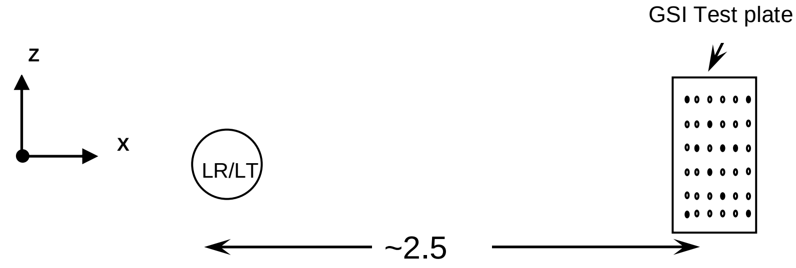
Chapter 1

Laser radar and laser tracker instrument comparison

This chapter explains the similarities between the different instruments after measuring the almost exact same target setup. We used data that we will mention in Chapter 4, which we collected with the laser radar (LR) and laser tracker (LT). In this chapter we want to show repeatability and agreement among the measurements. Both instruments were used separately to measure specific targets in the almost exact setting, and then best fitted their measurements using the software used to gather the data, Spatial Analyzer. The results of the fitting and the propagation error associated to each point are presented bellow.

1.1 LR and LT best fit transformation

The data used to apply the best fit transformation in this section is presented in Chapter 4. In that chapter it is used to measure the offset created by the presence of the window. In this chapter, we use it to compare the instruments to one another. To accomplish this assignment, the test setup consisted of the LR, LT and the GSI (Geodesic Systems Inc.) test plate approximately 2.5 meters away from the instruments to measure the targets, tolling balls (TB) and spherically mounted reflectors (SMR) respectively. We will later explain why we decided to use these targets. We located the targets on the plate, such that the line of sight between the laser beam emitted by the instruments and the middle of the plate lied in a plane roughly perpendicular to gravity, as shown in Figure 2.

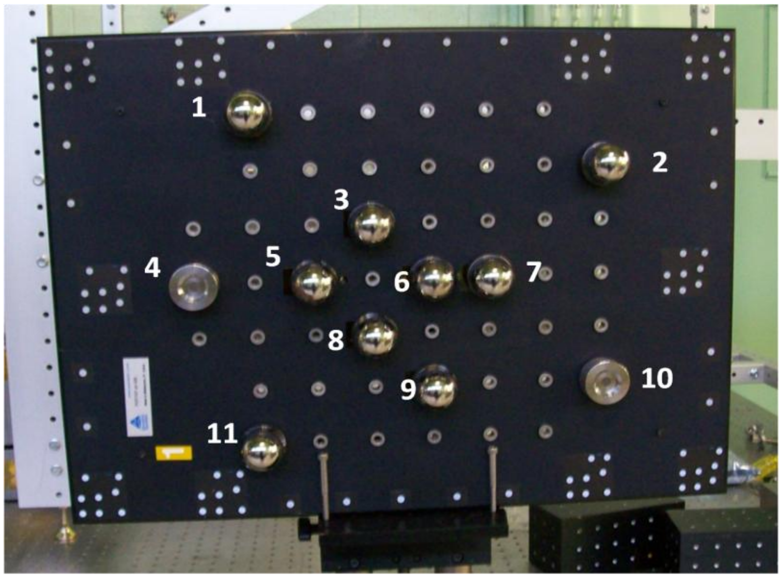


<u>Figure 2</u>: Experimental test setup without window (side view).

The instruments comparison is intended to show repeatability and agreement among the laser radar and laser tracker by doing a best fit analysis using spatial analyzer.

The LT has been commonly used for years to measure solid structures or to track certain displacements. The LR, on the other hand, was recently acquired and there are still many features left to examine and understand. Therefore, the objective of this comparison was to verify the laser radar's capabilities and determine how comparable this instrument is to the LT, which is known to have the capacity to resolve micrometer displacements.

We decided to compare the SMR to the TB because these targets are very similar to each other, given that both have the same diameter, 1", and both fit on the same GSI plate mounts. The 11 target distribution on the test plate in shown in Figure 3. It is important to mention that we decided to have an 11 target setup because we wanted the most amount of data and we only had 11 mounts; however we also only had 1 SMR and 9 TB, this implied that the targets would have to be relocated for almost every measurement. The target arrangement presented in Figure 3 had the widest spread for the measuring beam, since we had mounts all across the test plate.



<u>Figure 3</u>: Target arrangement on GSI plate.

We also measured each target location 10 times (10 cycles) with each instrument, giving us enough data to eliminate bad points (see Figure 24). The LT measured the 11 SMR locations and the LR measured the 11 tolling balls locations. We calculated the average and standard deviation for the 11 target locations and we used these values to calculate the propagation error.

After we measured all the target locations, we carefully observed each data point to verify with the naked eye that they were all on the same plane, because after we measured the first cycle, we found that the target mounts would sometimes move of out place. Since the mounts were introduced into the GSI plate holes, like the ones shown on locations 4 and 10 of Figure 3, the targets were held on to the mount magnetically. Because the mounts were magnetic, we observed that when moving the targets from one mount to the other, the mount could come out of the plate a few millimeters. We only noticed this happened at the end of the first measuring cycle, after we reviewed all the data on the screen. When we realized this occurred, we proceeded to measure the first cycle again, since we did not know exactly when this had happened. For the following measurements we were careful not to move the mounts out of place and dedicated close attention when changing the targets location. However, it is very possible that the mounts moved a few microns, since every cycle we had to move some targets around. The systematic error introduced by the possible plate motion will be taken into account in the standard deviation of the data at every specific location.

Ideally, we should not have moved the targets from mount to mount, but we simply did not have enough targets to match the amount of mounts.

Once we measured the targets and calculated their average value position in excel, we obtained 22 sets of coordinates that we plotted into spatial analyzer, 11 belonged to the LT and the other 11 to the LR. We then applied the best fit transformation to both sets of points. The best fit transformation is a mathematical procedure known as a Least Squares Adjustment (see appendix A). The transformation uses least squares optimization methods, to solve for and then apply the method to the measurements. This optimization method seeks to minimize the square of the distance between each pair of points in two coordinate sets.

The best fit transformation results are shown in Table 1 and indicate a reasonable agreement between the data collected with the laser radar and that collected by the laser tracker. The label 'Target' of Table 1 indicates the number and order of the targets shown in Figure 3. For most of the dMag values, which indicates the square of the distance between each pair of points, the distance is less than 40µm, and only 3 out of the 11 targets indicate a separation ≥ 40µm. ΔdMag indicates the error propagation. The formula used to calculate this error is shown in section 4.3 of Chapter 4.

Table 1: Best fit transformation results and its error propagation.

Target	dMag [mm]	ΔdMag [mm]
1	0.051	0.013
2	0.025	0.020
3	0.034	0.010
4	0.038	0.010
5	0.011	0.009
6	0.028	0.012
7	0.070	0.007
8	0.017	0.016
9	0.025	0.012
10	0.040	0.024
11	0.015	0.013

When looking at the distance with its corresponding error, in some cases, the error can make the distance difference reduce to only a few micrometers, so that some targets when optimized are almost exactly on the same location.

For the case of the distance of 70μm for target 7, it is possible that there could have been an error associated with the measurement, or perhaps the mount could have moved out of place a few micrometers. We previously mentioned that we observed this happen once and that an effort was made to avoid this, nonetheless, it is possible that it occurred again without our knowledge. Another acceptable justification for the small micrometer difference mentioned before could be related to the SMR. It is important to keep in mind that these targets have a small offset associated with their fabrication configuration. The apex of the corner cube does not agree exactly with the center of the sphere (see Figure 4), because it is shifted a few microns to the side, and the instrument measures the apex location, not the center. This creates an offset between the TB data and the SMR data, because the laser radar does measure the location of the center of the TB. This offset is not important when all the measurements are collected with the same instrument and targets, because it would remain constant throughout the entire data collection, but it becomes important when measuring with different instruments, like we are doing now.

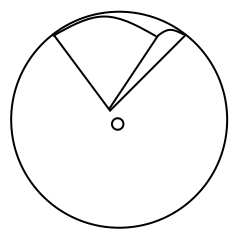


Figure 4: Spherically mounted retroreflector.

Since both targets, TB and SMR, have the same diameter, the slight center shift of the SMR could come into play when best fitting them, and this small micron shift could explain some of the disagreement between the data presented in Table 1.

Another possible explanation for the disagreement is the LR itself, as we mentioned previously, the LR is a reasonably new instrument in this field and there is still a lot to learn about it; but tests like these (comparative) help us prove their capacity when measuring similar targets in atmospheric conditions.

However, even considering the SMR offset and without a complete knowledge of the LR functionality, the best fit results still show agreement and indicate that the LR can measure the tolling balls almost as well as the laser tracker can measure the SMR, making the instruments comparable to the other.