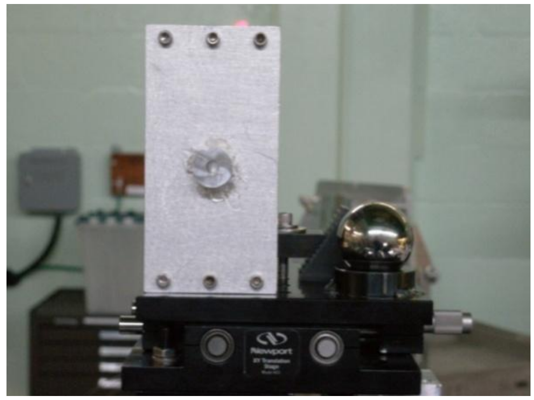
Chapter 2

Instrumental resolution verification and different target type comparison

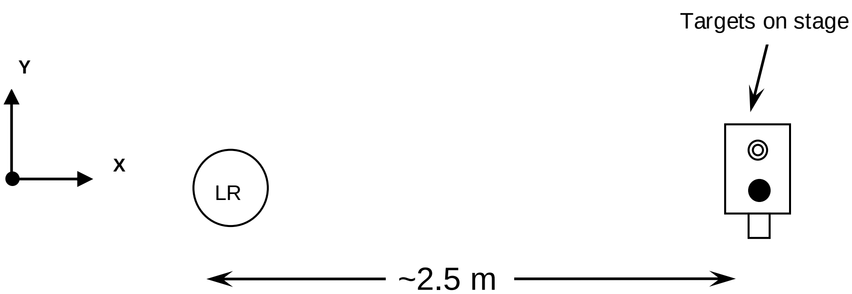
This chapter explicates how we verified the laser radar's fabricators resolution and how we compared the ability of this same instrument to measure two different types of targets. Resolution refers to the capacity of the instrument to resolve micrometer shifts. We used a translation stage for this test. The stage had two different measuring features on it, a hole and a tolling ball. We manually shifted the targets a small known distance with the stage knob and measured that distance with the LR. We verified the instruments resolution by manually and instrumentally measuring the same distance. To compare the laser radar's target discrimination ability, we measured both targets and then performed a best fit analysis to the averaged measurements.

2.1 Laser radar resolution verification

The setup we used for the resolution verification had 2 distinct target features on a translation stage, a hole feature and a tolling ball with a micrometer knob on the base of the stage for displacement. To verify the LR measurement, we measured the targets at 11 different locations using the micrometer knob. The distribution of the targets on the translation stage is shown in Figure 5. The experimental arrangement of the instrument with the targets is indicated in Figure 6 which is similar to the one presented in Figure 2, but this figure has a translation stage instead of a test plate.



<u>Figure 5</u>: Hole feature and tolling ball on translation stage micrometer.



<u>Figure 6</u>: Experimental setup with LR and targets on a stage (top view).

Figure 6 illustrates a distance of approximately 2.5 meters between the targets on the translation stage and the instrument. We determined this distance by a previously resolute arrangement, where a cryogenic calibration test would take place using the LR at approximately 2.5m from the observing targets. Since the data collected in this experiment will help determine which target is better measured with the LR, we had to comply with the 2.5m distance that would be used in the later experiment.

It is important to mention that an effort was made to have the measuring beam perpendicular to the direction of the displacement of the stage, which was on the y axis. However, since the stage had to be elevated to meet the LR beam, which we know is more accurate when is parallel to the floor, it is very possible that the stage was not lying on a completely flat surface and that a small inclination of the stage could appear in the measurements.

To verify the laser radar's resolution, we began to measure the position of the tolling ball followed by the position of the hole, using the hole feature on the software (SA), each of which was measured 10 times per location. The targets were measured at 0µm, 10µm, 20µm, 30µm, 40µm, 50µm, 100µm, 150µm, 200µm, 500µm, 1000µm. We considered the first measurement collected to be located at 0µm. We displaced each target with the stage micrometer, which can be seen in Figure 6 at the lower right side of the figure. The stage displacement was performed by the same person throughout the entire test, so that the error introduced by the manual shift would remain constant during the data collection. After we measured all 11 positions a total of 10 times each per target, we properly labeled the data and stored it in spatial analyzer.

SA stores the location of an object using x, y, and z coordinates and we set the origin of the system on the instrument's head, where the measuring beam of light was originated. The location of each target had a set of coordinates associated to it. We saved the data in excel spreadsheets to calculate the average coordinates of the 10 measurements for every location. Once in excel, we calculated all the averages and error propagations. During this process we completed an overall look of the measurements, to verify that the data did not include bad points, that could have appeared when labeling or even during the data collection, because in some cases the hole feature can get a bad signal return and can measure something other than the hole. Therefore, when calculating the averages, we took some time to corroborate that the measurements had logical values, because when they did not, we considered them to be bad points and were not taken into account when averaging and calculating the standard deviation. An example of what was considered a bad point is illustrated in Figure 24.

After we averaged all the data in excel, we created two new point groups in SA, one for the hole averages and the other for the tolling ball ones. Each point group contained 11 sets of coordinates, one for every target location. Afterwards, once we plotted the points, SA measured the distance between each point; we did this to compare the instrumental measured distance with that measurement done with the micrometer. The following 4 plots show the distances measured with the LR and compare those to the micrometer measurements. The plots also include the propagated error associated with each point calculated with equation *(9)*. Figure 7 and 8 illustrate the laser radar measuring the hole feature. Figure 7 shows the 11 data points and figure 8 zooms into figure 7 to show the instruments resolution for the first 6 locations, from 0µm to 50µm. Figures 9 and 10 illustrate the LR measuring the tolling ball, again, figure 9 shows all the points and figure 10 only the first 6 measured locations.

Figures 7 through 10 show an agreement between the measurements. The 3 distances indicated in Figure 7, when observing holes, are considered large displacements (200µm, 300µm and 500µm), given that the instrument is capable, according to its fabricators, of resolving up to 8µm for every meter away from the instrument. The targets are located approximately 2.5 meters away from the originated beam, so we would expect the instrument to resolve up to ~20µm. The distances indicated by the arrows in Figure 7 were 200µm, 300µm and 500µm. For the second and third distances (300µm and 500µm respectively), the LR measurements within its error, agree with the micrometer measurements. For the first case (200µm), within its uncertainty, there is a difference of

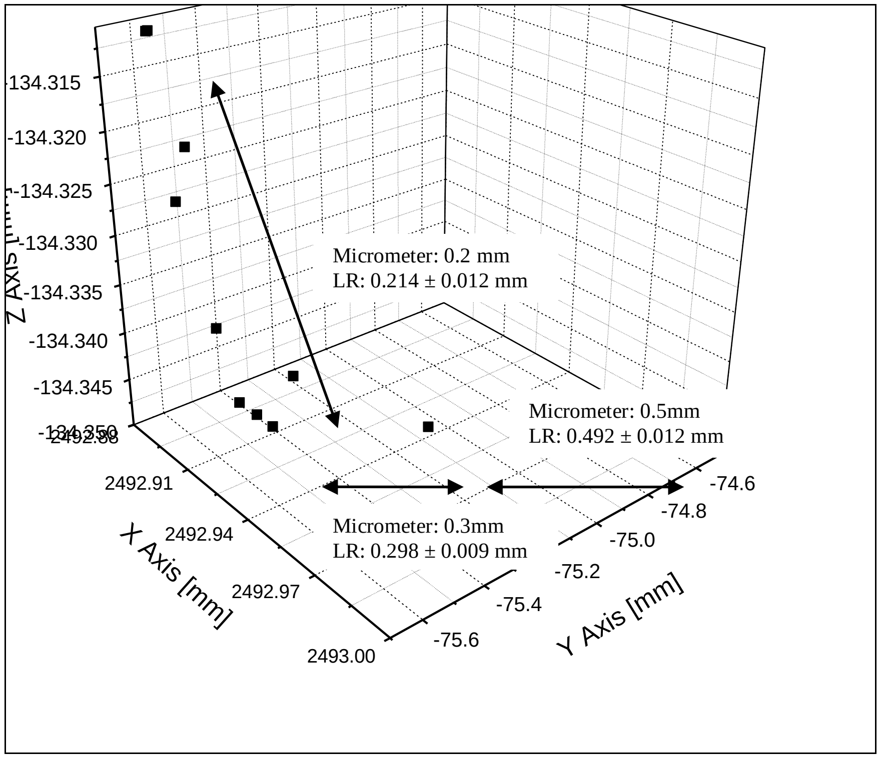
2μm from what we expected. Considering the capabilities of the LR previously mentioned, 2μm is an acceptable disagreement and the measurement is considered agreeable.

Figure 8 shows some of the data presented in Figure 7, but it is more resolute than the first one. The 5 steps showed on this plot are 10μm steps each. Two out of the three of the comparisons presented, even within the uncertainty, do not agree with the micrometer measurements. However the differences measured 2μm and 5μm disagreements, both of with are small and acceptable.

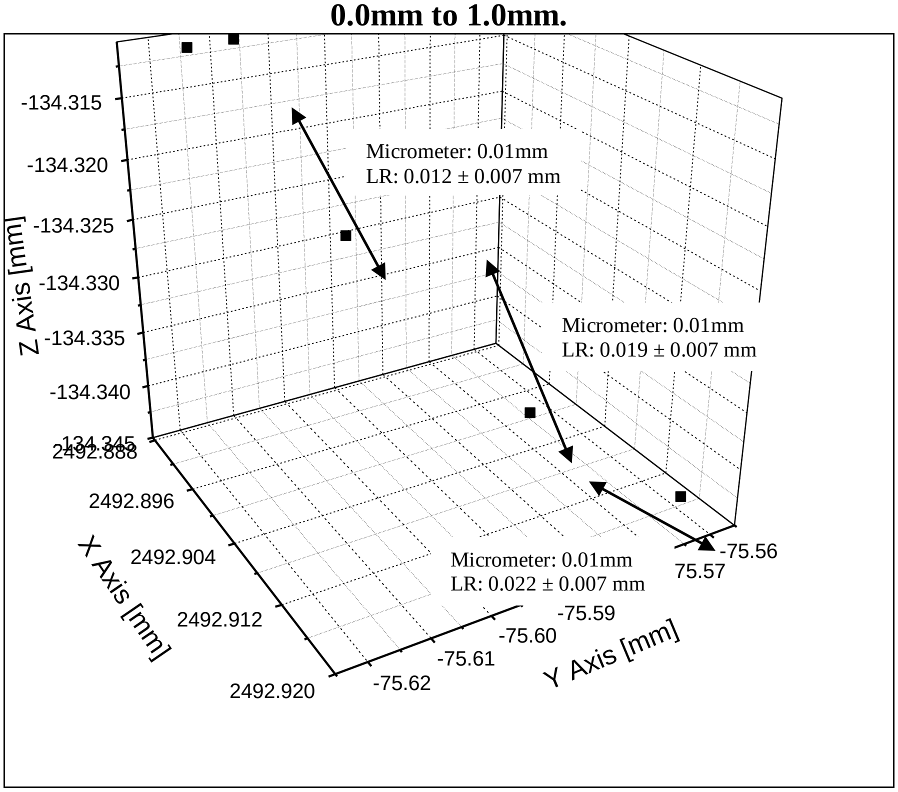
Figures 9 and 10 present the measurements collected by the LR when observing the tolling balls. Figure 9 exhibits a range of data gathered from 0.0 to 1.0 millimeters. This plot compares 200, 300 and 500 micrometer displacements. Most of the LR measured values agree with the micrometer measured values, and when they do not, the 1μm and 2μm disagreement is acceptable, as we had mentioned previously. Figure 10 zooms into Figure 9, showing the data collected from 0 to 50 microns, in 10μm steps. In this figure there is an agreement between all the results presented because all the LR measurements within its error agree with the micrometer measured values.

Looking at the 4 figures together and comparing the LR capabilities when measuring the hole feature and the tolling ball, we can say that the instrument can better resolve the tooling ball displacement rather than the hole displacement. The micrometer measurements had a better agreement with the TB data than with the hole data, when both were compared with the LR measurements.

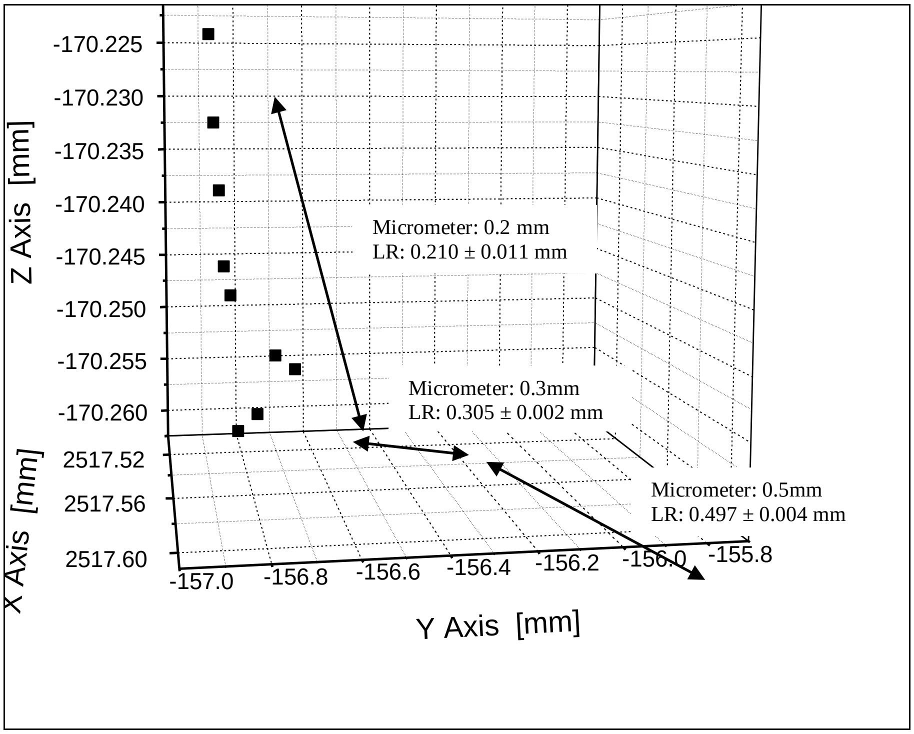
It is important to remember that according with the instrument's fabrication specifications, the laser radar should have a resolution of ~20μm for a 2.5m distance from instrument to target, however, the results presented above show that it is capable of resolving half of what the fabricators specified, ~10μm for a 2.5m distance from the instrument.



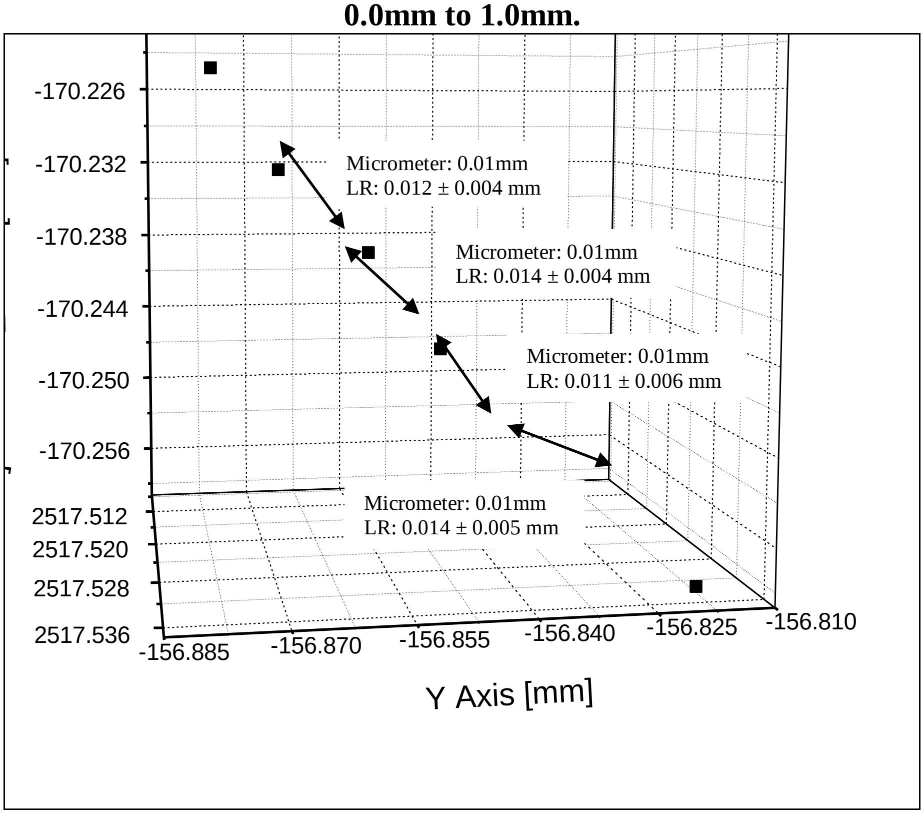
<u>Figure 7</u>: LR data vs. micrometer data measuring the hole feature from 0.0mm to 1.0mm.



<u>Figure 8</u>: LR data vs. micrometer data measuring the hole feature from 0.0mm to 0.05mm.



<u>Figure 9</u>: LR data vs. micrometer data measuring the tolling ball from 0.0mm to 1.0mm.



<u>Figure 10</u>: LR data vs. micrometer data measuring the tolling ball from 0.0mm to 0.05mm.

At the beginning of this section we had mentioned a couple of things that we will now discuss again. First that, we made an effort to have the translation stage shift in a perpendicular direction to that of the incident measuring beam, and second, that it was possible that the stage, because it was elevated from the work table, might have been lying on what seemed a flat surface but was not. After looking at Figures 7 and 9, if the stage was indeed on a flat surface and was displaced in a direction perpendicular to the incident beam, we would expect to see the measurements fall on a somewhat continuous linear fit and not a set of 'jumpy' non continuous points, which appear on the z axis. This could indicate that the stage was shifting up and down a few micrometers when we rotated the micrometer knob and/or the stage was not being displaced perpendicularly to the measuring beam, because we did measure a submicron shift in the z axis. For the purpose of this test, these small displacements in the z axis will be neglected, but it is important to note that they were present in the measurements.

All the plots presented show a strong agreement between the data measured with the LR and the displacement measured with the micrometer. This allowed us to verify the instrument's resolution stated by the fabricators specifications and to note that under ambient conditions the LR can have a resolution of up to ~10µm for a 2.5m distance away from the measuring instrument, rather than ~20µm for a 2.5m distance, stated by the fabricator, Metris.

2.2 Different target type comparison

Apart from knowing the instrument's resolution we were also interested in determining which target was more accurately measured by the laser radar, the hole or the tolling ball.

To measure the difference between these targets we used the data collected, averaged and saved in section 2.1. Afterwards, we labeled the target locations in SA. It was important that when we labeled the new points, we did it in the order they were measured and both points groups were labeled the same, otherwise, we would have not been able to best fit the 2 sets of data, because for SA they would have not been correlated. Subsequently, we performed a best fit transformation between the 2 sets. The best fit results and the error propagation associated with them are shown in Table 2.

Table 2: Best fit transformation results and associated error propagation

Target location	dMag [mm]	ΔdMag [mm]
1	0.003	0.010
2	0.008	0.008
3	0.003	0.006
4	0.011	0.007
5	0.006	0.008
6	0.002	0.010
7	0.003	0.008
8	0.009	0.009
9	0.006	0.010
10	0.006	0.009
11	0.006	0.007

The best fit transformation was the same one that we applied in Chapter 1, this transformation used an optimization method that seeks to minimize the square of the distance between each pair of points in two coordinate sets (see appendix A).

The best-fit transformation in SA allowed us to see the difference between two sets of measurements. The dMag in the table is the difference between the 2 sets of data. ΔdMag refers to the calculated error associated with dMag, we calculated this error using the error propagation formula (equation *(9)*), which takes into account the errors in all 3 dimensions. These errors originated from the calculated standard deviations of the 10 cycles of data. Target location refers to the location of the targets throughout the measurements. There were 11 locations in the following order: 0µm, 10µm, 20µm, 30µm, 40µm, 50µm, 100µm, 150µm, 200µm, 500µm, 1000µm.

When we began the data collection we observed that the LR could easily measure the TB feature, but the holes were more complicated to measure. When measuring a hole we had wait longer for the measurement to complete, we also had to input an approximate hole diameter, a rough champher size, and if the front surface was not completely flat, that could have represented a problem with the signal return. When measuring a tolling ball we did not have to define anything before measuring, the measurement was easy and straight forward and a lot faster to do. However, the best fit analysis shows a consistent agreement all throughout the 11 measurements for both targets. The minimum difference between the targets was 3µm and the maximum was 11µm. These small differences indicate a strong agreement between the measurements. The instrument was capable of measuring the hole feature equally as well as it can the tolling ball. Even when the target features are different and the measuring time varies also, both target measurements have the same quality and are equally as reliable.