How a Lidar instrument works (Recap)

- Transmits laser signals and measures the reflected light to create 3D point clouds.
- Wavelength is usually in the infrared (~1550nm) or green (532nm) spectrum
- 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

Reference value

Probability density

Accuracy

Precision

Value
Beam Divergence

\[ D_f = (\text{Divergence} \times d) + D_i \]

@100m,
\[ D_f = 36\text{mm} \]

@500m,
\[ D_f = 180\text{mm} \]

@1000m,
\[ D_f = 360\text{mm}! \]
Beam Divergence
Angular Step

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

Rule of thumb: scan at least 1/10th of the “wavelength” of the object you wish to image.
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 Maximum measurement range as function of target material
• 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
# 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>Parameter</th>
<th>70 kHz</th>
<th>100 kHz</th>
<th>150 kHz</th>
<th>300 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser PRR (Peak)</td>
<td>70 kHz</td>
<td>100 kHz</td>
<td>150 kHz</td>
<td>300 kHz</td>
</tr>
<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>1400 m</td>
<td>1200 m</td>
<td>950 m</td>
<td>450 m</td>
</tr>
<tr>
<td>for natural targets ρ ≥ 90%</td>
<td>700 m</td>
<td>600 m</td>
<td>500 m</td>
<td>350 m</td>
</tr>
<tr>
<td>for natural targets ρ ≥ 20%</td>
<td></td>
<td></td>
<td></td>
<td></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>
</tbody>
</table>

## Minimum Range

- **2.5 m**
- **near infrared**
- **0.3 mrad**

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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.
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. This will take 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.
Checklist:

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

300 lbs!!
Will this fit in your vehicle?

Who will carry it?

Basic Field Kit
Standard tie point workflow

- Reminders – use at least 5 targets. That is, every scan position should see at least 5 targets, every target should be seen by at least 2 scan positions.

- The more targets common to all scan positions, the better
Moab, Utah survey site
Multiple survey positions

Moab Utah
• 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.
GPS Errors

Ionosphere

Troposphere

Multi-Path
Adding GPS to a TLS survey

Traditional Tie Point Survey
Understanding coordinate systems - GPS

- Projected values (ex. UTM)
- Spherical coordinates
- Earth Centered Earth Fixed (ECEF)
• **SOCS – Scanner Own Coordinate System**
  - Each scan position has origin at scanner location

• **PRCS – PRoject Coordinate System**
  - Local coordinate system for entire project

• **GLCS – GLobal Coordinate System**
  - ECEF, UTM, State Plane, etc.
TLS data often handled in Earth Centered, Earth Fixed coordinates.

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

- Preferred by geodesy community
- Not GIS friendly! Requires transformations into 2D cartesian (e.g., UTM).
- Application of data matters
- Beware vertical datums…
Understanding coordinate systems - GPS

\[ H = h - N \]

- **H**: Orthometric Height
- **h**: Ellipsoidal Height from GPS
- **N**: Geoid Height

Diagram includes:
- GPS satellite
- Topography
- Ellipsoid
- Geoid
- Oceans
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 and Carlos will cover these).
- Export data to appropriate format.
Filtering/Cleaning data
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
- Etc, etc, etc!
Point Cloud

- 3D “point cloud” of discrete locations derived from range and orientation of scanner for each laser pulse.

- XYZ position in cartesian coordinates plus associated point attributes: intensity, RGB, etc.

- 3D point clouds are the basis for subsequent analysis and used to create CAD or GIS models

- Typically ASCII XYZ + attributes or LAS
  - E57 = New standard under development, minimal adoption

- UNAVCO *standard deliverable* = merged, aligned, georeferenced point cloud in ASCII or LAS format.
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.
Summary

Project Planning (Targets, Priorities, Field Constraints, Logistics, Costs, etc.)

Data Collection (TLS, GPS, Photos, etc.)

Registration (and Geo-Referencing) of Scans from Single Campaign

Editing and Cleaning of Point Cloud Data

Point cloud data reformatting (e.g. manufacturer proprietary format to ASCII, LAS, etc.) and/or interpolation.

Integration with Other Datasets (e.g. airborne LiDAR, GPR, GIS)

Photorealistic Modeling

Surface Modeling

Combination of Scan Data from Multiple Campaigns (e.g. Time Series)

More Editing and Cleaning of Point Cloud Data