Determination of the reference point of the Metsähovi SLR telescope

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Abstract

Metsähovi Geodetic Research Station (MGRS) operated by the Finnish Geospatial Research Institute (FGI) is one of the core stations of the GGOS. MGRS hosts all the major geodetic techniques with the next-generation SLR (METN) and VLBI systems being finalized. The FGI has been a part of a large EMPIR (European Metrology Research Programme) funded consortium to study the best methods for measuring and establishing reliable and accurate local ties between all the geodetic infrastructure. As a part of the project, we made the first local tie measurements to tie the new SLR system. The SLR telescope reference point is the point in the azimuth axis, which is nearest to the elevation axis, i.e., the axis intersection. To determine the coordinates of the point and get local ties to the other geodetic instruments we used a robotic total station to measure two points attached to the telescope structure from two pillar points outside the telescope dome. The coordinates of the measured points were used as observations in reference point estimation. Results of three different approaches to the reference point calculation are presented, namely antenna model with axis, sphere fitting and circle fitting. The purpose of the measurements was to get the first accurate reference point coordinates and to learn how the process should be automated in MGRS. The results of the antenna model and sphere fitting agreed well.

1. Introduction

The Metsähovi Geodetic Research Station in southern Finland hosts all the space geodetic techniques together with absolute and superconducting gravimeters. For establishing reliable and accurate global and local ties for the instruments, an extensive pillar network is built on a stable bedrock around the station. We have previously developed methods for the VLBI antenna local tie determination (Kallio 2012; 2022; 2023) using GNSS and a total station. We have now extended the method to the new SLR telescope reference point determination. The SLR telescope is still in the commissioning phase and may still undergo small movements during the finalization, hence these results are preliminary, and the measurements will be repeated once the system is fully finalized. The purpose of these measurements is to calculate the first accurate reference point coordinates for the new Metsähovi SLR (METN), possibly reveal major offsets in the axis intersection, and show a proof-of-concept and learn how the process should be automated at MGRS in the future.

2. Measurements

To determine the intersection of the azimuth and elevation axis of the SLR telescope and tie it to the local and global coordinates, we used a robotic total station Leica TC50 to measure accurate locations of two Bohnenstingl 1.5” retroreflectors attached to the telescope’s optical tube assembly, one above the main aperture and another on top of the detector box assembly, see Figure 2. The retroreflectors are magnetically attached on their mounts allowing free manual rotation towards the total station while maintaining a stable reference point.

Measurements were done from two pillars outside the dome (Figure 1.). In a total of 160 different Az and El positions of the SLR telescope were measured and connected to the surveying benchmarks around the observatory. The telescope was rotated around the azimuth axis with approximately 5-degree steps in two different elevation positions. The elevations were approximately 0 and 19 degrees in the first session and 0 and 33 degrees in the second one. The telescope was rotated manually without motor control or accurate angle information from the encoders since the telescope control system was not fully functional. The angle and distance observations of the measured points were connected to the local surveying network with automatic orientation observations to the other pillar points in the network and adjusted together with all network observations made in 2021-2022. The network was oriented in ITRF2014 using inner constraints for rotations using the combined solutions of the local GPS network as the datum and the geoid model for verticals. The position of the network is fixed to the MET3 GNSS-point in ITRF2014 epoch 20:232. The scale comes from Nummela standard baseline because the TC50 distance measurements were corrected using the scale and additive constant determined in the Nummela baseline. The observations were saved directly to the laptop using in-house software.

Figure 1. An aerial image of the MGRS showing the measurements from the pillars to the SLR and reference pillars.

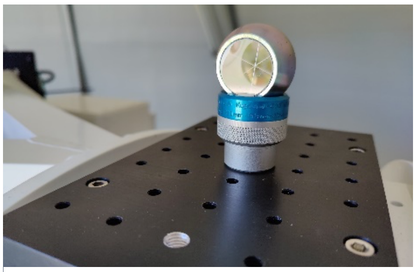


Figure 2. Bohnenstingl 1.5" retroreflector target attached on top of the telescope.

3. Methods for the reference point determination

We used three different calculation methods for the reference point determination: 1) *sphere fitting with a common centre;* 2) *circles around the azimuth axis*; and 3) *the antenna model*, which is a more complicated model with more parameters including axis directions and offset, and which we have used for example in reference point estimation of the VLBI telescope.

3.1 Sphere fitting method

In the simplest model, we fitted spheres to the measured prism points and determined the common centre, Figure 3a. and Table 1. The points of the tracked two prisms are on the surfaces of the spheres with the same centre providing that there is no axis offset and no deformations.

3.2 Circle fitting method

In the 3D circle fitting method, we only circled the azimuth axis. The elevations are kept fixed as best as possible. With the assumption that the circles have rotated around the same axis, we estimated the central points of each of the eight circles and the common axis, see Figure 3b. and Table 1. The position of the reference point in the axis remains unknown. However, the centre from the sphere fitting method fits well to the axis.

3.3 Metsähovi antenna model method

In the third method, we have the coordinates and rotation angles of the telescope as observables. However, as we did not get any *real* telescope angles from the control system, we calculated approximate rotation angles using the centre point of the spheres and the coordinates of the tracked points. The 0-azimuth direction was chosen to be the azimuth from the sphere centre to the first prism in approximate zero orientation. The 0-elevation was in the same direction with a levelled telescope. The approximate azimuths and elevations were calculated then from coordinates. The zero position was kept near fixed and the residuals of the calculated angles were estimated. With this approach, we could estimate the axis directions and axis offset. With the assumption that one Az-El position was common for the prisms, we got an axis offset of 0.33 *mm* ± 0.14 *mm*. Without the assumption, the axis offset was only 0.06 mm. The reference point coordinate between the two calculations was [0.13 *mm North;* -0.07 *mm East;* -0.19 *mm Up*] and agrees very well with the sphere fitting result, see Figure 3c. and Table 1.

Results

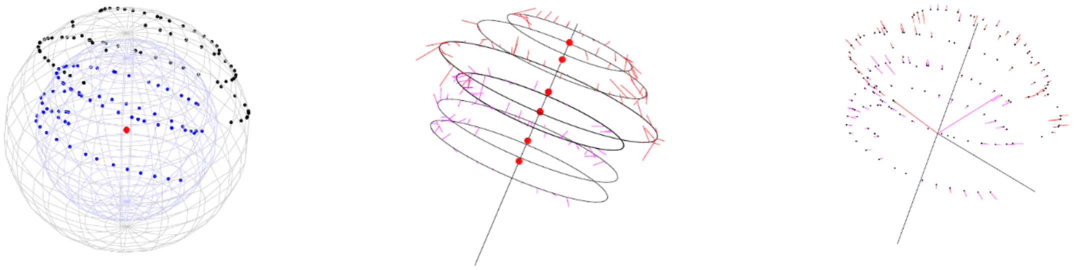
The results of the three approaches are collected in the Table 1. and agree very well. The standard deviations show mainly how well the measured points agree with the chosen model. It seems that we have achieved the goal: less than 1 mm uncertainty for the vector components from IGS GNSS station MET3 to the SLR reference point.

The geocentric *XYZ* coordinates of the METN SLR telescope are:

[X]	*[Y]*	*[Z]*
2 892 596.6060 *m*	*1 311 807.3203 m*	*5 512 611.0610 m*

To fully deploy the antenna model, we need more measurements from different elevation angles and accurate angle information of the telescope pointing. Once the telescope control system is finalized, we can automate the measurement process.

Figure 3a, b, c. From left: Sphere fit, Circle fit and the Antenna model.



Model	**N[m]**	**E[m]**	**U[m]**
std	**sN[mm]**	**sE[mm]**	**sU[mm]**
Metsähovi ant-mod	-17.18160	1.77116	-0.34877
	0.03	0.03	0.08
Spherical fit	-17.18159	1.77119	-0.34863
	0.04	0.04	0.1
circle 0° pr1 P1	-17.18130	1.77028	0.08574
	0.05	0.04	0.08
circle 0° pr2 P1	-17.18145	1.77066	-0.07675
	0.05	0.04	0.08
circle 19° pr1 P1	-17.18104	1.76965	0.35579
	0.05	0.05	0.08
circle 19° pr2 P1	-17.18169	1.77123	-0.31734
	0.05	0.05	0.1
circle 0° pr1 P2	-17.18130	1.77028	0.08584
	0.05	0.04	0.08
circle 0° pr2 P2	-17.18145	1.77066	-0.07618
	0.05	0.04	0.08
circle 33° pr1 P2	-17.18090	1.76932	0.49639
	0.05	0.05	0.08
circle 33° pr2 P2	-17.18185	1.77163	-0.48688
	0.05	0.05	0.08

Table 1. SLR reference point coordinates in North, East and Up from MET3 GNSS, for the spherical, circle and antenna models. P1 and P2 designate the pillars from which the prisms pr1 and pr2 were observed, angle is the approximate elevation angle of the telescope. See also Figures 3a,b,c.

References

Kallio U., Poutanen M., (2012). Can We Really Promise a mm-Accuracy for the Local Ties on a Geo-VLBI Antenna. In: Geodesy for Planet Earth, Springer Science Business Media, pp 35{42, DOI 10.1007/978-3-642-20338-1-5

Kallio, U. et al. (2022). Datum Problem Handling in Local Tie Surveys at Wettzell and Metsähovi. In: International Association of Geodesy Symposia. Springer, Berlin, Heidelberg. https://doi.org/10.1007/1345_2022_155

Kallio U., Eskelinen J., Jokela J., Koivula H., Marila S., Näränen J.,

Poutanen M., Raja-Halli A., Rouhiainen P., Suurmäki H. (2023). Validation of GNSS-based reference point monitoring of the VGOS VLBI telescope at Metsähovi. In the Proceedings of the 5th Joint International Symposium on Deformation Monitoring (JISDM), 20-22 June 2022, Valencia, Spain, Polytechnic University of Valencia Congress. http://doi.org/10.4995/JISDM2022.2022.13691