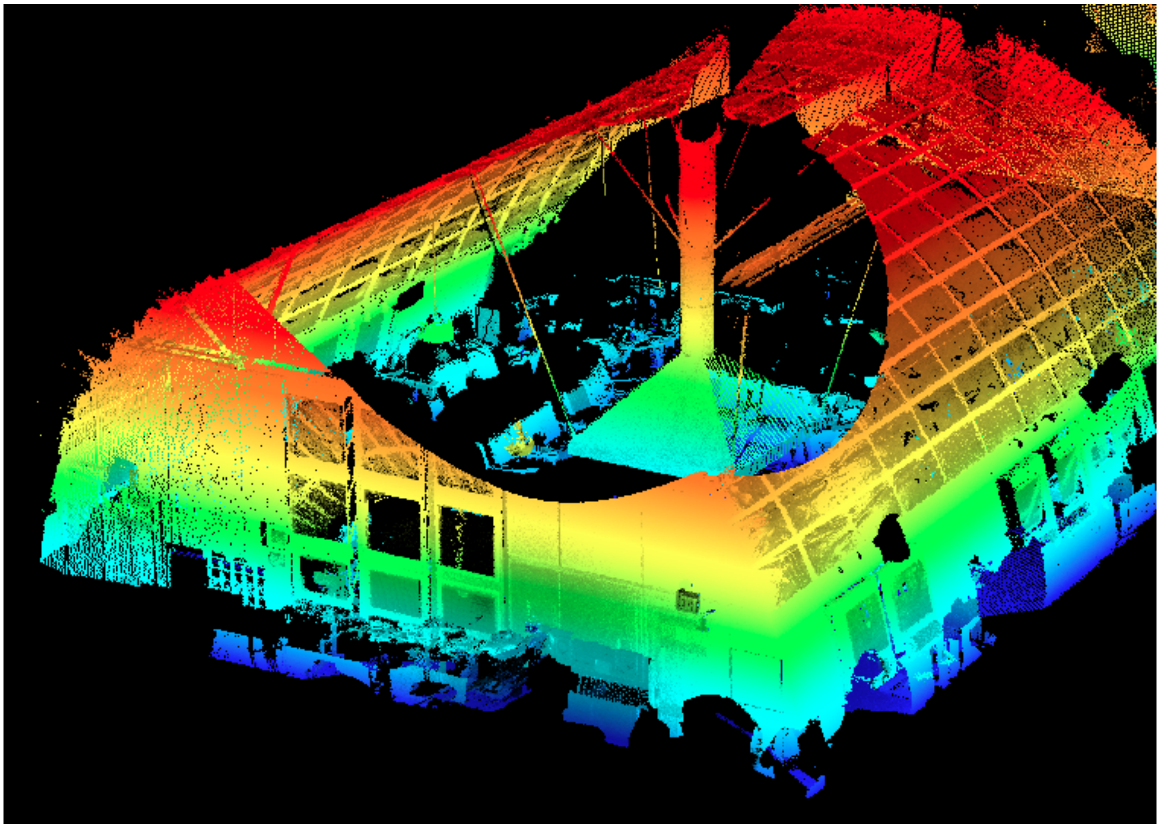

G429g

Geophysical and Tectonic Applications to Field Investigation in the Northern Rocky Mountains 2014

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Cover Image: TLS scan taken from within the Lodge at the IU Geologic Field Station. The image is seen as viewed from outside the TLS point cloud; with the image displayed with a color scale tied to elevation. The window providing a view of the Lodge interior is the upper cone of no data above the scanner reflecting the upper tilt angle on the Rigl VZ-400 scanner.

G429G - FIELD GEOLOGY IN THE ROCKY MOUNTAINS WITH GEOPHYSICAL EMPHASIS

Tentative Schedule – 2014

Monday: Introduction to Terrestrial Laser Scanning (TLS) [classroom]

AM - Field deployment of instruments [IUGFS]

PM - General field techniques and instrument capabilities, individual time with instruments; Log of field deployment procedures

Evening - Introduction to Riegl software package for data reduction and analysis

Tuesday: Characterization of sedimentary architecture [Lodgepole formation, Milligan Canyon]

AM - Field deployment of instruments; Characterization and assessment of scan parameter options

PM - Evaluation of TLS vs traditional direct measurement techniques; Assessment of scan positions relative to key target sites; Identification of para-sequence boundaries

Evening - Manipulation of data within Riegl software package

Wednesday: Characterization of an active alluvial channel [Negro Hollow, North Boulder

AM – Field deployment of instruments; Characterization and assessment of scan parameter options

PM - Use of intensity and characteristics of data to define key features to earmark for changes of a alluvial channel over time

Evening - Development of simple models for alluvial channel evolution from data; Individual time with instrument

Thursday: Independent student exercise - developing plan for a TLS survey of a new area

AM - Oral presentation and defense of plan; Vote for best plan to be implemented by class; Deployment of supporting instruments by individuals

PM - Individual time to complete assignments

Evening – Completion of final reports for individual projects; Individual time with instrument

INTRODUCTION TO G429G

The motivation behind the G429g week is to introduce students to new technologies that are becoming wide spread in geological investigations that make use of data collected by what are considered geophysical techniques (e.g. gravity or resistivity surveys; seismic reflection or refraction surveys). We will be focusing on the use of Terrestrial Laser Scanning (TLS). This relatively new method of data collection has already been applied to a wide variety of geological and geophysical problems; the combination of data types (amplitude of reflection; X,Y,Z position, and RGB color) and the resolution of individual data points make this technique applicable to investigations of a variety of geological processes. The overall nature of the field deployment of instruments and the gathering and analysis of the data mimic studies employing seismic, gravity, or electrical resistivity surveys that have been traditional geophysical methods. The focus of the work for the G429g concentration will emphasize the broad spectrum of applications of TLS including sedimentology and hydrologic/geomorphic processes as well as tectonic and structural applications. We are fortunate to have staff and equipment provided by UNAVCO, a university consortium that provides equipment and logistical support for geophysical and tectonic experiments. Much of the information and figures used in this document have been taken from materials prepared by the CyberMapping Lab at UT-Dallas in conjunction with UNAVCO and from UNAVCO manuals developed for users of equipment provided by UNAVCO. Participation by UNAVCO in teaching outreach is supported by a grant from the National Science Foundation.

Field Objectives for G429g TLS Scanning

Below is a list of procedures to follow and complete in the field. TLS exercise problems, a blank equipment list for checking equipment brought into the field, and instructions and forms for field site deployment and observations are also provided. Appendix B lists Riegl's manufacturer specifications for the VZ-400 scanner. Use field notebooks to answer questions and draw sketch maps if sheets are not provided and turn in all completed work after you have finished scanning for the day, if required to do so.

1. *Project Planning*
   1.1. Thoroughly read through the hand-out.
   1.2. Specify project objectives.
   1.3. Use Google Earth, topographic maps, or field photos to determine best locations for scanner, control targets, and GPS.
   1.4. Decisions should coincide with scanner capabilities and science research goals. Can you get the scanner and researchers safely into and out of the study site?
   1.5. Complete a list of equipment needed for the day is provided (to be used to gather equipment at the start of the day and inventory equipment as it is collected from field deployment).
2. *Pre-scan Metadata*
   2.1. What make and model scanner did the project require?
   2.2. What type, number, and size of reflector control targets are you using?
   2.3. Provide a sketch map describing the topographic layout of the field site. Instructions are included in Appendix A.
3. *Post-scan Metadata*
   3.1. Did you get a reference panorama scan with photos and how many of each?
   3.2. How many fine scans were obtained?
      3.2.1. Provide a sketch map of each fine scan using any and all applicable attributes listed in the sketch map instructions.
      3.2.2. List the fine scan parameters used for each along with your sketch maps. Include:
         3.2.2.1. Duration of scan, scan resolution, mean range to target, mean angle of incidence, and any other comments.
4. *Final Point Cloud*
   4.1. If you completed multiple scans, were they successfully merged and georeferenced?
   4.2. Do the images make sense and have achieved preliminary objectives of data collection?

Terrestrial Laser Scanning

1. Introduction

Terrestrial Laser Scanning (TLS) is based on LiDAR (Light Detection And Ranging) technology and may also be called Terrestrial LiDAR or Tripod LiDAR (T-LiDAR). It is a ground-based remote sensing tool that is similar to Radar and Sonar, but uses visible to near infrared light emitted from a laser instrument that then records the reflected light waves from its targets. These recorded light waves can then be converted into points with X, Y, Z coordinates that can be georeferenced with a GPS unit to produce highly precise and accurate 3-dimentional images called *point clouds*, which can then be analyzed for scientific research. TLS is a tool that is quickly becoming very popular in the Earth sciences for topographic mapping, temporal and spatial geomorphic and tectonic change detection such as earthquakes, volcanoes, landslides, stream morphology studies, glacier mass balance and snow depth measurements. TLS is also used widely in biomass investigations in forestry, and for numerous engineering applications.

Because the laser scanner is a static instrument, it provides excellent coverage of objectives that range from several meters to over a kilometer in scale. UNAVCO deploys a pool of Riegl and Leica TLS scanners with maximum ranges of 400-2000 meters with centimeter scale resolution (in ideal situations millimeter scale is possible). This is compared to airborne and satellite LiDAR systems that have resolutions on the 10's of centimeters to meters scales respectively. When fitted with a digital camera, which is common, digital photographic images (RGB) can be merged with point cloud data to produce photo-realistic 3-dimensional images (Figure 1).

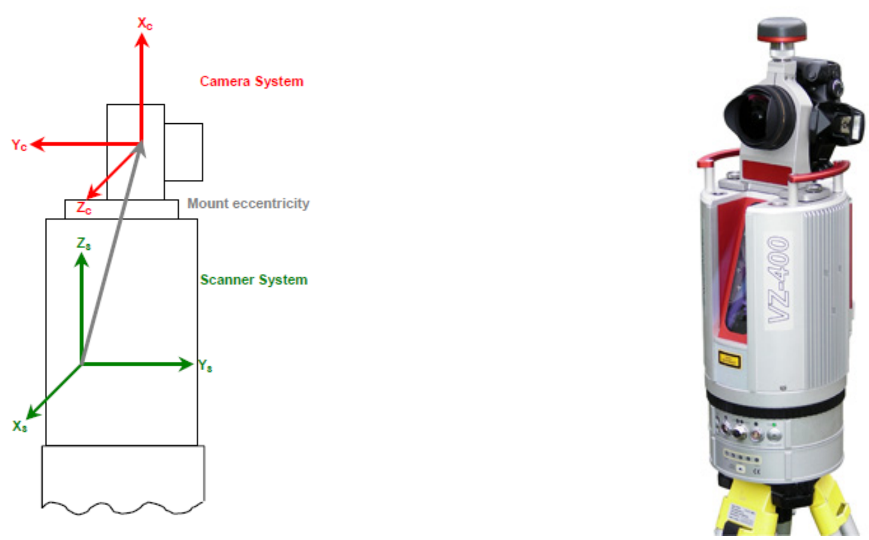


Figure 1. Left image shows the general schematic set up of a TLS scanner with laser housing and camera and the X, Y, Z coordinate system used to register points collected. The right image is of the **Riegl VZ-400** scanner, an instrument commonly deployed by UNAVCO for Earth science research (Images courtesy of Cyber Mapping Lab of UT-Dallas and Riegl USA).

Georeferenced point clouds are produce by measuring ("ranging") the distance between the scanner and the target. The process happens as the laser emits many short pulses of light that are reflected back and recorded by a receiver. Distance is then calculated by multiplying the round trip time of flight of the initial pulse and return capture by the speed of light, then dividing that in half (Figure 2).

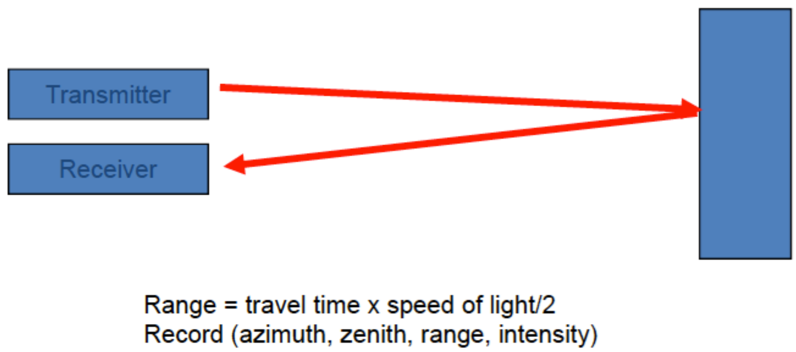


Figure 2. A simple schematic of a laser pulse emitted by the scanner, reflected off of a target, and received by the scanner (UTD CyberMapping Lab).

2. Scan Parameters

Beam Divergence

An important consideration in TLS scanning is beam divergence. The laser beam is a cylindrical beam of photons (light) that slightly deviates when it is first emitted from the laser. As it travels from the TLS laser, the beam begins to widen as a narrow cone that increases in diameter the further it travels called the "beam divergence" (Figure 3).

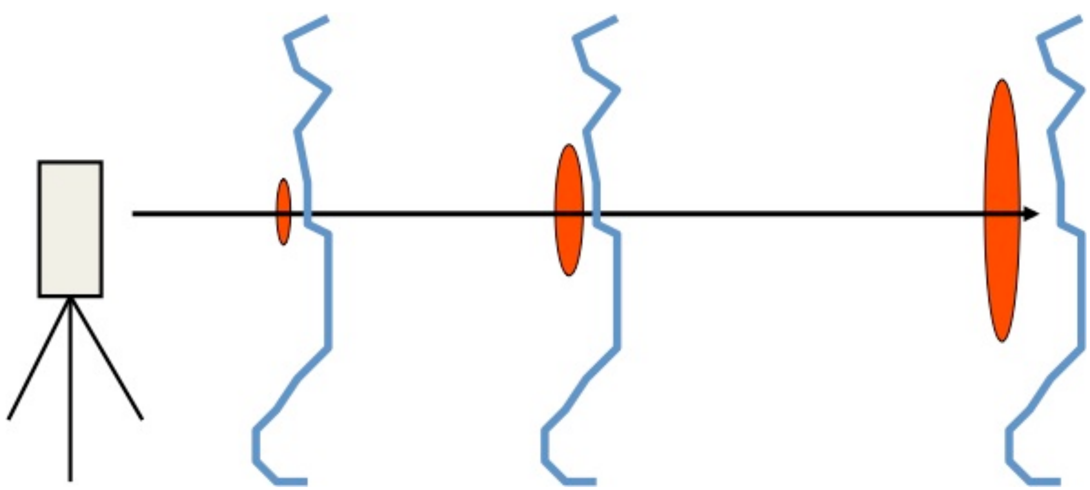


Figure 3. An idealized example of beam divergence as distance increases from laser. Ovals represent beam spot size and the blue lines represent a hypothetical rock out-crop (Image courtesy of Cyber Mapping Lab of UT-Dallas).

Initial beam diameter and divergence varies by LiDAR instrument model and can range from 0.1-1.0 millirads (Gatziolis and Anderson, 2008). The Riegl VZ-400 has a beam divergence of 0.35

millirads and an initial beam diameter of 0.007 meters. Therefore, the spot size on a target will be a function of the diameter of the initial beam as it exits the laser, the beam divergence, and the distance it travels until it hits a target. This corresponds to the beam widening ~ 3 cm per 100 m. The resolution of the scan will be affected by this parameter as the final spot size of the beam that intercepts its target illuminates a certain area. The attributes within the spot are averaged and recorded by the receiver. Thus, the wider the spot size diameter, the less overall detail you will gain on a scale smaller than the spot size (Figure 4).

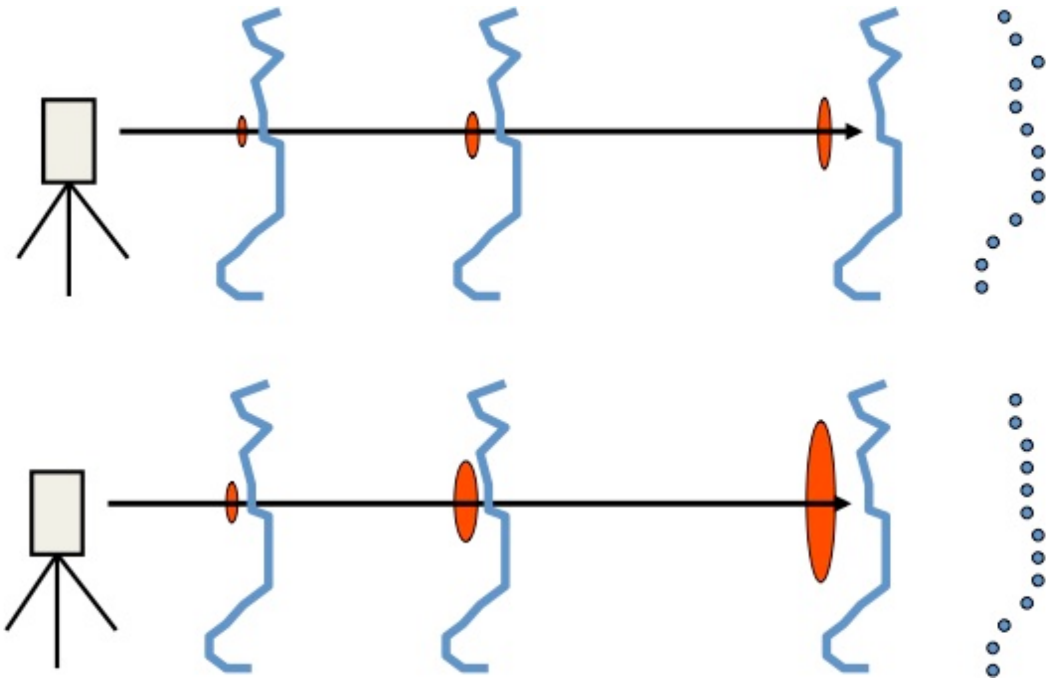


Figure 4. The lasers in this example are both hitting the same target(s) traveling the same distance, but the top laser has a smaller beam divergence resulting in smaller spot sizes that allow for increased resolution and a finer detailed image (blue dots) of the irregularities of the rock outcrop. The bottom example produces a lower resolution, less detailed and averaged (blurry) image (Image courtesy of Cyber Mapping Lab of UT-Dallas).

Spot Spacing

A second important scan parameter that will affect the resolution before you start scanning is **spot spacing** (aka. angular resolution). A function of the stepping angle (increments for each set of pulses) of the laser and range to the target, spot spacing can be reduced or increased by adjusting the stepping angle (aka. angular step) in the scanning software. This will result in increasing or reducing the resolution respectively and the corresponding density of spots or points collected by the scanner (Figure 5). Increasing distance increases spot spacing; so angular step would need to be reduced to obtain a high-resolution scan at long ranges. Angular step can be adjusted for both the vertical and the horizontal, as the Riegl VZ400 scanner has a scanning range of 360° in the horizontal and 100° in the vertical (60° up/ 40° down). TLS point clouds are very dense, with the scanner collecting 10's of 1000's to 100's of 1000's of points/sec. Depending on your project resolution requirements and the amount of data you want to compile and analyze, angular step can be adjusted accordingly. Extremely dense point clouds require more storage space and processing power on computers, and take a longer time to scan. This will impact the time spent out in the field collecting data and also how long data processing will take, so should be factored into the project design.

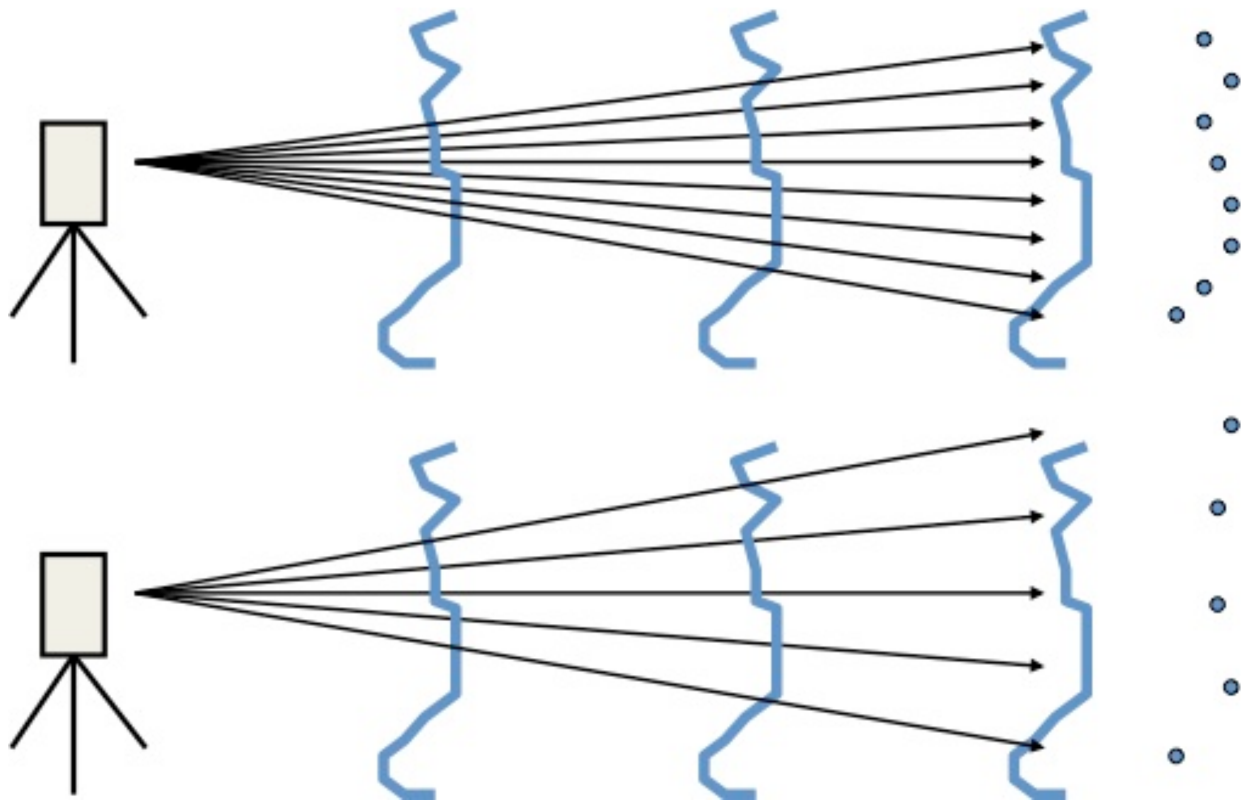


Figure 5. As the angular step and distance of the scanner from its target is increased, the result will be a greater spacing between spots as is shown in these two examples. The lower example has a greater step angle, resulting in increased point spacing and a less detailed, lower resolution image (Image courtesy of Cyber Mapping Lab of UT-Dallas).

Scan Partitioning

In reality most large area topographic scans will contain varying ranges within the target scan that can affect point density and resolution. If the same resolution and point density is desired over a wide range of distances at one scan location (say, a river channel and adjacent terraces and hill slope), the scan will need to be broken up into several scans at determined mean distance intervals. Then, the stepping angle will need to be adjusted as a function of that mean distance to achieve the same resolution and point density. If this is not done, the extremes of the scan distances, “r1” and “r3” in Figure 6, will either be too dense with points or too sparse. Since the TLS scans in the vertical and horizontal orientations, vertical and horizontal partitioning needs to be taken into consideration during a complex project. Remember, *beam divergence* still plays a roll in desired resolution and will determine the location of scan positions as well.

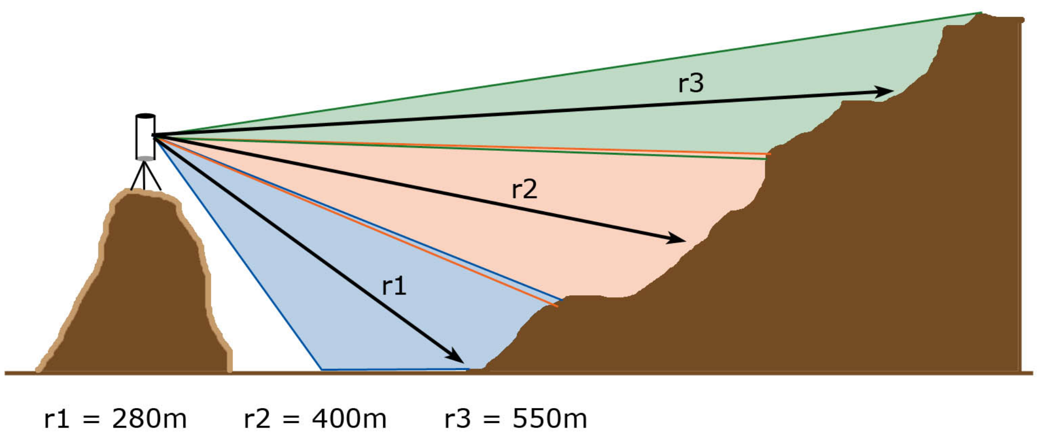


Figure 6. Scan partitioning in the vertical field of view showing sectioned ranges for scans using different stepping angles to achieve the same spot spacing (resolution) and spot density (point density) in each of the three sections. For this example, if the same stepping angle used for “r3” was used for “r1”, then the spot density for “r1” could be 10-15x that of “r3”, requiring an extraordinary amount of time to scan and eating up memory on the computer (Image courtesy of Cyber Mapping Lab of UT-Dallas).

3. Set up and Work Flow

1) *Scan Position:* The first step is selecting effective scan positions that will maximize coverage of the target site to minimize occluded views that will lead to blank spots in the point cloud. A good practice is to pick at least two oblique locations to the target for scanning (Figure 7), but having a third is best, so you’ll have left, middle and right viewpoints providing strong angles of incidence with targets. If you want a true 3D model of a feature (e.g., a building), then you must move the scanner around the structure to capture all sides.

Scan Positions

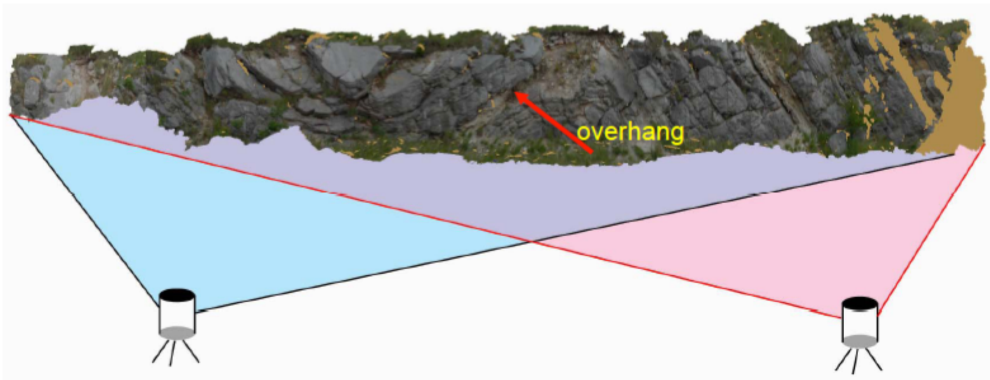


Figure 7. Multiple scan positions are needed to obtain the maximum coverage of a feature, through overlapping illumination of the target. This minimizes the amount of un-illuminated area and thus un-measured features. Having a third scan in the middle would help with this issue, but may not always be necessary (UTD CyberMapping Lab).

2) *Control Target (tie point) Set up*: Control targets are essential to register multiple scans, as they are static markers that allow for easy merging of multiple scans to produce a 3-dimesional image. The control targets should not be placed in a linear fashion or bunched up, but should be as evenly dispersed around the entire scan site as much as possible (both horizontally and vertically) (Figure 8). A bare minimum of three control targets can be deployed, but it is highly recommended to have at least five to account for uncontrollable sight-line blockages from complex topography and other problems such as dense vegetation. The more targets in common between adjacent scans, the better the accuracy of the final point cloud data product (again, a minimum of 3 - 5). Targets should not move during scanning, so secure placement is vital. Movement will introduce error and may possibly be severe enough that you will have to restart the entire project, **do not accidently bump into or move targets.** Steps 1 and 2 are the most important for a successful scan and should be planned out before scanning (Figure 9).

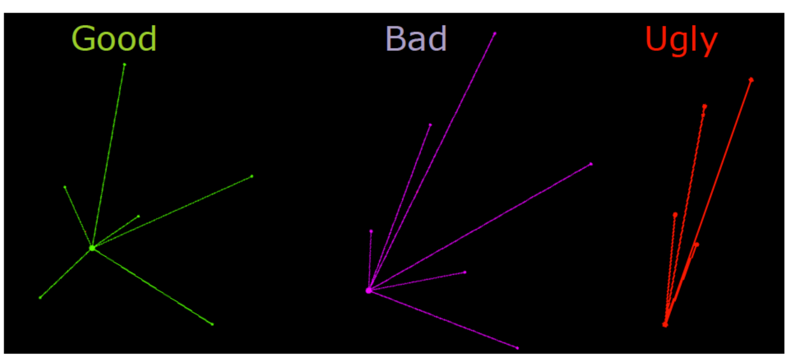


Figure 8. Examples of good to bad control target geometries represented by the vectors radiating from the center point (scanner) to control targets (out-lying points). Avoid Bad and Ugly at all costs.

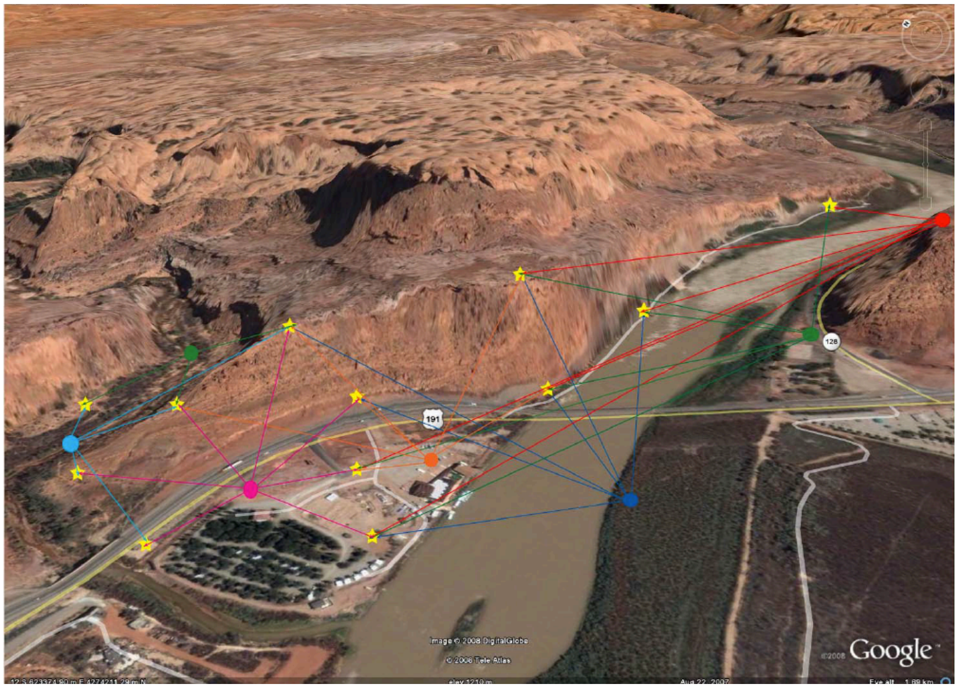


Figure 9. Above is a Google Earth image of a site near Moab, UT and a great example of good scanner placement and control target set up. Six scan positions, represented by the colored circles, were utilized to capture the topography. The stars represent the control targets. Notice how each scan position contains several targets in common with each other to allow for proper registration of the multiple scans.

3) *GPS Set up:* If georeferencing scans is required by the project, the two most common GPS techniques used in TLS are Static (long occupation) and Real Time Kinnematic (RTK) GPS (short occupation). Which one is used depends on the specific needs of the project and equipment availability. Both are forms of differential GPS requiring a base station within range and clear sky views for accurate and precise measurements.

   a. *Static GPS:* Static GPS surveying is the most accurate method. It involves at least 3 antenna receivers configured in a triangular geometry on top of specific control targets within the project location. Long occupations of up to 6-8 hrs are required to obtain an optimal position solution of centimeter to sub-centimeter resolution (the longer the better). A base station, placed on site (collecting data for the day/week/month duration of project) or an established one (ideally < 20km away), with known coordinates is also required to post process and differentially correct the GPS data later in the lab.

   b. *RTK GPS*: **R**eal **T**ime **K**inematic GPS is useful as it is quick, providing real-time position solutions and potentially requires less equipment to carry to the field site. It involves a base station set up on site at the beginning of the project that collects data through out the day; this base then provides "real-time" correction data via a radio link to a receiver called a "rover unit". Therefore, occupation times can be seconds to minutes with no need for post processing. Position solutions are on the centimeter scale ranging on average between 2-5cm. A disadvantage for RTK vs. Static is the need for a clear line of site for radio communication between the base station and the rover, which can be limited by dense vegetation and complex topography.

4) *Parameters:* As discussed above, it is important to consider several parameters such as beam divergence, spot spacing, and scan partitioning before beginning your scan. Other parameters to be aware of are angle of incidence, which is related to the angle of the beam that intersects the target. You want to make sure you have strong angles, maintaining maximum coverage and overlap between scans. Environmental conditions will play a factor such as the position of the sun relative to the scanner. The albedo (reflectance) of the scanned material, visibility limitations due to clouds, dust, topographic relief, and vegetation also affect the quality of return data.

5) *Collecting Data:* After the control target and GPS framework has been established to coincide with pre-determined scan positions, data collection can begin. Start with a panorama scan of the area accompanied by digital photos. Next fine scan all the control targets as part of the scan registering process. Once that is complete, fine scan an area of interest that is the focus of the project (if necessary). After the first scan is complete, move to the next scan position. For each successive scan position repeat above basic steps then register (tie together) adjacent scans by finding “corresponding points”. Check the accuracies of scan registration in the field so there are no surprises when you are miles away from your site back in the lab. GPS data can be imported into scan project following scanning. Once all scanning is complete make sure you: **Save all data**!

4. TLS Coordinate Systems

Data collected from a terrestrial laser scanner can be tied to one of three coordinate systems (Figure 10):

1) *Scanner Own Coordinates* (SOCS): the first set of coordinates established for an individual scan related to the scanner's position.
2) *Project Coordinates* (PRCS): multiple scans registered (tied) together using stationary control targets (tie points) dispersed around the project area.
3) *Global Coordinates* (GLCS): independent GPS coordinates are then imported and registered to the point cloud to create a georeferenced final product.

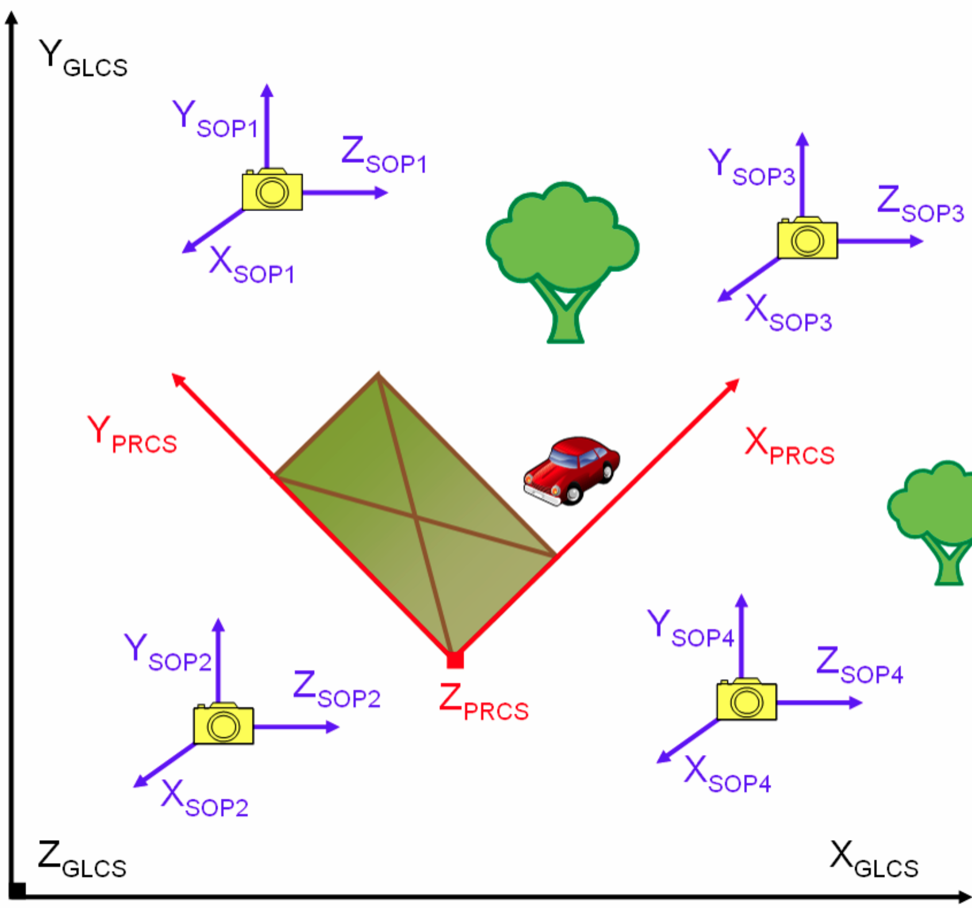
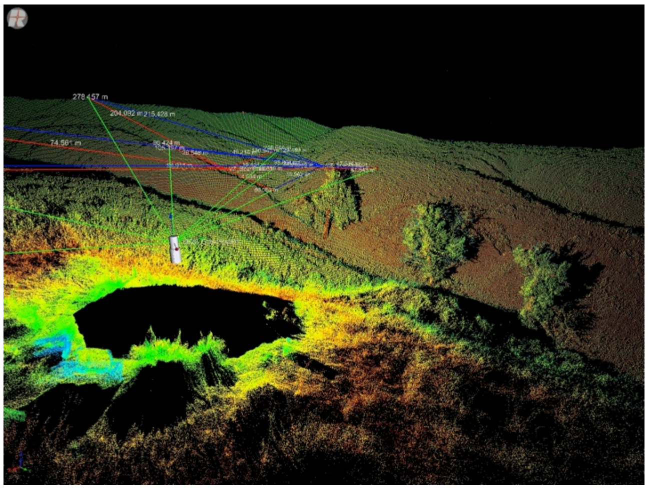


Figure 10. This diagram is a general schematic of the 3 coordinate systems and how they relate to one another. The four scan coordinates (SOP_{1-4}) involving a scan of the car for example, are then registered together to create the overall project coordinates (PRCS). Until GPS data is applied to the point cloud, the project is floating in space. After the GPS data is applied, GLCS is created and your point cloud is now georeferenced. SOP (Scanner Own Position) is another version of SOCS.

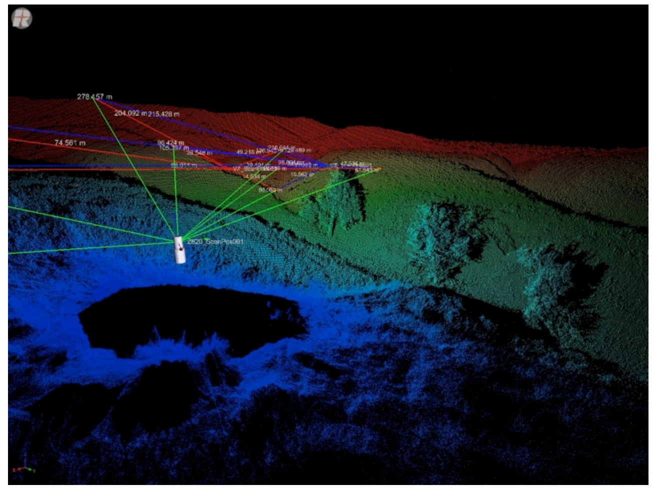
5. Products

After a day in the field collecting TLS data, you will be able to produce highly accurate 3-dimensional, georeferenced point clouds of your field site and all specific targets involved that can be analyzed later in a lab. The digital photos that you took can also be merged with the point clouds to produce a 3-dimensional-photo-realistic point cloud. Below are some examples.

A



B



C

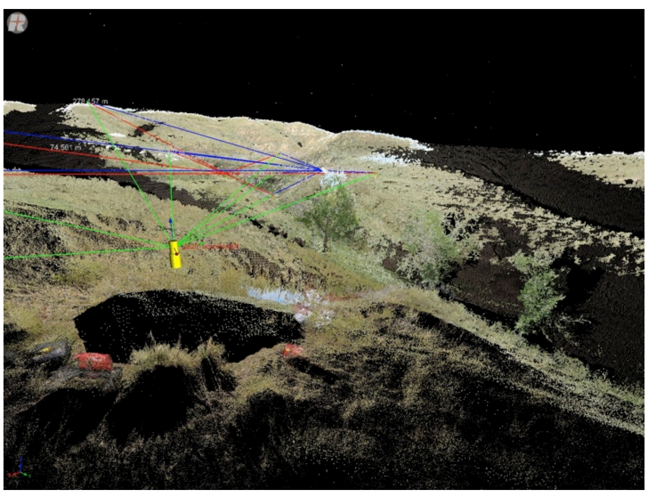


Figure 11. The three images above are visualizations of point clouds from the same same scan position but displaying different basic attributes. (A) Reflectance intensity. (B) Range (distance) from scanner. (C) True color image of the scan site after digital photos are merged with the point cloud. Notice that vectors are connecting with the various control targets dispersed around the scanner. The scanner has a minimum detection distance of about 1.5 m, hence the black spot underneath the scanner.

In addition to looking at the entire data set, select portions of the data may be isolated to provide a specific view that allows for specific measurement, or, to create a specific display of a feature for analysis. An example of a fault scarp profile, created from a data cloud, is shown in Figure 13.

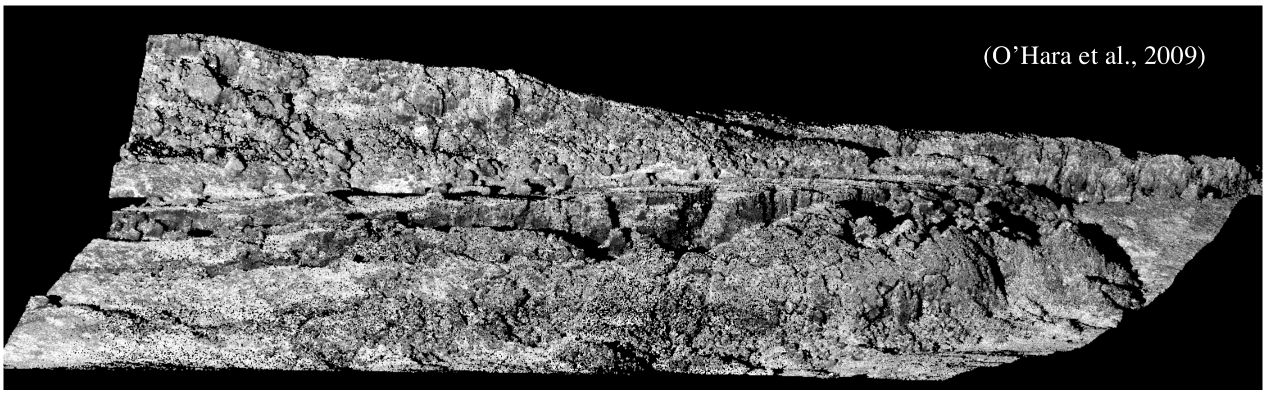


Figure 12. Masters student Caroline O'Hara of Penn State University, along side advisor Peter La Femina, was conducting part of a long-term geologic deformation study utilizing TLS equipment supplied through UNAVCO. The purpose was to investigate the formation and geometry of normal and strike-slip faults across the plate boundary in Iceland. The top photo is the digital photo of her study site with scanner in the bottom right, followed by the final point cloud image below the field photo.

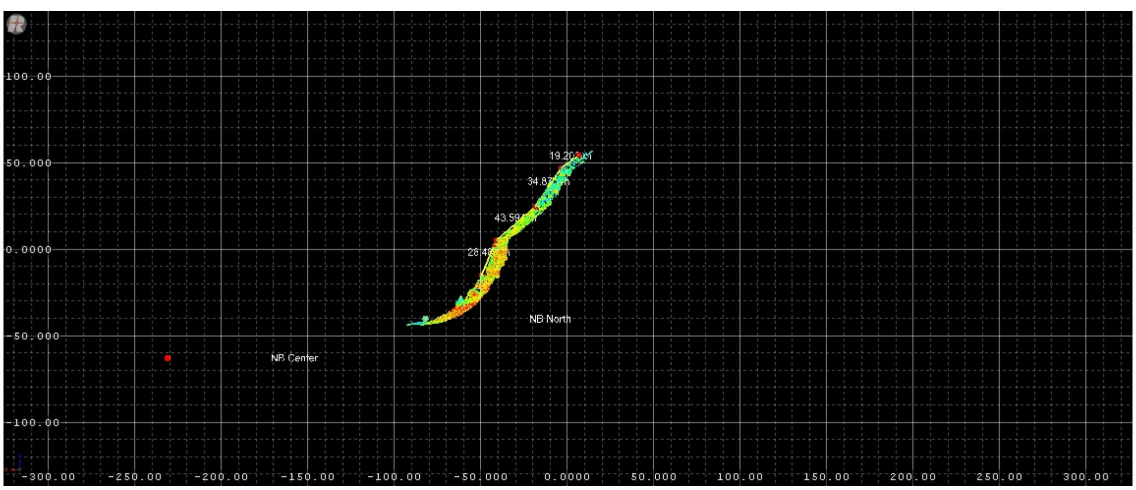


Figure 13. This is an image created by selecting a small strip of data from within a point cloud and then rotating the strip to provide a profile. This profile can then be measured and analyzed to produce a data set from which to evaluate fault scarp rollback.

6. Sketch Map of Study Area

In science, it is always important to take down as much information as possible to allow for repeatability of your research as well a proof to back up what you have done. Sketch maps have been a staple in field geology since the beginning and are a great reference to remind yourself of field conditions. It is no different for TLS scanning and allows you to document the set up of your scan site that photos may not be able to entirely capture. Plus you can make those intangible notes on a sketch map then and there that may not be possible with a photo. When processing TLS data back in the lab, occasionally months after it was collected, a detailed sketch map can be invaluable for fixing problems with data and for reacquainting yourself with the field site.

Use your field notebooks and include:

1. Scanner Locations
   a) Label 1^{st}, 2^{nd}, 3^{rd} positions, etc., however many scans the project needs.
2. Control Target/Reflector Locations
   a) Reflector type and shape
3. GPS locations and which control target they coincide with.
4. Distinguishable geologic, hydrologic, biologic, or man-made features (rock out-crop, stream, big tree, building, ect.)
5. Cardinal Directions clearly labeled.
6. The more details, the better. You want it to make sense if you need to revisit the site for a repeat scan another day.

Example Problems

EXAMPLE PROBLEM #1

Beam Divergence Formula

Df = (BD * d) + Di

Df = Final beam diameter
BD = Beam divergence
d = distance traveled
Di = Initial beam diameter

Spot size of the beam 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. Using a Riegl VZ-400 scanner, with a beam divergence of 0.35 millirads and an initial beam diameter of 0.007 m, calculate the final beam diameter at various distances. Use the above given formula and remember to convert millirads to radians.

Beam Divergence (radians)	Distance traveled (m)	Initial Beam Diameter (m)	Final Beam Diameter (m)
	10		
	50		
	75		
	100		
	200		
	350		
	500		
	800*		

*Beyond the range of a VZ-400

EXAMPLE PROBLEM #2

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 range, but remember that range of targets can and will 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

$$SS = SA * R$$

SS = spot spacing
SA = stepping angle (radians)
R = range

Based on Riegl TLS specifications, we will use a minimum stepping angle of 0.0024° and a maximum of 0.288° for the vertical orientation. Given the various stepping angles, calculate the spot spacing of each scan with a target at 280 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°, but with a larger maximum angle of 0.5°. Notice the effect changes in stepping angle has on resolution and think about how to approach a project with targets at varying ranges, to maximize time efficiency and quality of data collection. It is important to note that the smaller the stepping angle, the more data you'll 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)	Range (m)	Spot Spacing (m)
0.0024°		280	
0.005°		280	
0.01°		280	
0.05°		280	
0.1°		280	
0.15°		280	
0.2°		280	
0.288° (vert. max)		280	
0.394° (horizontal)		280	
0.5° (horizontal max)		280	

Riegl VZ-400 Equipment List

Principal Investigators: ______________________________

Project Site: ______________________________ **Date:** ____________

Items	Quantity	Notes

Notes