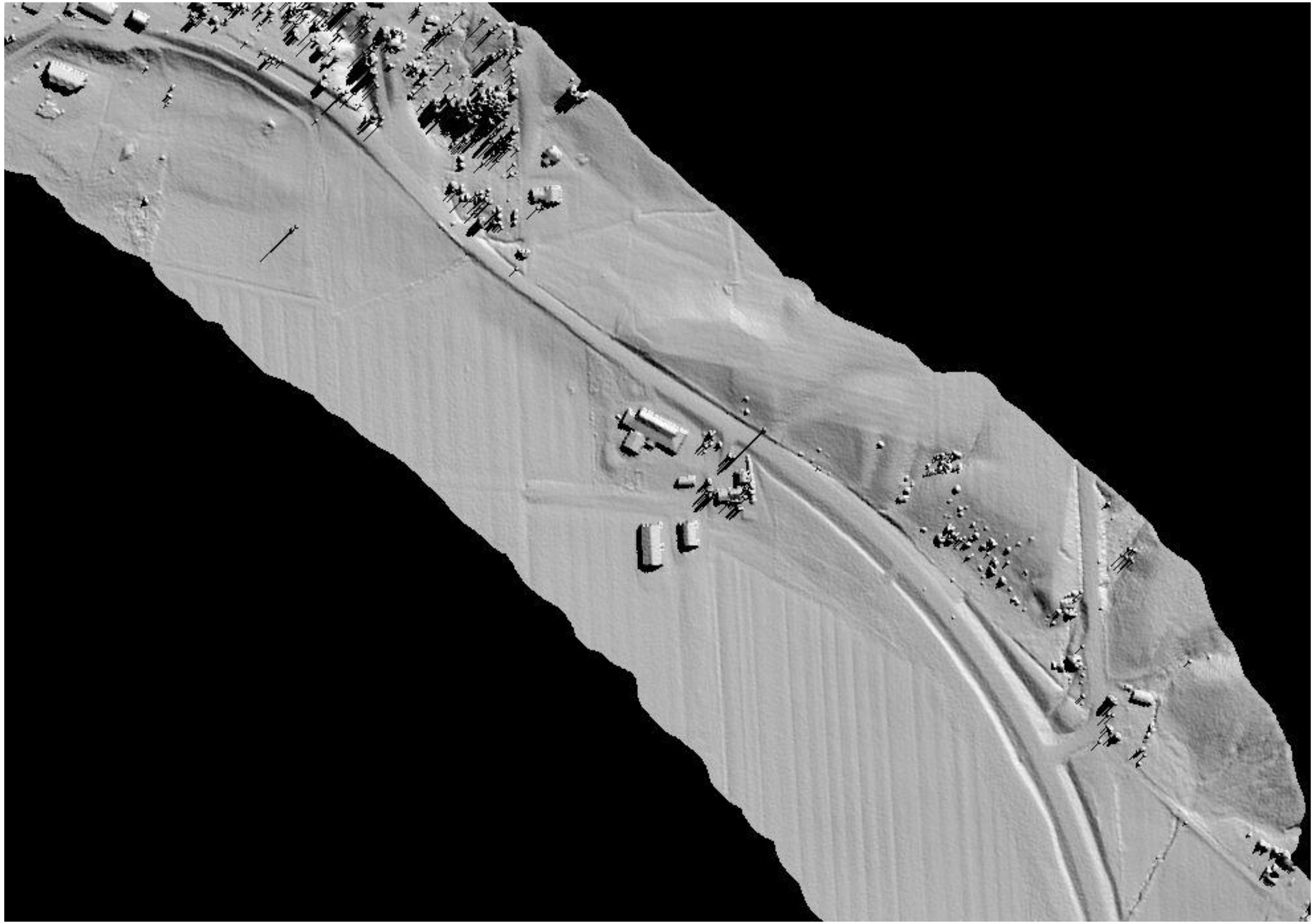
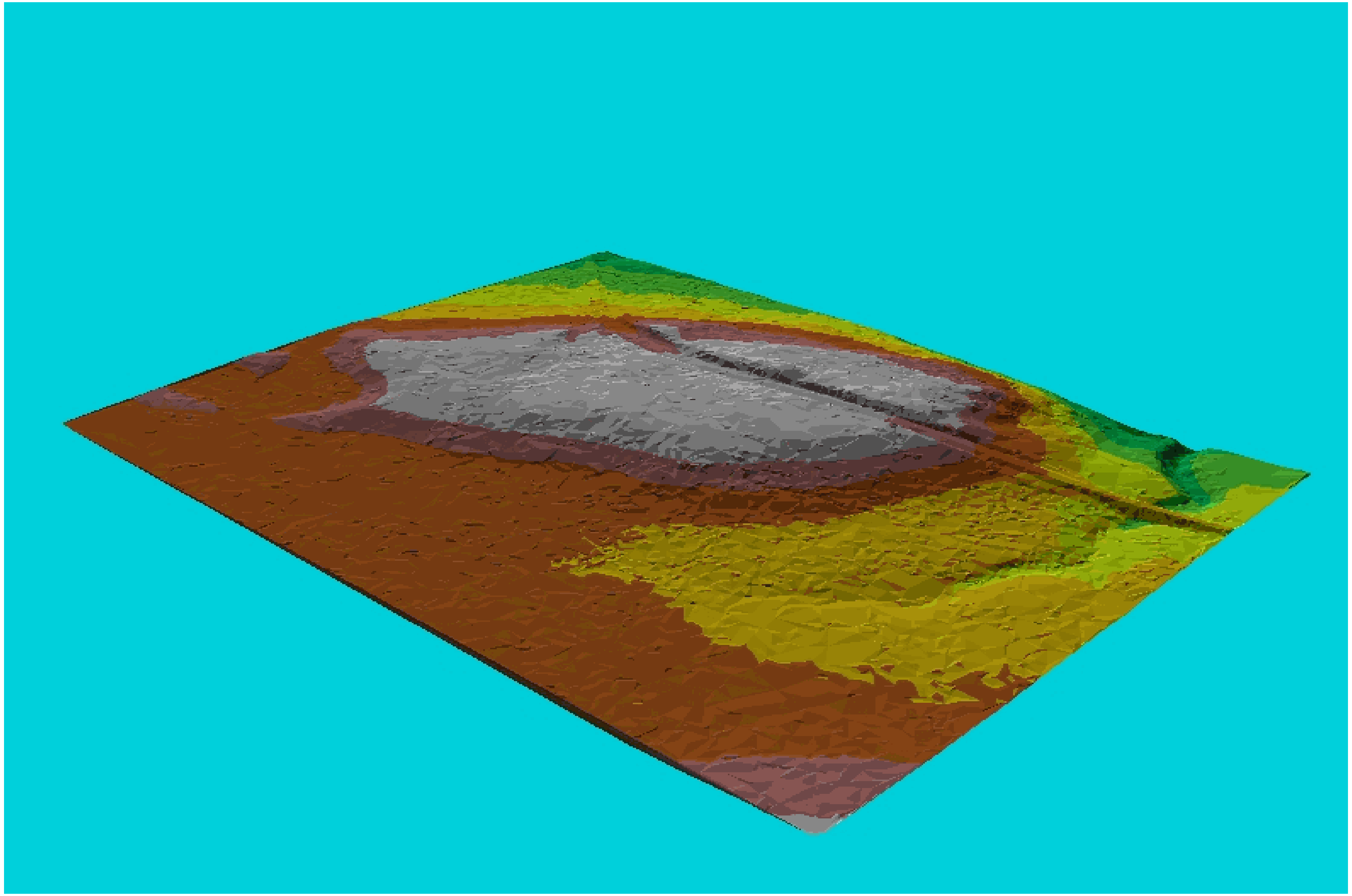
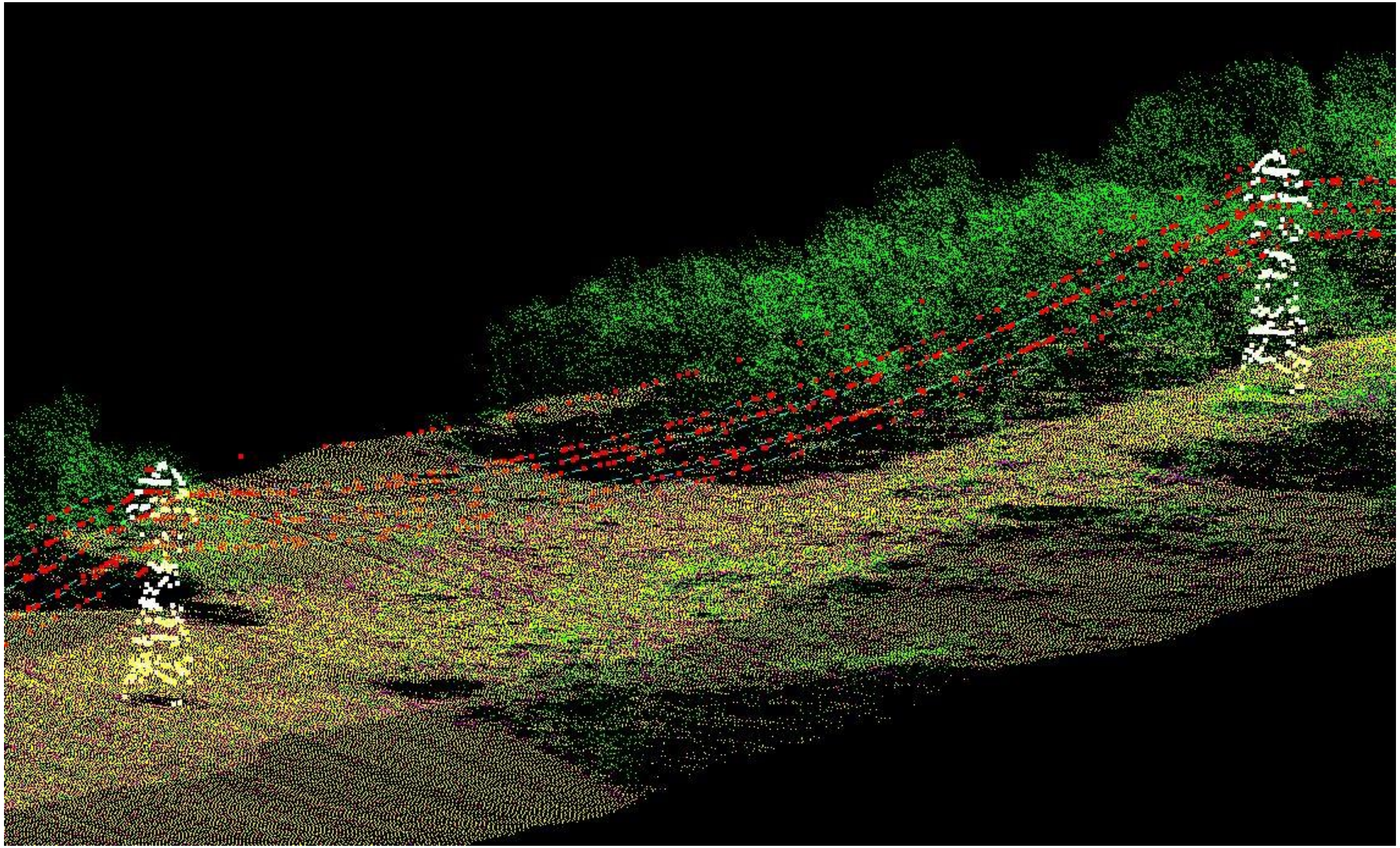
Transportation – Highway Expansion



Cut and Fill Applications



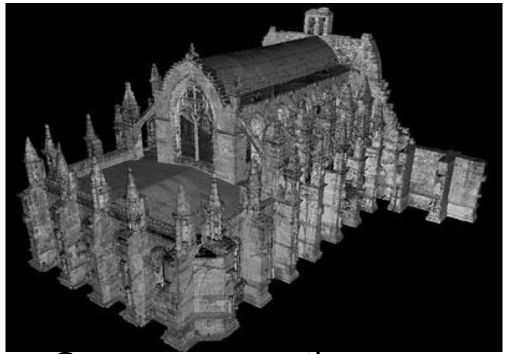
Power Line Mapping



LiDAR Mapping: Final Remarks

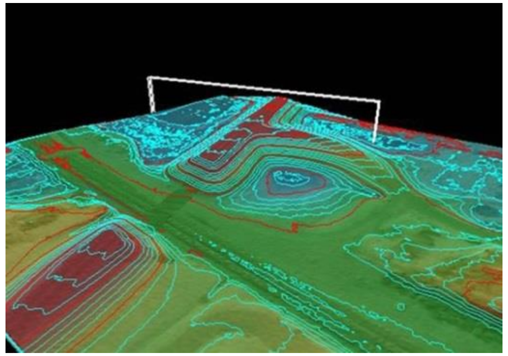
LiDAR Data Applications

Heritage Documentation



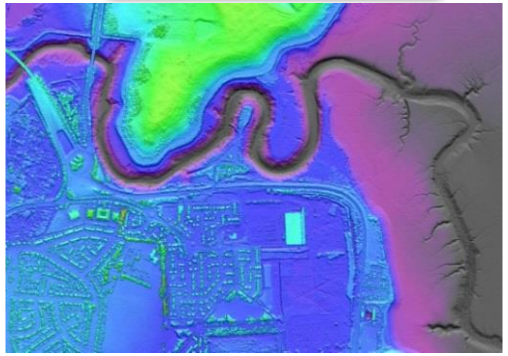
Source: www.nytimes.com

Transportation Planning



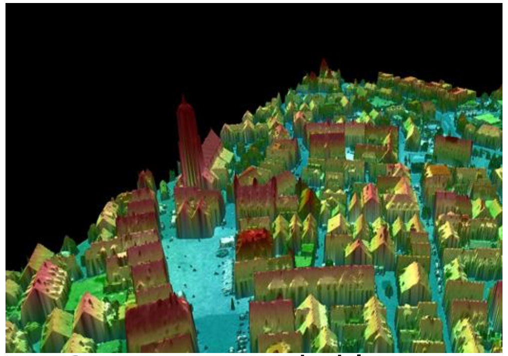
Source: www.isgs.uiuc.edu

Flood Plain Mapping



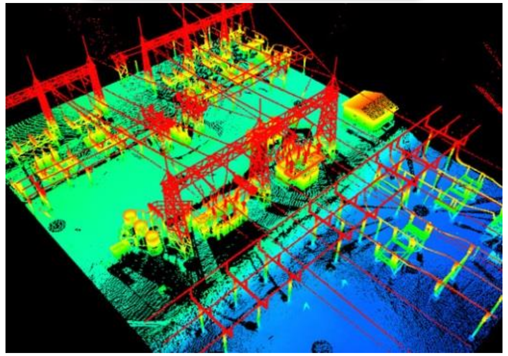
Source: www.maritimejournal.com

3D City Modeling



Source: www.trimble.com

Power Line Mapping



Source: www.merrick.com

We need to understand the underlying principles of LiDAR point positioning and the factors that affect the quality of derived points/products.