Using Differential GPS to Determine Range Accuracy and Precision of Terrestrial Laser Scanners

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Introduction

Terrestrial Laser Scanners (TLS) use LiDAR (Light Detection And Ranging) technology to create three dimensional point clouds of surfaces. They operate by emitting a pulse of light that reflects off of surfaces and back to the scanner, measuring the time of flight to accurately position the return in 3D coordinates. These data can be used to create high resolution topographic maps and calculate volumes of land and ice masses. Manufacturers of TLS equipment often only give accuracy and precision measurements for a100m range, however researchers in the field often need to scan areas greater than 100m and must have the ability to report errors at these larger distances. As the range increases, beam divergence causes the laser spot size, or beam diameter, to increase which in turn decreases both accuracy and precision. This project builds on the 2015 Geo-Launchpad TLS project in which initial accuracy and precision results were obtained, though without a conclusive trend and without the use of an independent measuring device to obtain true point locations. This year, the project was expanded to use differential GPS, a technology capable of sub-centimeter positioning, in conjunction with the TLS equipment to determine the variation in accuracy and precision of the RIEGL VZ-400 TLS scanner.

Figure 1: The RIEGL VZ-400 terrestrial laser scanner with the Zephyr Geodetic antenna mounted on top.

Figure 2: Alex Olsen-Mikitowicz displays the target mounted to the lateral translation bar.

Figure 3: Red target with Zephyr Geodetic Antenna.

Methods

We scouted and selected an adequate field site at Boulder Reservoir in Boulder, CO. Within the UNAVCO warehouse, we constructed a mount to fit a reflective target onto a lateral translation slide. This target was capable of accurately translating horizontally to 0.1mm. Field site set up was performed the same for every data collection day.

1. A GPS station was affixed over a municipal benchmark approximately 1 mile from the scanner in order to provide a local base station with which to derive accurate GPS solutions.

2. The scanner system was centered and leveled over a mark on the ground (in this case, a nail with a dimple in the center) and fixed with a Trimble Zephyr Geodetic antenna.

3. The target, a reflective red disc 16.25cm in diameter, was centered and leveled over a mark at 100m intervals from the scanner, with ranges running from 100-500m for a total of 5 data collection points.

4. A Trimble Zephyr Geodetic antenna was affixed atop the target, and once the scanner warmed up, atmospheric conditions were recorded at both the scanner and target locations in order to effectively calibrate the RIEGL VZ-400.

5. Scans of the target location were taken ten times and recorded using RIEGL software, RiSCAN.

6. The target remained stationary for 2 hours to provide an ample GPS occupation measurement in order to reduce error to 2-3mm.

The process was repeated at the 5cm interval, and again a 3rd time at the 10cm interval. Each target scan produced a point cloud of the target which the scanner then used to calculate center point coordinates. Scanner native coordinates and the GPS global coordinates for each set of scans were manipulated to the same coordinate system, using the laser source as the coordinate system origin. Using this new coordinate system, the scanner-determined coordinates of the target center points were compared to the GPS solutions, allowing for the accuracy and precision of the RIEGL VZ-400 to be determined for each 100m range interval. We expected to identify a trend line illustrating how precision and accuracy are affected by range.

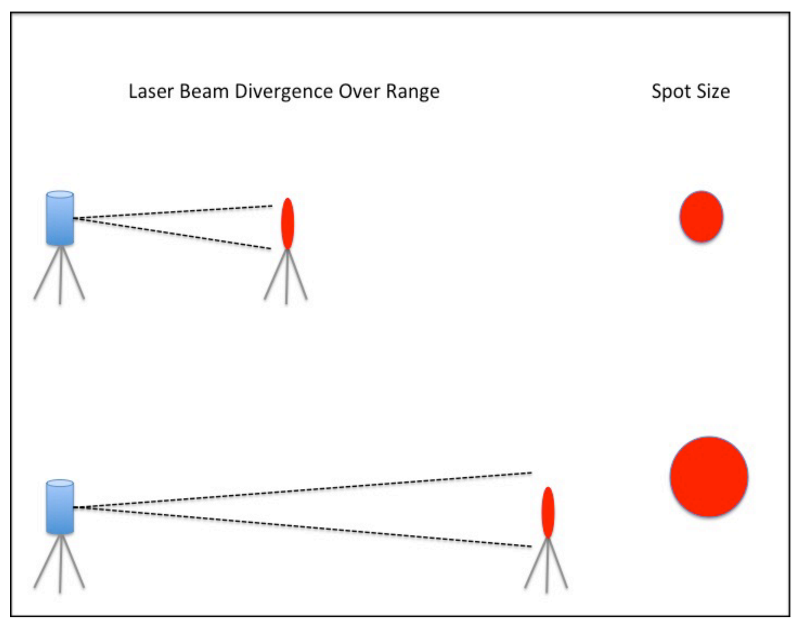


Figure 4: Laser beam divergence increases over range which causes an increase in the spot size.

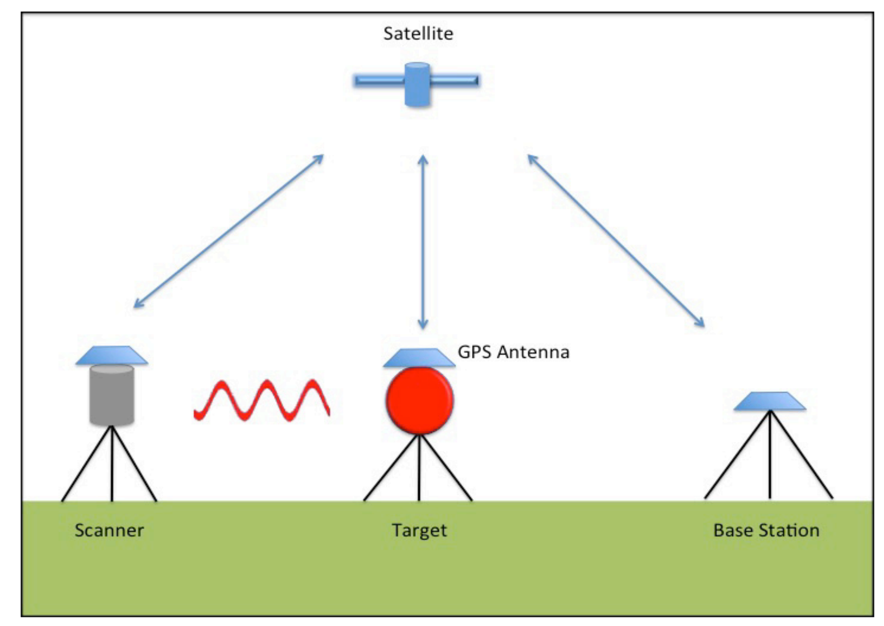


Figure 5: Three stations; the laser scanner, the target and the base station each had a Zephyr Geodetic antenna attached to the top in order to gather differential GPS data.

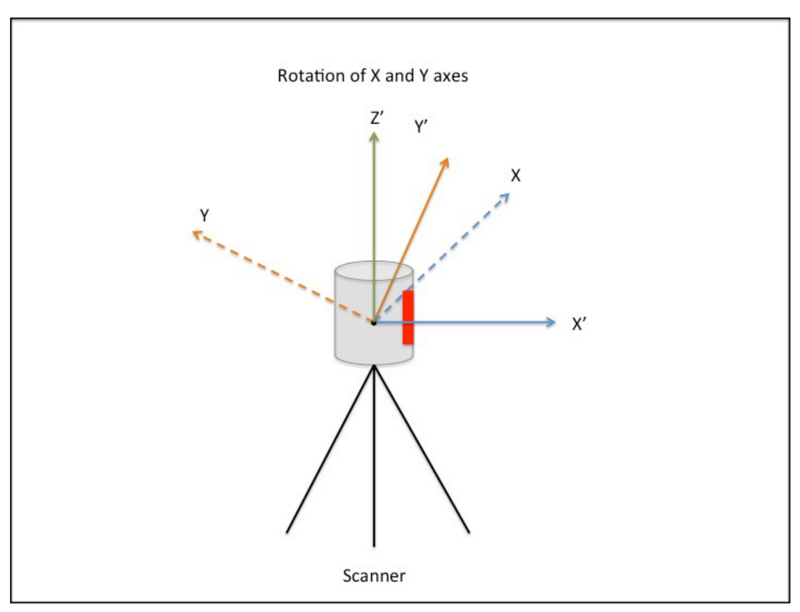


Figure 6: Rotational matrix computations were used to allign the scanner native coordinates with 0cm lateral target location.

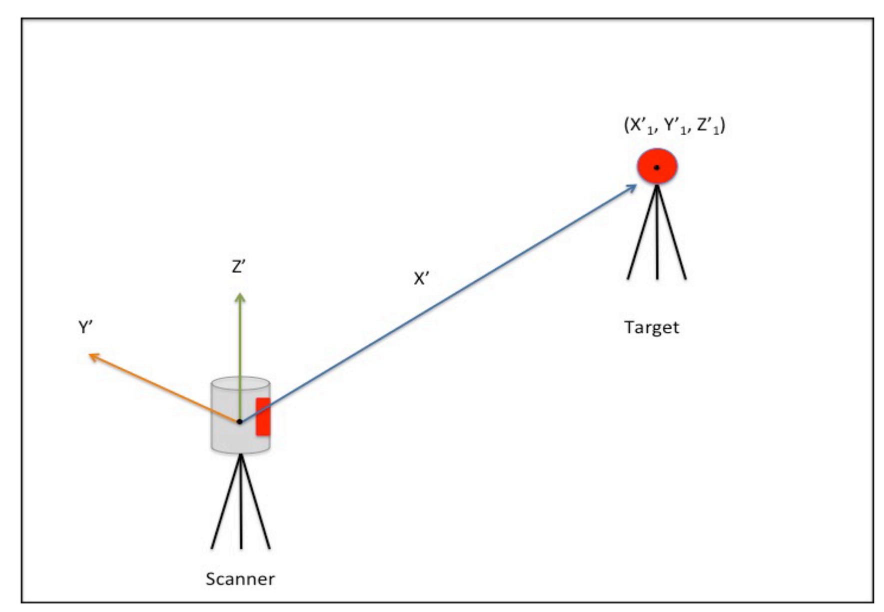


Figure 7: Resulting project coordinate system. Both scanner and GPS native coordinate systems were centered at the laser source and leveled with the vertical. The X' axis was oriented along the the 0cm target position.

Field Test Results

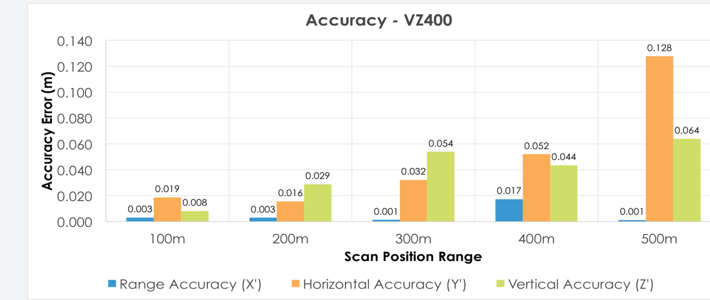


Figure 8: Average accuracy values for 3-D components. Accuracy for VZ-400 is dependent on y and z error due to limitations of the level compensator and beam divergence. Accuracy increases with range.

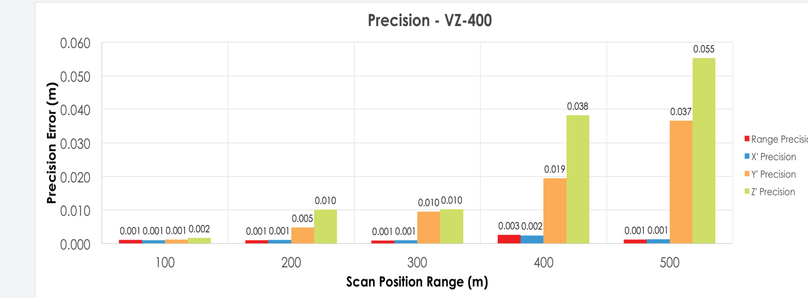


Figure 9: Standard deviation of center point coordinate derived from VZ-400 scans. Over large distances (>100m) precision becomes dependant on y and z error due to limitations in the scanner's level compensator and beam divergence. Precision increases with range.

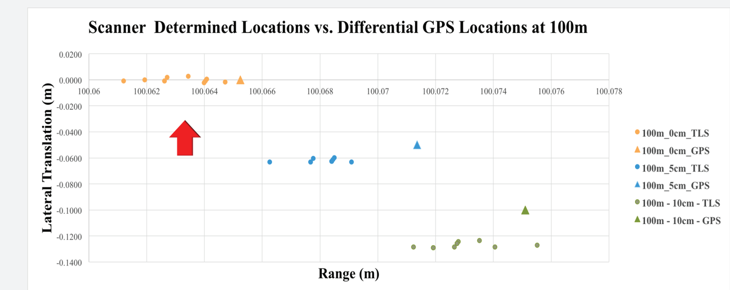


Figure 10: At 100m the scanner-derived locations and the GPS determined location are within 1-2cm (accuracy). Center point clusters for each lateral translation are within 3-5mm (max precision error).

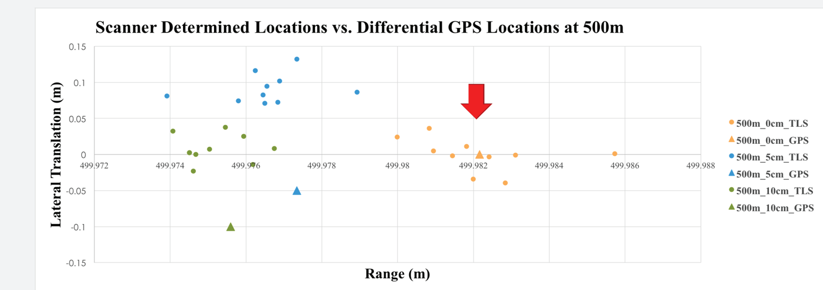


Figure 11: At 500m accuracy error increases to 10-15cm and precision errors increase to an average of 5cm.

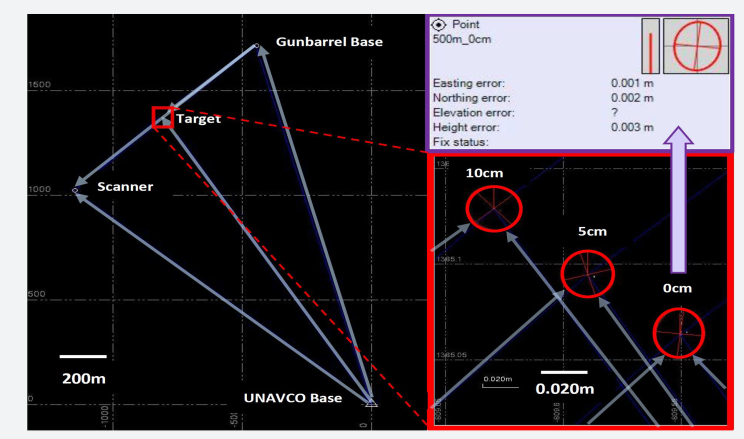


Figure 12: GPS solutions for the scanner origin and target positions were determined using two local bases stations, UNAVCO and Gunbarrel (solution shown for 500m data). GPS positioning errors ranged from 1-2mm in the horizontal plane and from 2-3mm in the vertical. The error for the 500m, 0cm target position is shown.

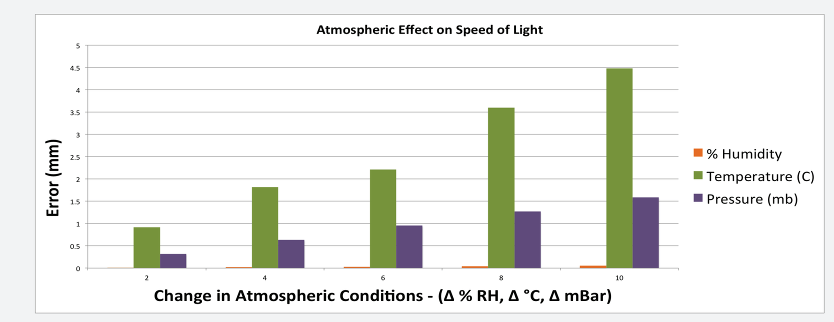
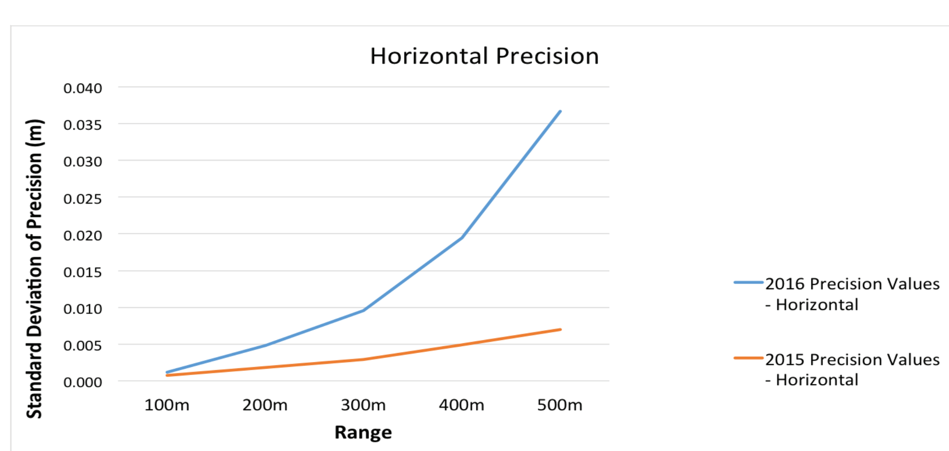


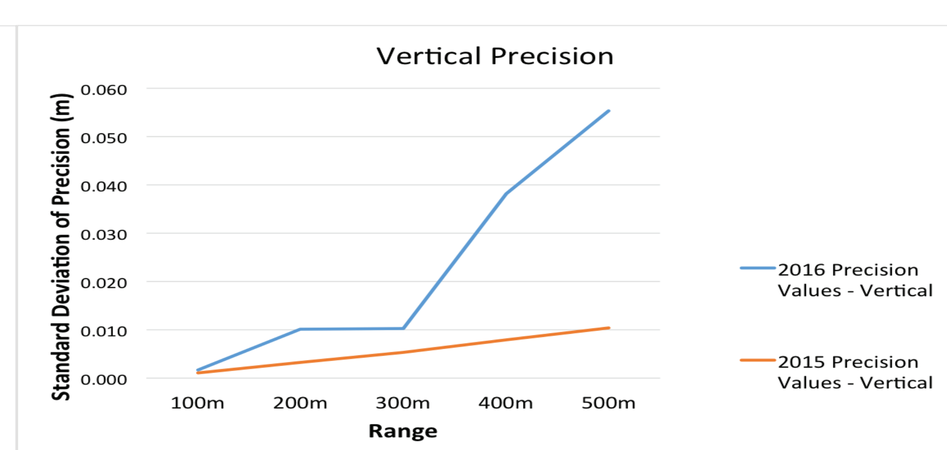
Figure 13: Ranging error associated with change or error in relative humidity (orange), temperature (green) or atmospheric pressure (purple) for a target at 300m (600m total distance traveled). Speed of light calculated using the modified Edlén refractive index equation.

Discussion

As expected, the precision of the RIEGL VZ-400 was inversely proportional to range. When the precision was broken into range (x'), lateral (y'), and vertical (z') components it became evident that range precision remains high and fluctuates very little at increasing distances. The high level of range precision can be attributed to the scanner's ability to consistently measure the laser's time of flight. In the horizontal and vertical planes however, the precision is much lower. These components made up over 90% of the standard deviation of precision (with the vertical component accounting for the largest error). We believe this is attributed to the instrument's diminished ability to measure angle of incidence when returning to the scanner, which is partially dependent on the instrument's internal leveling mechanism.

Scanner accuracy was also inversely proportional with range. Data collected showed as range increased, scanner accuracy decreased. Again the scanner accuracy was broken down into range (x'), lateral (y'), and vertical (z') components and analyzed individually. As with the precision analysis, range was highly accurate due to internal processes for measuring laser time of flight. Scanner accuracy was predominately comprised of lateral and vertical error components, each increasing with range. As with precision, accuracy error in the lateral and vertical components is believed to be in part caused by the instrument's internal leveling mechanism limitations.





Comparative Geo-Launchpad TLS Analysis - 2015/2016

1. Target used in 2016 was approximately 60% size of target used in 2015 - A larger target will provide more scanner returns at greater distances

2. Vertical values were left uncorrected in 2015 - Due to lack of GPS incorporation

3. Different instruments were used which contributed to some comparative error

Conclusion

- Differential GPS can be used to determine TLS scanner precision and accuracy values.
- A trend may not be obvious; values for precision and accuracy may need to be calculated for each survey using GPS control points to truth the laser measurements.
- Atmospheric effects – including particulates such as dust or smoke in the air introduce significant errors in point cloud precision and accuracy.
- Instruments of the same make and model may have differing internal sources of errors; this should be evaluated.

Spot Size
- Spot size of scanner diverges by 0.35mrad.
- At 500m, spot size is 17.5cm while the target size was only 16.5cm. Only 1 point represents a 17.5cm area
- Greater spot size diminishes scanner's ability to differentiate objects.

Atmospheric Effects
- Speed of light is affected by medium. Differences in temperature, relative humidity and pressure will affect speed.
- Differences reported between scanner and target each day; these were averaged.
- Measured using Kestrel Weather Station; not very precise
- Temperatures varied from 65 – 100 F, Relative humidity from 20% to 65%, pressure by 1-2 mbar due to diurnal cycle, storm patterns, etc.
- Scans were sometimes collected 1hr after atmospheric conditions measured.
- Smoke from local forest fire may have also impacted speed of light (smoke scent was observed during 100m and 200m data collection days).
- Above factors could account for 2-5mm errors.

Inconsistent Equipment Usage
- On day of 300m data collection, a different VZ-400 scanner was used.
- Further testing with different instruments needed to determine scale of error associated with different instruments.

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