REMOTE SENSING 101 & LIDAR
MODERNIZING 4FRI IMPLEMENTATION - PROGRESS
REMOTE SENSING 101

- Lidar is an active sensor
- Pulse emitted with known direction, contacts something and reflected back to device
- Device recognizes these time-stamped, reflected photons
- Calculates the time between emission and return
- Produces a “cloud” of points

REMOTE SENSING, LIDAR, UAS
TYPES OF LIDAR

li·dar
/ˈlɪdər/
noun
a detection system which works on the principle of radar, but uses light from a laser.

A. Airborne lidar (ALS)
- onboard GPS and IMU constrain position and orientation of aircraft
- distance between scanner and ground return determined from delay between outgoing pulse and reflected return

B. Terrestrial lidar (MLS)
- lines show track of scan across ground
- circles show actual ground return footprints

C. Structure from Motion (SfM*)
- motion of camera provides depth information
- scene structure refers to both camera positions and orientations and the topography
- features matched in multiple photographs

Adapted from: Johnson et al. 2014
NOT ALL LIDAR IS CREATED EQUAL

28.26 returns/m²
0.19 m pt spacing
Quantum Spatial
2019

7.84 returns/m²
0.36 m pt spacing
Sanborn Mapping
2013

2.49 returns/m²
0.63 m pt spacing
Who knows?
2009

QL0*:
Accuracy: RSME, 5 cm
Pt density: ≥8 pulses/m²

QL1:
Accuracy: RSME, 10 cm
Pt density: 8 pulses/m²

QL2:
Accuracy: RSME, 10 cm
Pt density: 2 pulses/m²

*Heidemann and Karl 2018

0.2 ha near A1 Mtn, Flagstaff, AZ
HOW IS IT USED?

- Classify and utilize the returns
- Create a digital surface model (DSM) from the first returns
- Or flip the point cloud and create a digital terrain model (DTM) from the ground returns
- Subtracting the DTM from (non-ground) returns to get height above ground level (i.e. a canopy height model or CHM)
- 1st-Order Products or Derivatives
MORE ON USING LIDAR

Classification
- Building
- Created, never classified
- Ground
- High Vegetation
- Low Point (Noise)
- Unclassified

Intensity

REMOTE SENSING, LIDAR, UAS
TWO MAIN APPROACHES IN FORESTRY

Area-based  →  Individual-based
AREA-BASED APPROACH

- Extract lidar data associated with sample locations
- Quantify lidar metrics
- Process plot data and develop relationships between lidar metrics and plot metrics
- Computer lidar metrics on a grid (i.e., raster)
- 2nd-Order Products or Derivatives
INDIVIDUAL-BASED APPROACH

• Normalize the point cloud
• Use algorithm to classify points into unique tree id’s
• Process points to quantify individual tree attributes
• Computer tree metrics for all trees (i.e., vector)
• ??-Order Products or Derivatives
LIDAR AVAILABILITY, STRATEGY, AND TRAINING

MODERNIZING 4FRI IMPLEMENTATION - PROGRESS
LIDAR COVERAGE FOR 4FRI
GTAC Image Server

Four standard lidar derivatives hosted on the Image Server

https://image-services-gtac.fs.usda.gov/arcgis
Regional Lidar Strategy

SW Regional Restoration Committee requested a more comprehensive strategy for future investments in lidar

Three phase process

- Phase 1 – Develop maps and tables to document current and planned coverage by acres and type
- Phase 2 – Gather and document how lidar information is being used in the Region
- Phase 3 – Restoration Steering Committee to review info from Phase 1 & 2 and develop comprehensive strategy for budget discussions
Regional Lidar Strategy Components

- Establishment of Regional Lidar Technical Group (RLTG)
  - Tom Mellin (Geospatial), Jack Triepke (EAP), Ryan Heaslip (Forestry), Will Reed (Heritage), Mark Christiano (GIS-Kaibab)

- Vetting of Lidar proposals

- Business case/Prioritization of acquisition areas.

- Awareness and Training
Geospatial Training

- Overview of Lidar Technology and FUSION Software
- Lidar Point Cloud Visualization
- Lidar Derivatives: Processing and Analysis
USES OF LIDAR FOR OPERABILITY, ACCESSIBILITY, AND FEASIBILITY

MODERNIZING 4FRI IMPLEMENTATION - PROGRESS
USES OF LIDAR FOR OPERABILITY, ACCESSIBILITY, AND FEASIBILITY

10m Resolution Digital Elevation Model

1m Resolution Digital Elevation Model
USES OF LIDAR FOR OPERABILITY, ACCESSIBILITY, AND FEASIBILITY

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10m Resolution Digital Elevation Model

1m Resolution Digital Elevation Model
USES OF LIDAR FOR OPERABILITY, ACCESSIBILITY, AND FEASIBILITY

Existing Roads (Levels 2 & 1)

Additional Linear Features Identified from Lidar Digital Elevation Model
Operability – Santa Fe National Forest: Temp Road Example
Operability – Santa Fe National Forest: Operability Example
Operability – Bill Williams Mtn. Example
USES OF LIDAR FOR OPERABILITY, ACCESSIBILITY, AND FEASIBILITY

NAIP Imagery

1m Resolution Canopy Height Model
USES OF LIDAR FOR OPERABILITY, ACCESSIBILITY, AND FEASIBILITY

1m Mean Canopy Height for 30m x 30m Neighborhood

1m Resolution Canopy Height Model
CREATE TILE PACKAGES FROM IMAGE SERVICES

Scripts

Forest Service Image Server:
https://image-services-gtac.fs.usda.gov/arcgis/services
CREATE TILE PACKAGES FROM LIDAR MOSAIC DATASETS

Scripts

Forest Service Image Server:
https://image-services-gtac.fs.usda.gov/arcgis/services
CREATE TILE PACKAGES – FOR YOUR AREA OF INTEREST

Scripts

Area of Interest
PRELIMINARY LESSONS INTEGRATING LIDAR WITH TWO-PHASED SAMPLING
MODERNIZING 4FRI IMPLEMENTATION - PROGRESS
WHAT DOES THIS WORK RESPOND TO?

As managers are asked to determine stand characteristics and obtain volume estimates to appraise and prepare timber sales for larger and larger landscapes, remote sensing and especially lidar, have to become integral components of the Forest Service’s work pipeline.
WHAT WAS DONE?

Utilizing existing timber sales that occurred within lidar acquisition footprints, associated cruise plots were located using sub-meter gps and analyses is currently underway to assess the potential of lidar to increase the efficiency of existing cruising methods using a two-phase sample approach.

Two-phase sampling design is a sampling design where the sample selection is performed in two phases

- first phase the auxiliary variable \( x \) (lidar-derived estimates of volume to be removed)
- second phase the study variable \( y \) (cruise-derived estimates of volume to be removed)
WHAT WAS THE PROCESS?

Identified potential timber sales
Collect existing/new fixed area plot data to be used in conjunction with lidar data
Determine a way to estimate volume removed (cruised) using lidar in the first phase.
Examine the reduction in plots required to achieve desires sample error in second phase.

REMOTE SENSING, LIDAR, UAS
WHAT WORKED

Well, it’s ongoing....

but I can offer some preliminary lessons learned/observations that will be key for implementation.

I’ll come back to this at the end!
KEY POINTS FOR IMPLEMENTATION

High accuracy (sub-meter) GPS locations are imperative.
Sampling based on frequency will likely need to shift to list or gradient sampling when using remote sensing.
KEY POINTS FOR IMPLEMENTATION

With more and more prescriptions moving towards DxP, remote sensing’s ability to estimate “volume removed” becomes increasingly difficult.

Remote sensing is best suited for estimating gross volume/biomass.

Solutions “simulating” silvicultural prescriptions and harvest activities may be necessary to obtain estimates.

Development, training, and support will be essential.
RECOMMENDATIONS

• Increase awareness/availability of high-accuracy GPS.

• Alterations in sample selection (list sampling) and sample design (geographically balanced sample) needed.

• Novel ways to model attributes of interest (e.g., stand characteristics or yield estimates following DxP) are needed.
RECOMMENDATION

• Programming a DxP is... hard.
• 2PRS stemmed from a 3P approach (3PRS) utilizing aerial photo interpretation and maybe the need suggests an approach with new (old?) tools.
• First Phase calls of Relative Volume (removed) Index (RVI) in the office.
• List sampled plots visited for second phase estimates.
USING LIDAR PRODUCTS TO ESTIMATE VOLUME

MODERNIZING 4FRI IMPLEMENTATION - PROGRESS
WHAT DOES THIS WORK RESPOND TO?

Using remotely sensed data products to estimate field based derivatives

Efficiencies

Industry Support
WHAT WAS DONE?

Approach…

- Estimate Gross Volume with LiDAR
- Compare to Volume Removed estimates from cruising
- Develop Ratio of:
  
  \[
  \frac{\text{Predicted Total Existing Volume}}{\text{Estimated Volume Removed}}
  \]
WHERE DID WE DO IT?

**Coconino**
- Johnneys
- Chimney Springs

**Kaibab**
- Moonset
- Junction
- Clover
- Dude
- Zorro
WHERE DID WE DO IT?

**Coconino**
- Johnneys
- Chimney Springs

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- Moonset
- Junction
- Clover
- Dude
- Zorro
WHAT WAS DONE?

Gross Volume Estimation - LiDAR 2nd Order products

1. Area based volume predictions
2. Individual tree list volume predictions
WHAT WAS THE PROCESS?

Estimate existing gross volume

1 Area-Based Approach

Plot data

and....

1st order products

Random Forest models

Raster of predicted volume

Donager and Sanchez Meador 2019
WHAT WAS THE PROCESS?

Estimate existing gross volume

2 Individual Tree Segmentation Approach

LiDAR point cloud segment individual trees

Predict diameter and volume for each tree

Summarize tree list by unit and strata
WHAT WAS THE PROCESS?

Estimate existing gross volume

2 Individual Tree Segmentation Approach

- LiDAR point cloud segment individual trees
- Predict diameter and volume for each tree
- Summarize tree list by unit and strata
WHAT WORKED?

...and what didn’t?
WHAT WORKED?

- 64% variance explained
- 27% error in estimates of validation plot data
- Very little bias in estimates

Model Results

Total CUFT Volume >5"

LIDAR CRUISING
WHAT DIDN’T?

• 36% variance explained

• 82% error in estimates of validation plot data

• Underprediction in estimates where higher volume exists
## WHAT WORKED?

**Ratio**

### Estimated Volume Removed

<table>
<thead>
<tr>
<th>Project Area</th>
<th>Area-based Total Volume Ratio</th>
<th>ITS Total Volume Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coconino</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Johnneys</td>
<td>0.32</td>
<td>0.48</td>
</tr>
<tr>
<td>Chim. Springs</td>
<td>0.39</td>
<td>0.58</td>
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<tr>
<td><strong>Kaibab</strong></td>
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<td></td>
</tr>
<tr>
<td>Clover</td>
<td>0.48</td>
<td>0.56</td>
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<tr>
<td>Zorro</td>
<td>0.62</td>
<td>0.67</td>
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<tr>
<td>Dude</td>
<td>0.56</td>
<td>0.64</td>
</tr>
<tr>
<td>Junction</td>
<td>0.42</td>
<td>0.58</td>
</tr>
<tr>
<td>Moonset</td>
<td>0.48</td>
<td>0.57</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>0.51</td>
<td>0.58</td>
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<tr>
<td><strong>Stand. Dev.</strong></td>
<td>0.10</td>
<td>0.06</td>
</tr>
</tbody>
</table>
WHAT WORKED?

Volume Estimates
WHAT WORKED?

Volume Estimates

- Total CUFT Volume >5":
  - Green: Tree
  - Red: Water
  - Orange: Residue
  - Purple: Inv.

- Estimated Volume Removed (CuFt):

  - AB_Estimate
  - Cruise_Estimate
  - ITS_Estimate

- Model Type:
  - AB Estimate
  - Cruise Estimate
  - ITS Estimate
KEY POINTS FOR IMPLEMENTATION

WORK IN PROGRESS!!!!

Improved training dataset
- Stratified plot network to improve model
- Measurements of both total existing volume and volume removed based on Rx

Developing products requires spatial and modeling analysis skills
RECOMMENDATIONS

WORK IN PROGRESS!!!!
RECOMMENDATIONS

WORK IN PROGRESS!!!!

ECHO WHAT ANDREW SAID!!!!!
RECOMMENDATIONS

WORK IN PROGRESS!!!!

In addition to a potential cruising toolset...

Project implementation process

Economic/Operational feasibility

Landscape scale understanding/planning
THANK YOU

<table>
<thead>
<tr>
<th>Presenter</th>
<th>E-mail</th>
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</thead>
<tbody>
<tr>
<td>Andrew Sanchez Meador</td>
<td><a href="mailto:andrew.sanchezmeador@nau.edu">andrew.sanchezmeador@nau.edu</a></td>
</tr>
<tr>
<td>Tom Mellin</td>
<td><a href="mailto:thomas.mellin@usda.gov">thomas.mellin@usda.gov</a></td>
</tr>
<tr>
<td>Mark Nigrelli</td>
<td><a href="mailto:mark.nigrelli@usda.gov">mark.nigrelli@usda.gov</a></td>
</tr>
<tr>
<td>Travis Woolley</td>
<td><a href="mailto:twoolley@tnc.org">twoolley@tnc.org</a></td>
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