



## High Resolution Topography Unit 1-TLS: Introduction to TLS for a Geology Field Course – Student Exercise

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*In this introductory module, you will learn the basics of designing and conducting a TLS survey. Laser scanners emit short pulses of light and detect the returned signal as the laser light bounces off the target object. The scanner calculates the distance to the target from the time delay of the returned signal. TLS requires a range of equipment, careful planning, and many hours of scanning in order to complete a successful survey, but it yields a high resolution topographic model valuable for addressing a range of geologic research questions. Unit 1-TLS may be used alone or concurrently with Unit 1-SfM.*

### Introduction:

This unit introduces terrestrial laser scanning (TLS), a ground-based, remote-sensing tool that generates three-dimensional point clouds, with widespread research applications in geodesy, geomorphology, structural geology, paleoseismology, and other sub-fields of geology. After an introduction to the basics of TLS, you will design and conduct a TLS survey of a geologic feature. Following survey completion, you will learn the basics of TLS data exploration/visualization to answer questions about the scan resolution and findings that can be determined from the data.

### Project Description:

Below is a description of the workflow to follow when working on this project. This exercise is expected to take eight to ten hours, with additional time to learn the TLS data exploration techniques using the software RiScan.

**NOTE:** *All survey instruments should be treated with care. These instruments are used by many scientific researchers and may be on loan from a community pool maintained by UNAVCO or your institution. These instruments are in high demand, so careful and cautious handling of the equipment is essential, both for the success of the immediate project but also for others who depend on the equipment being in excellent working condition at the end of the day.*

### Field Notes and Metadata Collection:

While in the field, record field notes as you would on any other field day (weather, rock type[s], measurements of strike and dip or other features, a sketch of the outcrop) as well as detailed metadata related to the scans and an equipment list for a TLS survey (attached below). Metadata includes a sketch of the scanner locations, target locations, and study area; justification (including the limitations) of the selection of these locations; file naming conventions and locations; the surface texture, color, and condition, and how the reflectance may affect the scan; the survey team; and the object of the project. You want to capture enough information about the survey and the field site and conditions that you can clearly recall what was done days or weeks after the data collection, when you are working to process the data in the lab. The reflectance vs. scanner range chart is in your TLS Field Manual, so refer to this when noting the impact of the reflectance of the material on the scan.

Make measurements of three prominent geologic features in the scan area. Examples include a bed thickness, distance between two large clasts, distance between two trees obstructing the scan area, distance between offset beds, or any other clearly identifiable feature within the scan area. These will be used in your final write-up for the unit.

One of your objectives for the unit is to write step-by-step instructions for setting up a TLS survey, so also take notes on this process as your group sets up the scanner.

#### Problem Set:

In addition to recording metadata when not collecting scans, work through three problems: beam divergence, spot spacing, and scan resolution parameters. These are included below. Complete a scan resolution parameter worksheet for each scan location.

#### Data Exploration:

In addition to the *TLS Field Methods Manual*, a *TLS Data Processing and Exploration Manual* has been handed out. The manual has sections on project loading, scan registration, and visualization; evaluating tie points and georeferencing; data selection and cleaning; and exporting the data. This manual is for the module as a whole, so not all sections are relevant to this unit.

#### Write-up:

After collecting and exploring the TLS survey data, create a write-up detailed below about workflow, metadata collection, and results of data exploration.

### **Project Report:**

#### Part A: Workflow

The first section of the write-up for the unit should be step-by-step instructions for setting up a TLS survey. Use details like sketches of the scanner setup from field notes to explain each step. Remember to include:

1. A list of the equipment needed
2. A map of the scan positions, the target locations, and the GPS locations
3. A summary of the necessary metadata
4. Operational procedures for setting up a scan (like general considerations for scanner position, target location, GPS location, the scan resolution, time, registering scans, and kinds of scans done)
5. General steps for visualizing the data.

#### Part B: Why TLS?

In this section, detail the societal impetus for using TLS for research, including the importance of this technology for society. Many examples of the wide range of applications of TLS were given in lecture this morning. Consider the commonalities between these examples to demonstrate why TLS is useful in a general sense, not just in a sub-field of geoscience or in geoscience. Recall the object of the project at the field site and summarize why TLS was the best method of accomplishing that object.

#### Part C: Data Summary

Summarize the data collected by the class.

1. What scans were done at each scan position?
2. What are the files called? Where are they stored?
3. Are there photos associated with each scan?
4. In addition, detail the high resolution scans from each group by creating a map of the scan partitioning.
5. Include scan resolution parameters worksheets as well as the other two worksheets from the field.

**Part D: Data Exploration and Analysis**

Finally, identify occluded (or shadowed) portions of the scan.

1. How do these occluded portions affect or not affect your ability to study that feature?
2. Demonstrate the resolution of the scan vs. reality by showing the difference between measurements of clear geologic features in RiScan and when measured in the field.

After completing these portions of the write-up, briefly answer the following question:

1. What surprised you the most about using TLS?



**Field Sketch:**

**Notes: atmospheric conditions, scan file names, number of scans, etc.**

## Terrestrial laser scanning (TLS) Calculations Worksheet

### Scanner-specific parameters

	Riegl VZ400	Riegl Z620	Other scanner
<b>Beam divergence (radians)</b>	0.3 millirads = 0.0003 radians	0.15 millirads = 0.00015 radians	
<b>Initial beam diameter (m)</b>	0.007 m	0.014 m	
<b>Effective meas. rate (#/second)</b>	122,000 high speed 42,000 long range	11,000 high speed 8,000 low speed	
<b>Max measurement distance* (m)</b>	600 m	2000 m	

\*Assuming standard clear atmosphere and highly reflective natural surface; actual distance will be less in most cases.

### Part 1: Beam diameter at different distances

Beam diameter (or spot size) can be calculated with a simple formula and can be helpful when determining where to locate your scanner, depending on the resolution of data your project requires. Parameters for several commonly used scanners are above. If you are using another scanner, your instructor will provide the scanner specs. In column 1, calculate the final beam diameter at various distances. Use the above formula (use radians, not millirads).

Beam Divergence Formula

$$D_f = (BD * d) + D_i$$

$D_f$  = Final beam diameter

$BD$  = Beam divergence (radians)

$d$  = distance to target (aka range)

$D_i$  = Initial beam diameter

When the scanner is at an angle to the target, the beam diameter is further spread out. In the last two columns, calculate the max ellipse diameter for angles of incidence other than 90°.

$$D_m = \text{Max ellipse diameter} = D_f / \sin(\text{angle-of-incidence})$$

Distance to target (m)	Final beam diameter at 90° angle (m)	Max ellipse diameter at 70° angle (m)	Max ellipse diameter at 45° angle (m)
10			
50			
75			
100			
200			
350			
500			
800*			

\*Beyond the range of a Riegl VZ-400

Part 2: Determining spot spacing

Now we want to calculate the spot spacing (aka angular resolution) of a scan with varying stepping angles to get an idea of changes in spot (aka point) density. We will keep it simple by using a constant distance (aka range) to the outcrop, but remember that this distance will actually change while scanning. Angular resolution will need to be figured for both the vertical and the horizontal scanning process. The formula for calculating spot spacing is as follows:

Angular Resolution Formula

SS = spot spacing

SA = stepping angle (radians)

$$SS = SA * d$$

d = distance to target

Based on Riegl scanner specifications, we will use a minimum stepping angle of  $0.0024^\circ$  and a maximum of  $0.288^\circ$  for the vertical orientation. Given the various stepping angles, calculate the spot spacing of each scan with targets at 50, 100, and 200 meters. You will need to convert degrees to radians for the formula to work. Similarly, the horizontal can be calculated using the Riegl specification range with the same minimum angle of  $0.0024^\circ$ , but with a larger maximum angle of  $0.5^\circ$ . Notice the effect changes in stepping angle have on resolution and think about how to approach a project with varying distances to the target, to maximize time efficiency and quality of data collection. It is important to note that the smaller the stepping angle, the more data you will collect, providing a higher resolution scan, but taking more time in the field, and yielding considerably more data that will need to be processed later.

Stepping Angle (Degrees)	Stepping Angle (Radians)	Spot Spacing at 50 meters (m)	Spot Spacing at 100 meters (m)	Spot Spacing at 200 meters (m)
<b>0.0024°</b>				
<b>0.005°</b>				
<b>0.01°</b>				
<b>0.1°</b>				
<b>0.2°</b>				
<b>0.288° (vert. max)</b>				
<b>0.5° (horizontal max)</b>				

Part 3: Scan Design Considerations and Resolution Parameter Worksheet

1. What is the objective of this scan?

2. What is the size/shape of the smallest features you that you are trying to resolve?

**Table 1. Scan parameters at the outcrop**

Scan site and scan number	Distance to target (m)	Final beam diameter (m) [Df: see Part 1]	Angle of Incidence to target	Ellipse max diameter (m) [Dm]	Proposed stepping angle (rad)	Spot spacing (m)
	Min					
	Mean					
	Max					

*Note: in order to resolve an object or layer, a reasonable rule of thumb is that you need to be able to hit it about 10 times. For instance, if you want to define a layer that is 20 cm thick, you should aim to have 10 hits across the thickness of the layer (about every 2 cm). If more than one scan will cover the same area, it is the sum number of hits that matters.*

3. Bearing this in mind, do you think that your proposed stepping angle is matched with the survey needs?  
Also consider the size of the beam when it reaches the target. Is the current distance going to allow you to achieve your survey goals? (I.e., if your spot size is similar to or larger than what you want to measure, you have a problem.)
4. Based on your answers to #3, do you need to consider changing your survey in any way? Possible changes could include: moving your scanner, adjusting the step angle, or reconsidering the resolution goal for the survey.

**Table 2. Scan duration**

Scan site and scan number	Horizontal scan length (m)	
	Optimal # horizontal measurements	
	Vertical scan length (m)	
	Optimal # vertical measurements	
	Duration for optimal scan (minutes) [#horiz * #vert / effective measurement rate]	

5. Is this time frame reasonable given the time available and other tasks for the day?

Repeat the same process for other scan sites if directed to by your instructor

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**Table 2. Scan duration**

	Scan site and scan number	Scan site and scan number
<b>Horizontal scan length (m)</b>		
<b>Optimal # horizontal measurements</b>		
<b>Vertical scan length (m)</b>		
<b>Optimal # vertical measurements</b>		
<b>Duration for optimal scan (minutes)</b> [#horiz * #vert / effective measurement rate]		

Do any changes need to be made to your scan/s based on the above calculations?

## Unit 1 Rubric - Introduction to TLS for a geology field program

*This rubric covers the material handed in for Unit 1 student exercise and is the summative assessment for the unit.*

Component	Exemplary	Basic	Nonperformance
<b>General Considerations</b>	Exemplary work will not just answer all components of the given question but also answer correctly, completely, and thoughtfully. Attention to detail—as well as answers that are logical and make sense—is an important piece of this.	Basic work may answer all components of the given question but answers are incorrect, ill-considered, or difficult to interpret given the context of the question. Basic work may also be missing components of a given question.	Nonperformance occurs when students are missing large portions of the assignment, or when the answers simply do not make sense and are incorrect.
<b>Part A: Workflow (6 points)</b>	6 points: Workflow as a whole is detailed and makes sense; someone who has not used a scanner could follow along. Includes the filled-in (and correct) equipment sheet, sketches of a setup in the field explaining scanner position and target and GPS location, a list of required metadata, operational procedures, and general steps for data visualization.	3–5 points: Characteristics of an 8-point response but missing 1-2 of the pieces listed  AND/OR Workflow is not logical and is difficult to follow, but still usable.	0–2 points: Missing 3–5 of the pieces listed for the workflow  AND/OR The workflow is unusable.
<b>Part B: Why TLS? (4 points)</b>	4 points: Detailed and thoughtful answer about why to use TLS for research; includes examples and a discussion of the importance;  Research objective of the project/why use TLS for this objective (1 point)	2–3 points: 1–2 of the three listed for an exemplary example; judge based on the number of points assigned to each factor.	0–1 points 0–1 of the factors listed for an exemplary example.

<p><b>Part C: Data Summary</b> <b>(6 points)</b></p>	<p>4 points: Includes a list of data collected, including the scan position, scans collected at that position, images, filenames, a map of the scan partitioning, and completed scan resolution parameters worksheets for all scans, as well as the beam divergence and spot spacing worksheets.</p>	<p>2–3 points: Missing details of the survey (3–4 of the six listed characteristics) AND/OR lack of detail in student response in 2–3 so they are unusable answers.</p>	<p>0–1 point: Includes only 1–2 complete and detailed characteristics listed for an exemplary answer.</p>
<p><b>Part D: Data Exploration and Analysis</b> <b>(4 points)</b></p>	<p>4 points: Identifies occluded portions of the scan, and the difference between the measurements done by hand or done in RiScan. Also, all calculations must be correct (3 points); Reflective and complete answer about what surprised them about working with TLS (1 point)</p>	<p>2–3 points: Includes all of the characteristics listed for an exemplary answer but 1 listed characteristic is incorrect or missing (1–2 points); Answers question about positive and negative aspects of working with TLS, but answer is not thoughtful or reflective (0.5 points)</p>	<p>0–1 point: One listed characteristic that is correct; all listed characteristics but none were calculated correctly (0–1 point); Does not answer reflective question (0 points)</p>