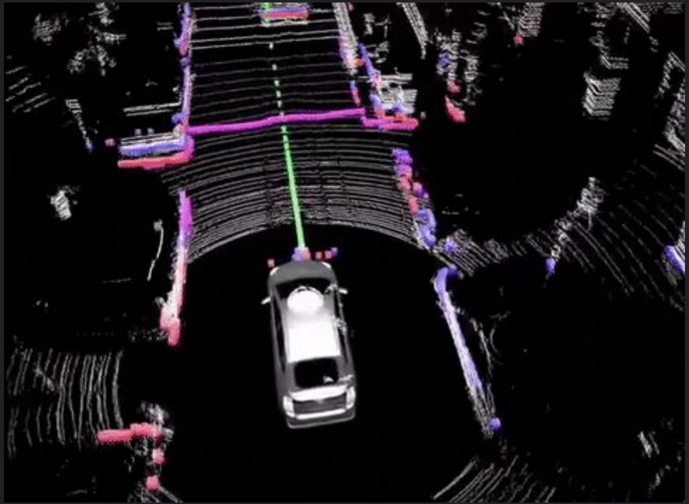
Introduction to LiDAR technology

Airborne laser scanning—an introduction and overview

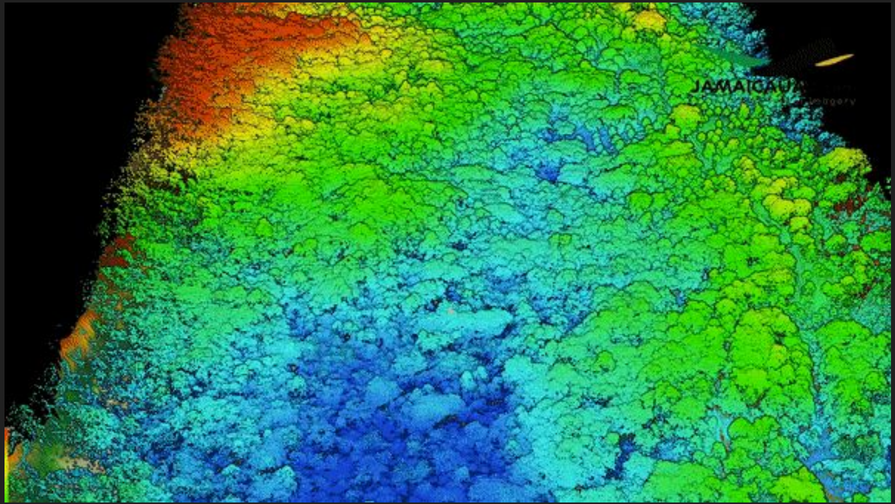
Nicholas Kory
Abenezer Wudenhe

LiDAR

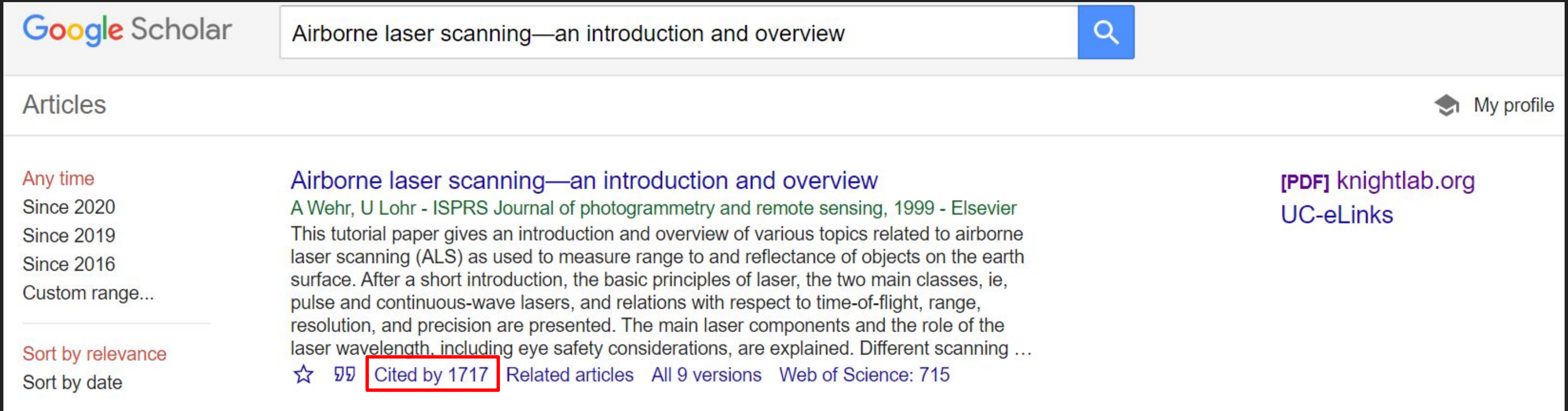
- Lidar (Light Detection & Ranging)



Ground LiDAR



Aerial Topographic LiDAR


Google Scholar
Airborne laser scanning—an introduction and overview
Articles
My profile
Any time
Since 2020
Since 2019
Since 2016
Custom range...
Sort by relevance
Sort by date
Airborne laser scanning—an introduction and overview
A Wehr, U Lohr - ISPRS Journal of photogrammetry and remote sensing, 1999 - Elsevier
This tutorial paper gives an introduction and overview of various topics related to airborne laser scanning (ALS) as used to measure range to and reflectance of objects on the earth surface. After a short introduction, the basic principles of laser, the two main classes, ie, pulse and continuous-wave lasers, and relations with respect to time-of-flight, range, resolution, and precision are presented. The main laser components and the role of the laser wavelength, including eye safety considerations, are explained. Different scanning …
Cited by 1717
Related articles
All 9 versions
Web of Science: 715
[PDF] knightlab.org
UC-eLinks

Outline

- Why this problem
- Why this is important
- Why it is challenging
- What the validation method is
- What the novel contributions are
- What the limitations of the related work are

The Problem

The Problem - The Ability to “See under Trees”

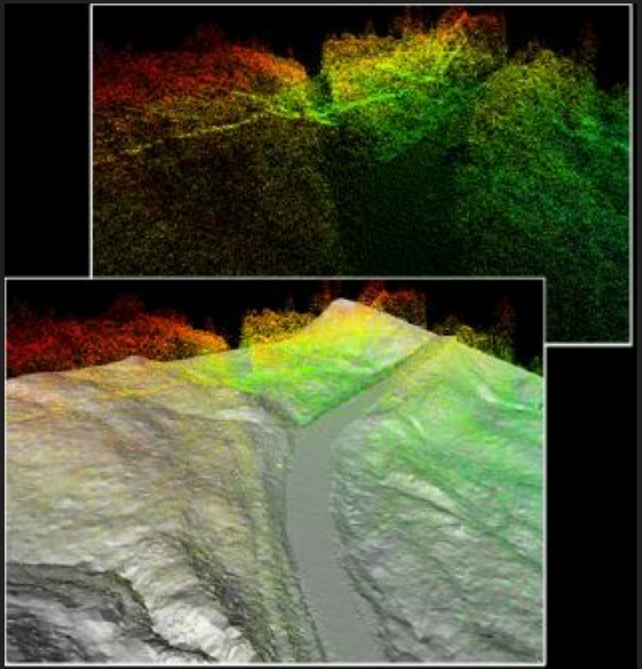


Fig 1: Lidar point and surface products

The Problem - Microwave Radar Technique

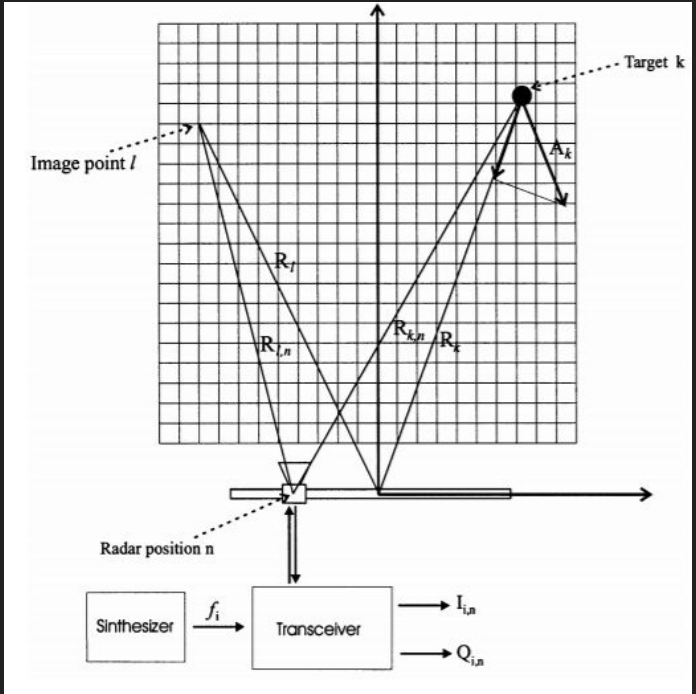


Fig 2: Working principle of microwave radar techniques

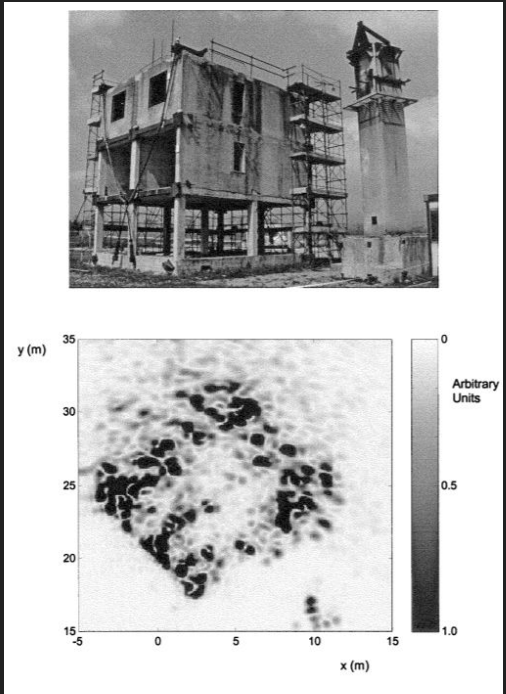


Fig 3: Picture of the structure and radar image acquired through a horizontal scan

The Problem - LiDAR

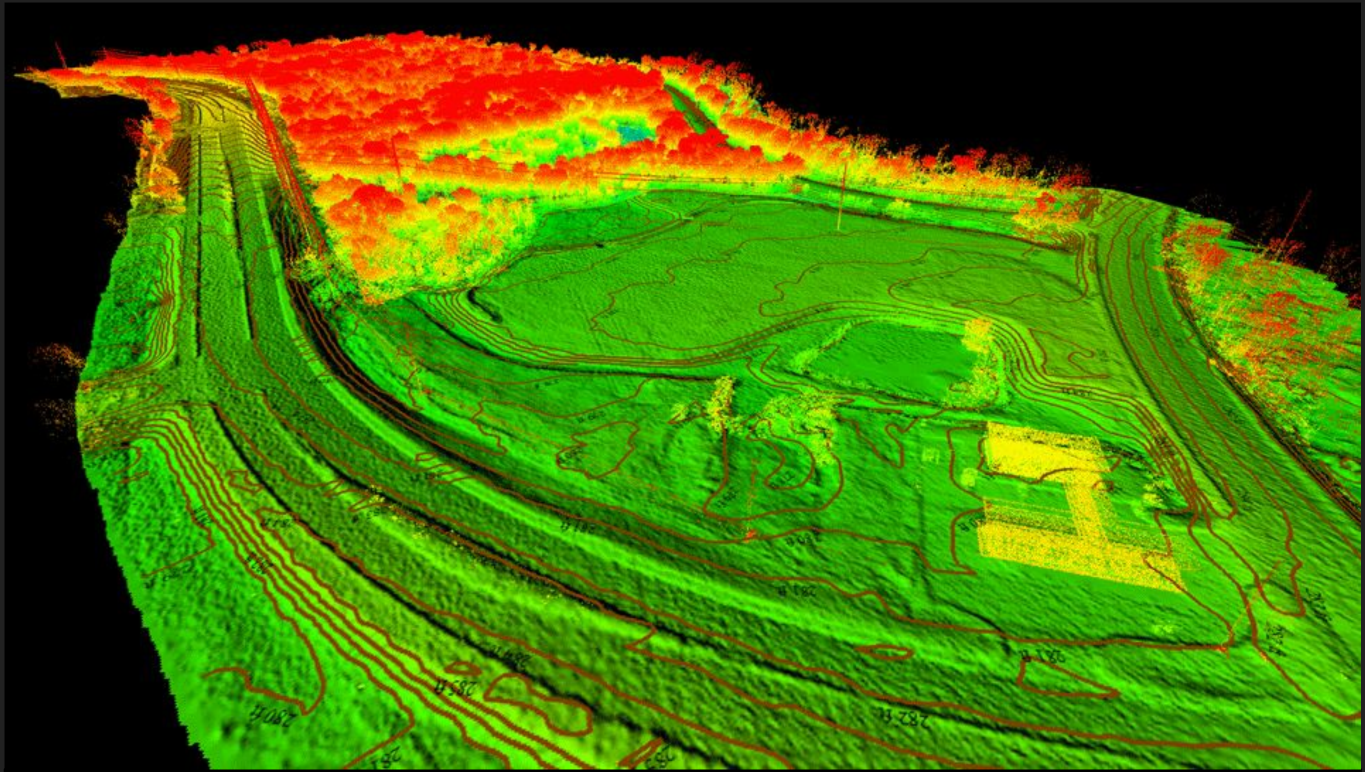
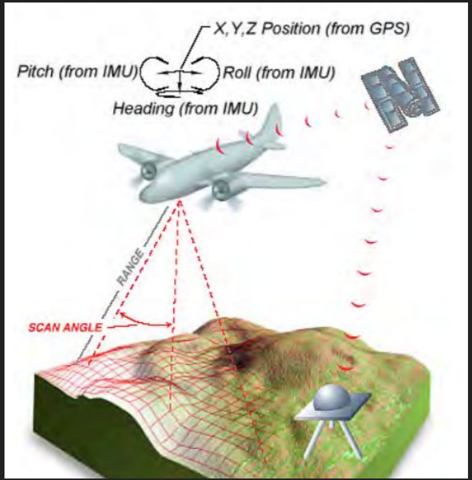
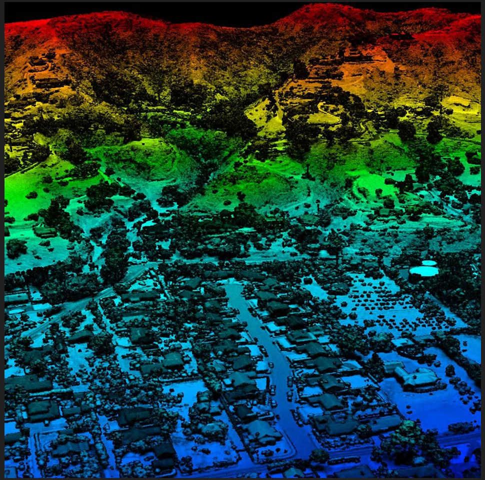


Fig 4: High-density LiDAR data used to create a 3D topographical maps in a variety of file formats

The Problem - How it Works

- Measure distance based on sending & receiving light emissions





The Problem - LiDAR Systems in Airplanes

- Airborne Topographic LiDAR takes place in two phases
    - **Phase 1:** Scanning
        - Different Scan Mechanisms lead to different scan pattern on the ground
        - Patterns include (oscillating mirror, Palmer scan, fiber scanner, rotating polygon
    - **Phase 2:** Post Scan processing

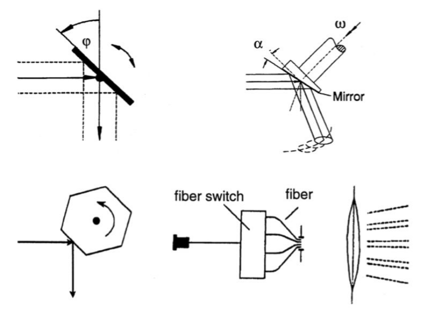
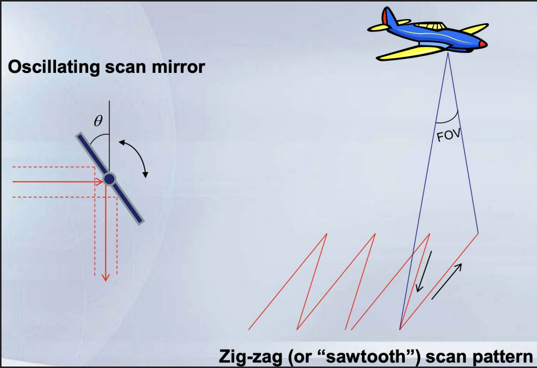
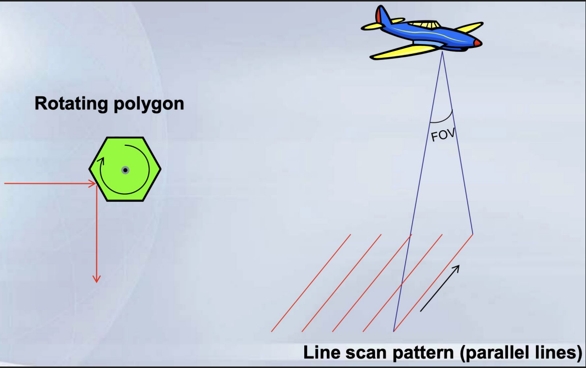


Fig. 6. Scanning mechanisms (from top left, clockwise): oscillating mirror, Palmer scan, fiber scanner, rotating polygon.





The Problem - LiDAR Systems in Airplanes

Components:

- Inertial Measurement Unit (IMU)
- Position and Orientation System (POS)
- Laser power supply
- Laser
- Scan
- Optics
- Receiver

The Problem - The Lasers Used

- Lasers
  - Pulse Laser
  - Continuous Wave Laser (CW)

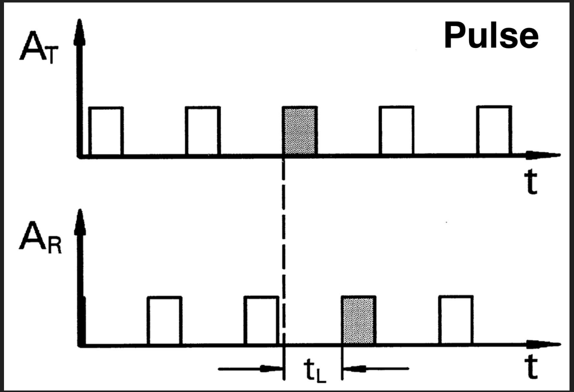
Pulse:

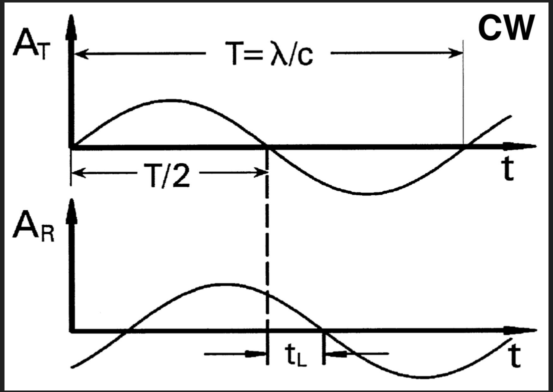
Range: $R = \frac{1}{2} c \cdot t_L$

Range Resolution: $\Delta R = \frac{1}{2} c \cdot \Delta t_L$

Max. Range: $R_{max} = \frac{1}{2} c \cdot t_{L\,max}$

Range Accuracy: $\sigma_R \sim \frac{c}{2} t_{rise} \cdot \frac{1}{\sqrt{S/N}}$





Sinusoidal CW-Modulation:

Travelling Time by Phase Difference: $\left.\begin{matrix} T \triangleq 2\pi \\ t_L \triangleq \Phi \end{matrix}\right\} \Rightarrow t_L = \frac{\Phi}{2\pi} \cdot T$

Range: $R = \frac{1}{2} c \cdot \frac{\Phi}{2\pi} \cdot T = \frac{\lambda}{4\pi} \cdot \Phi$

Max. Unamb. Range: $R_{max} = \frac{\lambda_{long}}{2}$

Range Resolution: $\Delta R = \frac{\lambda_{short}}{4\pi} \cdot \Delta\Phi$

Range Accuracy: $\sigma_R \sim \frac{\lambda_{short}}{4\pi} \cdot \frac{1}{\sqrt{S/N}}$

The Importance

The Importance - Flood Insurance Rate Maps

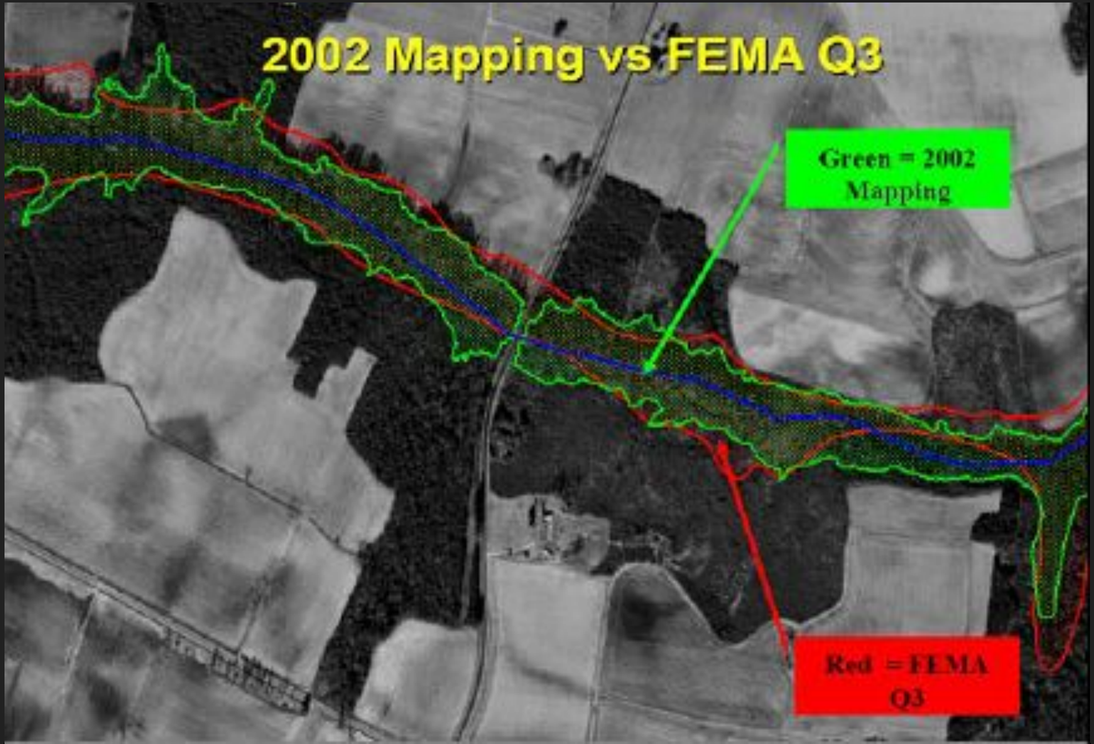
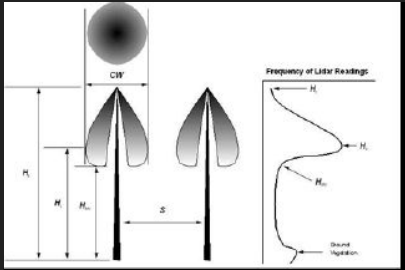


Fig 5: Lidar-derived floodplain used to delineate flood boundaries contrasted with previously mapped Federal Emergency Management Agency (FEMA) flood zone boundaries

The Importance - Forest and Tree Studies



H = height
CW = crown width
S = spacing

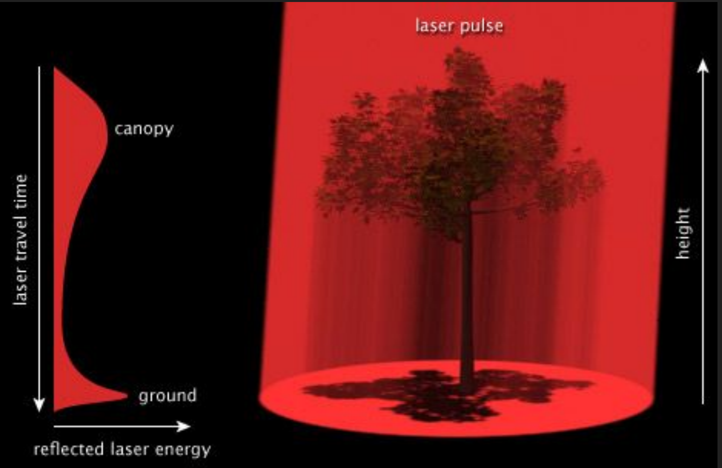


Fig 6: Tree canopy information

The Importance - Coastal Change Mapping

Fig 7: Coastal studies undertaken by the U.S. Geological Survey on Dauphin Island before and following Hurricane Katrina

The Importance - Additional

- Mapping of corridors, e.g., roads, railway tracks, pipelines, waterway landscapes
- Mapping of electrical transmission lines and towers including ground/tree clearance
- DTM and DSM generation in urban areas, automated building extraction, generation of 3-D models for city planning
- Measurement of snow- and ice-covered areas, including glacier monitoring
- Measurement of wetlands
- Derivation of vegetation parameters, e.g., tree height, crown diameter, tree density, biomass estimation, determination of forest borders
- Hydrographic surveys in depths up to 70 m.

The Challenges

The Challenges - Reflectivity

Material	Reflectivity (%)
Dimension lumber (pine, clean, dry)	94
Snow	80–90
White masonry	85
Limestone, clay	Up to 75
Deciduous trees	Typ. 60
Coniferous trees	Typ. 30
Carbonate sand (dry)	57
Carbonate sand (wet)	41
Beach sands, bare areas in dessert	Typ. 50
Rough wood pallet (clean)	25
Concrete, smooth	24
Asphalt with pebbles	17
Lava	8
Black neoprene (synthetic rubber)	5

Tbl 1: Typical reflectivity of various diffuse reflecting materials for 900 nm wavelength

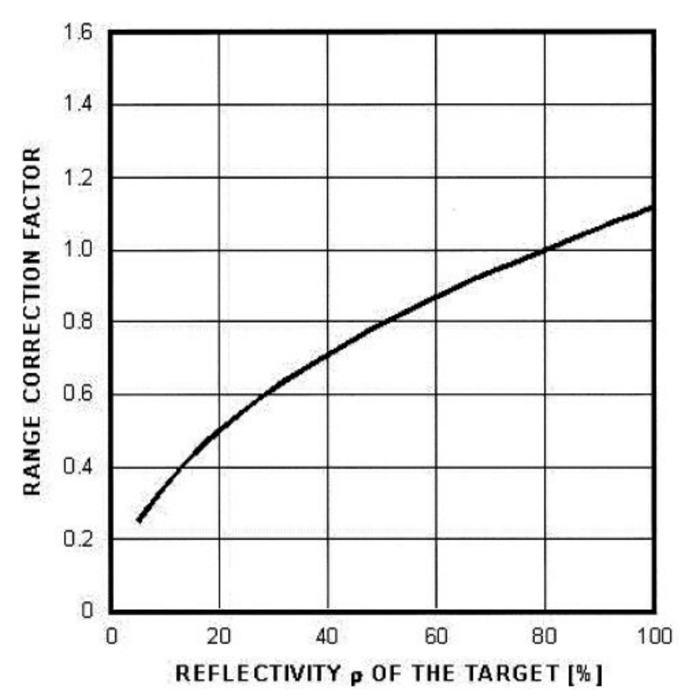


Fig 8: Correction factor for maximum laser range, depending on target reflectivity

The Challenges - Spot Size

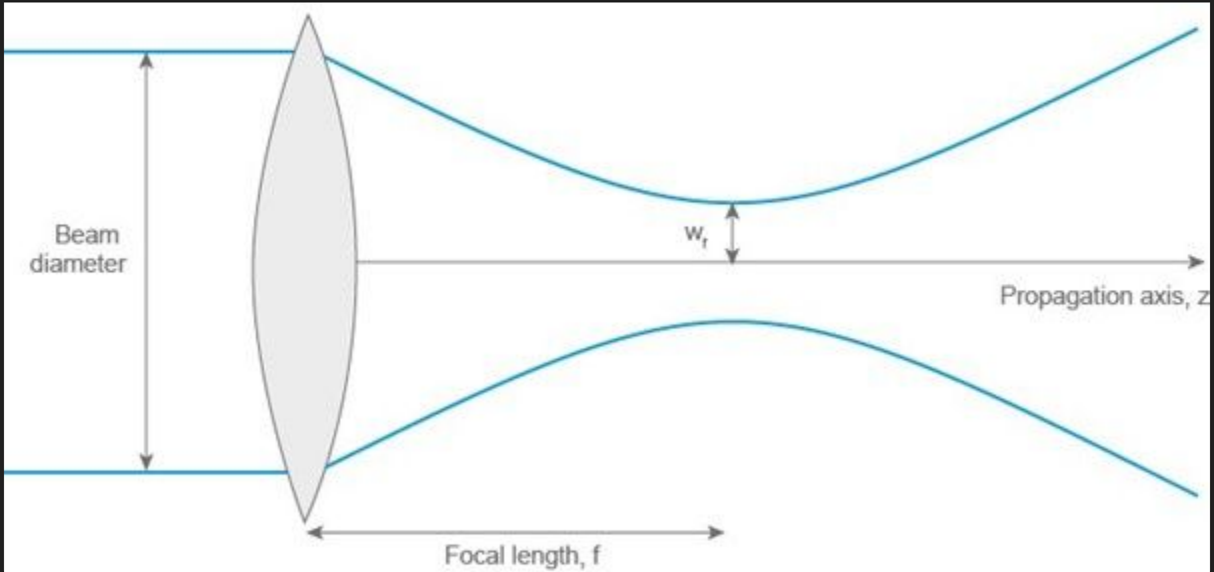


Fig 9: Spot size of a laser beam

The Challenges - Frequency

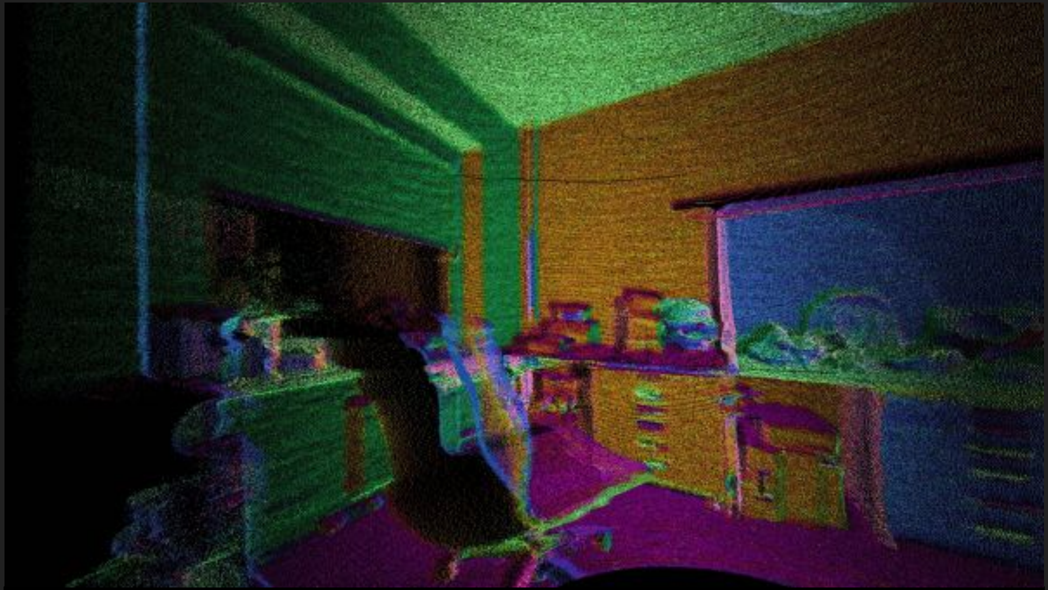
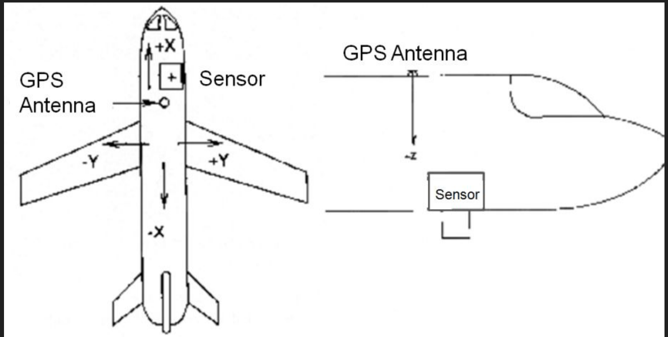


Fig 10: LiDAR used to image a room

The validation method

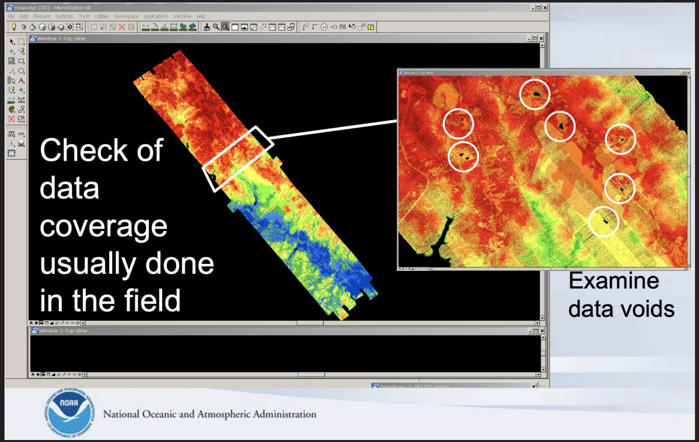
What is the validation method?

- Calibration
  - At the time of the paper, multiple ways to calibrate and not officially standardized
  - Recorded along with POS Data & Ranges for post scan processing
  - Includes mounting parameters of the laser
  - 2 types of calibration
    - System calibration
      - Factory Calibration (Manufacturer provides some calibration method)
      - In-Situ calibration (Performed by flying over calibration site that has been accurately surveyed using GPS)
    - Data Calibration (Rigorous data adjustment)



What is the validation method?

- Processing Chain
  - Adjustment to ranges made during multiple stages after scanning
  - Includes both mathematical model adjustment and human quality check
  - Can still result in holes in data



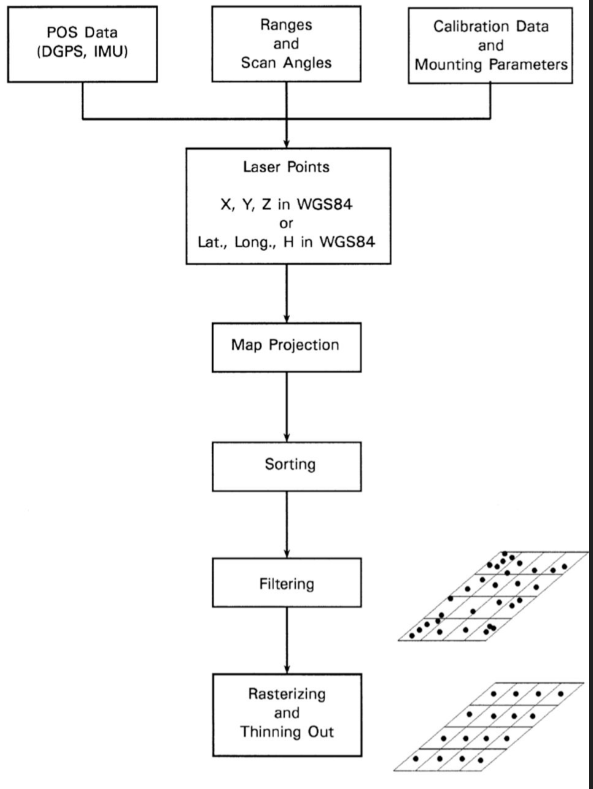
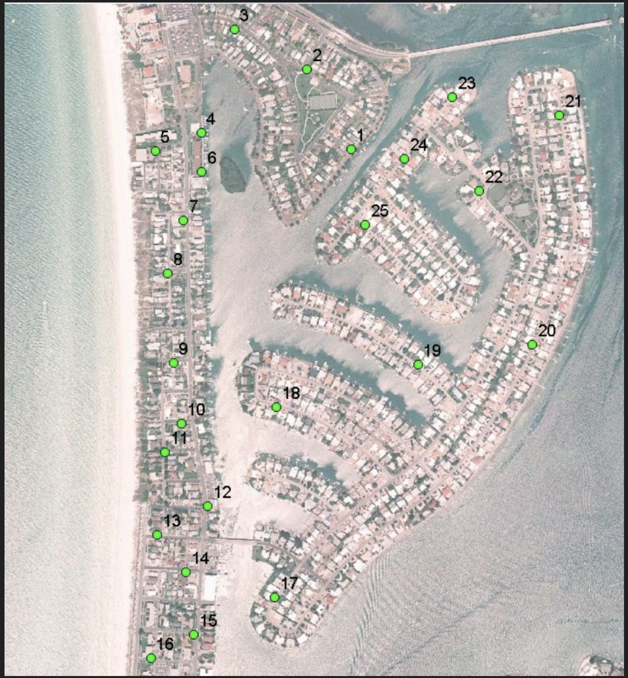


Fig. 12. Typical processing steps for laser scanner data.

What is the validation method?



- Accuracy
  - Now multiple industry and government host LIDAR data
  - Example:
    - National Standard for Spatial Data Accuracy (NSSDA) w/ American Society for Photogrammetry and Remote Sensing (ASPRS)
      - Require vertical accuracy with confidence of 95% or higher
      - Require a minimum of 20 checkpoints (30 preferred) for each type of land mass

$$Lidar\ Horizontal\ Error\left(RMSE_r\right) = \sqrt{\left(GNSS\ positional\ error\right)^2 + \left(\frac{\tan(IMU\ error)}{0.55894170}\ x\ flying\ altitude\right)^2}$$

ASPRS Lidar Horizontal Error Formula

The novel contributions

What are the novel contributions?

- The paper gave a proper introduction and overview of lidar for topology and geographical use
- Seminal paper with >1500 citations
- Define the pipeline structure to create lidar systems

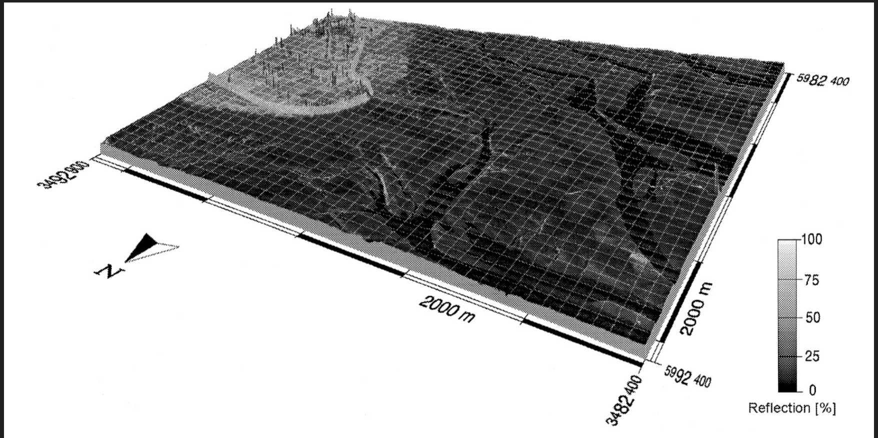


Fig. 13. Intensity data overlaid on DSM (heights multiplied by 50), both produced using the ScarLARS laser scanner. The image shows the shore and shallow of Friedrichskoog, Germany.

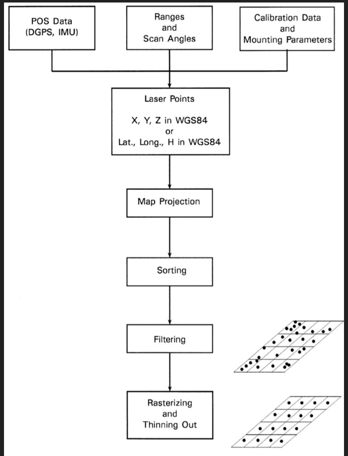
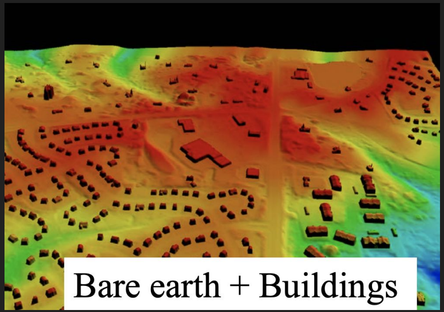


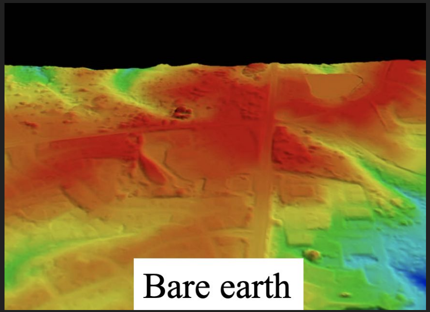
Fig. 12. Typical processing steps for laser scanner data.

The limitations of the related work

What are the limitations of the related work?

- Currently have to do all processing post scanning
- Post processing is slow compared to scanning at the time of the paper
- Some software for processing is proprietary leading to irregular processing among different people
- Improve filter/removal and classification/separation of object methods





and ARC/Info. Currently, the processing time for a DTM computed from laser scanner data is typically three times the data acquisition time.

Questions
Comments
Concerns

Sources

- Wehr, A. and U. Lohr, 1999. Airborne laser scanning—an introduction and overview
- Christopher Parrish. Lidar and Height Mod Workshop link:https://www.ngs.noaa.gov/corbin/class_description/Parrish_Lidar_and_Height_Mod_Presentation.pdf
- Carter, J., Schmid, K., Waters, K., Betzhold, L., Hadley, B., Mataosky, R., & Halleran, J. (2012). An introduction to LiDAR technology, data, and applications. NOAA Coastal Services Center, 2. link:https://coast.noaa.gov/data/digitalcoast/pdf/lidar-101.pdf
- Young, J. (2011). LiDAR for Dummies. Hoboken. link:https://ibis.geog.ubc.ca/courses/geog373/lectures/Handouts/LiDARforDummies.pdf
- Lidar Wikipedia. link:https://en.wikipedia.org/wiki/Lidar