How a Lidar instrument works (Recap)

- Transmits laser signals and measures the reflected light to create 3D point clouds.
- Wavelength typically in the near infrared (~1550nm) or green (532nm) spectrum
TLS Instrument and Survey Parameters

- Precision/Accuracy
- Spot size (range, divergence)
- Spot spacing (range, angular resolution)
- Spot density (range, angle, number of setups)
- Angle of incidence (spot shape, intensity, range)
- Edge effects
- Registration
- Targets
- First return, last return, “other”
- Shadows, Field of View
- Area of Interest
Accuracy vs. Precision

- Low accuracy, Low precision
- Low accuracy, High precision
- High accuracy, Low precision
- High accuracy, High precision
Beam Divergence

$Df = (\text{Divergence} \times d) + D_i$

@100m,
$Df = 36\text{mm}$

@500m,
$Df = 180\text{mm}$

@1000m,
$Df = 360\text{mm}$!
Angular Step

Spacing = d(m) * TAN(step)
Angular Step

Rule of thumb: scan at least 1/10\textsuperscript{th} of the “wavelength” of the object you wish to image.
Shot Spacing / Sample Density

- Shot spacing varies as a function of range to target.
- Choose angular scan resolution to optimize sample density.
**Scan Positions**

Choose scan positions to minimize occluded (shadowed or hidden) geometries.
Targets

- Reflective objects that serve as reference points for scans.
- Same targets must be common between scan positions.
- Use at least 5 reference targets to register scan positions (the more the better).
- Different shapes and colors serve different functions.

(images not to scale)
TLS Instrument and Survey Parameters

Riegl VZ400 – Max. measurement range as function of target material

The graph shows the maximum measurement range in meters as a function of target reflectivity. The target materials are categorized into different reflectivity levels, each represented by a line with a distinct color. The reflectivity levels are:

- Standard clear atmosphere: visibility 23 km
- Clear atmosphere: visibility 15 km
- Light haze: visibility 8 km
- Medium haze: visibility 5 km

The graph also indicates different modes:

- Long Range Mode: PRR = 100 kHz
- High Speed Mode: PRR = 300 kHz

The target materials are:
- Wet ice, black tar paper
- Dry snow
- Coniferous trees
- Dry asphalt
- Deciduous trees
- Terra cotta
- Construction concrete
- Cliffs, sand, masonry
- White plaster work, limestone
- White marble
• Precision/Accuracy
• Spot size (range, divergence)
• Spot spacing (range, angular resolution)
• Spot density (range, angle, number of setups)
• Angle of incidence (spot shape, intensity, range)
• Edge effects
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• Targets
• First return, last return, “other”
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• Area of Interest
### Technical Data 3D Scanner Hardware RIEGL VZ®-1000

#### Laser Product Classification

Class 1 Laser Product according to IEC60825-1:2007

The following clause applies for instruments delivered into the United States: Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated June 24, 2007.

#### Range Performance

<table>
<thead>
<tr>
<th>Laser PRR (Peak)</th>
<th>70 kHz</th>
<th>100 kHz</th>
<th>150 kHz</th>
<th>300 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Measurement Rate</td>
<td>29 000 meas./sec.</td>
<td>42 000 meas./sec.</td>
<td>62 000 meas./sec.</td>
<td>122 000 meas./sec.</td>
</tr>
<tr>
<td>Max. Measurement Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>for natural targets ρ ≥ 90%</td>
<td>1400 m</td>
<td>1200 m</td>
<td>950 m</td>
<td>450 m</td>
</tr>
<tr>
<td>for natural targets ρ ≥ 20%</td>
<td>700 m</td>
<td>600 m</td>
<td>500 m</td>
<td>350 m</td>
</tr>
<tr>
<td>Max. Number of Targets per Pulse</td>
<td>practically unlimited</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>8 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>5 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum Range</td>
<td>2.5 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laser Wavelength</td>
<td>near infrared</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Divergence</td>
<td>0.3 mrad</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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1) with online waveform processing
2) rounded values, selectable by measurement program
3) typical values for average conditions. Maximum range is specified for flat targets with size in excess of the laser beam diameter, perpendicular angle of incidence, and for atmospheric visibility of 23 km. In bright sunlight, the max. range is shorter than under an overcast sky.
4) limited by PRR
5) details on request
6) Accuracy is the degree of conformity of a measured quantity to its actual (true) value.
7) Precision, also called reproducibility or repeatability, is the degree to which further measurements show the same result.
8) One sigma @ 100 m range under RIEGL test conditions.
9) Measured at the 1/e² points. 0.3 mrad corresponds to an increase of 30 mm of beam diameter per 100 m distance.
Project Planning

• Choose instrument based on capabilities and science/data goals.
• Schedule based on instrument availability, science requirements, environmental factors.
• Use Google Earth, field site photos, etc. to establish preliminary locations for scan positions, control targets, registration targets, etc.

Instrument calibration & data collection

Post-processing & Analysis

• Make a copy of the data collected in the field. Keep the original project(s) in a safe place. Post process using the copy of the project.

Metadata

• Project summary document.
• GPS data (raw files, rinex files, antenna heights, log sheets, etc.).
• Field photos.
• Google Earth files, etc.
Before heading out into the field

- GPS network – identify base stations, benchmarks and **make sure they are operational!**

- Understand field site, anticipate challenges you may encounter (complex landscape, is power available in evenings, etc.)

- Give equipment a test run.
Checklist:

- Scanner
- Power supply
- Laptop
- Scanner tripod
- Reflector tripods
- Flat and Cylindrical Reflectors
- GPS receivers
- Safety gear
- Permit

Up to 300 lbs!!
Will this fit in your vehicle?

Who will carry it?

Basic Field Kit
At the field site

- Take a walk around the field site before setting anything up. Identify scan positions, target positions and your GPS base station.

- Set up targets and start GPS data collection. 1-2 hours.

Only now are you ready to start scanning!

- Scan Position 1
  - 360-deg Panorama scan + Image acquisition if desired.
  - Target finescan
  - Area of interest finescan

- Scan Position 2 and beyond
  - Same as Scan Position 1 + registration to previous scans + quality check.
Standard tie point workflow

- Reminders – use at least 5 targets.
  - Every scan position sees at least 5 targets
  - Every target is seen by at least 2 scan positions
- The more targets common to all scan positions, the better
TLS Survey Workflow

Big Spring Run, Lancaster County, PA

800 m

200 m
Targets set up
• Constellation of 31 satellites which each house an atomic clock.
• Precise time information is sent to a receiver on earth.
• A minimum of 4 satellites in sky view is needed to obtain a coordinate.
Uses known reference points (base stations) on the Earth to provide corrections for unknown points.

- Advantage is cm to sub-cm precision!
- Base station and unknown points must share same occupation time
- Base stations and unknown points must “see” same errors (same sky view). Practical limit is 100km.
- Vertical precision will always be ~2x less precise than horizontal precision.
- **SOCS** – **S**canner **O**wn **C**oordinate **S**ystem
  - Each scan position has origin at scanner location

- **PRCS** – **P**roject **C**oordinate **S**ystem
  - Local coordinate system for entire project

- **GLCS** – **G**lobal **C**oordinate **S**ystem
  - ECEF, UTM, State Plane, etc.
Earth Centered, Earth Fixed (ECEF)

- Origin = center of mass of the Earth.
- Three right-handed orthogonal axis X, Y, Z. Units = meters.
- The Z axis = Earth’s rotation axis.
- The (X,Z) plane contains the Earth’s rotation axis and the prime meridian.
- The (X,Y) plane in equatorial plane.

- Preferred by geodesy community
- Not GIS friendly! Requires transformations into 2D cartesian (e.g., UTM).
- Application of data matters
- Con: \( Z \neq \text{height} \)
After data collection is complete…

- The bulk of the work begins…not a joke! Data processing will be the most time consuming (and hardest) portion of the project.
  - Colorize data from photos
  - Filter/clean points
  - Re-register all scans to get best fit (especially important for larger field areas)
  - Georeference point cloud(s)

- Archive your raw data set/project ASAP – multiple copies.
- Archive final project and create metadata.
- Create higher order datasets (Chris will cover these).
- Export data to appropriate format.
Sources of Error

- Instrument precision and accuracy
  - Increases with range, different for each point

- Scaling errors

- Registration errors
  - Scan-to-scan registration
  - Global registration

- GPS solution errors
  - Depends on occupation times, space weather, etc.

- Operator error…
  - Noise, false returns, phantom points, etc.
Instrument precision and accuracy

- Increases with range
- Manufacturers typically only provide #s for 1 range, no info on trend
Registration errors

- Scan-to-scan registration – usually < 1cm
- Global registration – can range 3mm - 3-5 cm
Longer surveys are generally more accurate
GPS solution errors

- Depends on type of survey, baseline lengths, environmental factors (solar flares, multipath), instrument error (clock drift)

<table>
<thead>
<tr>
<th>Survey type</th>
<th>Occupation Time</th>
<th>Error – horizontal (vertical = 2x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>2 hours – days</td>
<td>0.5 – 1 cm</td>
</tr>
<tr>
<td>Fast static</td>
<td>20 minutes – 2 hours</td>
<td>1 – 3 cm</td>
</tr>
<tr>
<td>Post-processing Kinematic</td>
<td>20 minutes – 2 hours</td>
<td>2 – 5 cm</td>
</tr>
<tr>
<td>Real-time kinematic</td>
<td>Seconds – hours</td>
<td>2cm – 5cm (range dependent)</td>
</tr>
</tbody>
</table>
Sources of Error

- Scaling errors
  - Atmospheric conditions can vary across a field site – long range scanners can’t correct for this.
  - Effect is generally minimal – mm in range calculation over 100’s of meters.
What does that leave us with?

<table>
<thead>
<tr>
<th>Error type</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument precision &amp; accuracy</td>
<td>3.5 mm - ___ cm</td>
</tr>
<tr>
<td>Registration/Alignment</td>
<td>0.3 – 3 cm</td>
</tr>
<tr>
<td>GPS solutions</td>
<td>0.2 – 5 cm</td>
</tr>
<tr>
<td>Scaling (atmospheric)</td>
<td>0.1 – 2 mm</td>
</tr>
<tr>
<td>Operator error</td>
<td>?</td>
</tr>
</tbody>
</table>

Best case scenario: ~ 1 cm
Worst case scenario: ~10-20 cm … or more
All of the information you can think of!

- Project objectives
- Atmospheric conditions
- GPS observations
- Who, what, when, where
- Someone tripped over the tripod, cow knocked over target…
- Target types and geometry
- Coordinate system
- Error reporting
- Etc, etc, etc!
Exports
UNAVCO standard deliverable: merged, aligned, georeferenced point cloud in ECEF in LAS format

UNAVCO TLS Data Archive
- [https://tls.unavco.org](https://tls.unavco.org)
- All project materials archived
- All materials available to public free of charge
- User account required to download – please sign up!
Data volume can be a problem:

• Technology outpaces most software for data processing & management.

• Just because you can, doesn’t mean you should

• Science application should define data collection.
## Understanding coordinate systems - GPS

### Table: Point ID Coordinates

<table>
<thead>
<tr>
<th>Point ID</th>
<th>Northing</th>
<th>Easting</th>
<th>Elevation</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Ellip. Height</th>
<th>X (ECEF)</th>
<th>Y (ECEF)</th>
<th>Z (ECEF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF - UTD1</td>
<td>1370462.012</td>
<td>577608.894</td>
<td>94.429</td>
<td>-77.72225</td>
<td>162.27091</td>
<td>40.108</td>
<td>-1296058.157</td>
<td>414350.03</td>
<td>-6210455.012</td>
</tr>
<tr>
<td>BF - UTD2</td>
<td>1370484.93</td>
<td>577645.326</td>
<td>78.213</td>
<td>-77.72203</td>
<td>162.27239</td>
<td>23.892</td>
<td>-1296088.759</td>
<td>414322.955</td>
<td>-6210433.867</td>
</tr>
<tr>
<td>BF - UTD3</td>
<td>1370451.914</td>
<td>577632.2</td>
<td>92.861</td>
<td>-77.72233</td>
<td>162.27192</td>
<td>38.539</td>
<td>-1296056.922</td>
<td>414324.606</td>
<td>-6210455.347</td>
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<tr>
<td>BF - UTD4</td>
<td>1370446.605</td>
<td>577618.488</td>
<td>95.796</td>
<td>-77.72238</td>
<td>162.27135</td>
<td>41.474</td>
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<td>414335.745</td>
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<td>BF - UTD5</td>
<td>1370480.558</td>
<td>577607.267</td>
<td>97.233</td>
<td>-77.72208</td>
<td>162.2708</td>
<td>42.912</td>
<td>-1296075.07</td>
<td>414358.23</td>
<td>-6210453.832</td>
</tr>
</tbody>
</table>

### Diagram: Coordinate Systems

- **Projected values (ex. UTM)**
- **Spherical coordinates**
- **Earth Centered Earth Fixed (ECEF)**