The 2008 Local-tie Survey at the Onsala Space Observatory

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Abstract. We describe an innovative approach to perform a local-tie survey at a fundamental geodetic station. The work was performed in September 2008 at the Onsala Space Observatory and used a laser tracker as survey instrument. Both the reference point of the radio telescope used for geodetic VLBI and the local tie between the latter and the reference point for GNSS measurements were determined. The application of the laser tracker allowed fast survey work and resulted in accurate coordinates with complete covariance information in a local true cartesian coordinate system. This project is highly relevant for the Global Geodetic Observing System (GGOS).

Keywords. reference point, local-tie, VLBI, GNSS, GGOS, laser tracker

1 Introduction

The Global Geodetic Observing System (GGOS) of the International Association for Geodesy (IAG) aims at a combination and integration of observations and results of the various geodetic techniques in order to support the monitoring of the Earth system and global change research (Rummel et al., 2005). Fundamental geodetic stations that host co-located equipment for different geodetic space techniques, e.g. Very Long Baseline Interferometry (VLBI) and Global Navigation Satellite Systems (GNSS), play a key role for the GGOS. A meaningful combination and integration can only be achieved if the local-ties at these fundamental stations are know accurately. The local-ties are the coordinate differences between the reference points of the geodetic space techniques. The requirements for the reference points are that they are known with an accuracy of better than 1 mm (Niell et al., 2006) and that the full covariance information is available. For the GGOS even a continuous terrestrial monitoring of the local-ties at an accuracy of 0.1 mm is desirable (Plag and Pearlman, 2008).

Usually, local-tie surveys at fundamental stations are performed every couple of years. One of the main reasons for this low repeat frequency is that the local-tie survey work usually is a difficult and time consuming engineering task. Furthermore, did survey work often also mean a considerable downtime for the geodetic space techniques, which is undesirable of course. Traditionally is the local-tie survey often a mixture of direction and distance measurements with tachymeters and height differences from levelling work. Often the local-tie information is incomplete, i.e. the covariance matrix is not complete.

The increased requirements on local-tie information call for new strategies and approaches. In this work we describe an innovative and promising new approach that makes use of a laser tracker as the survey instrument.

2 Laser tracker measurements

Laser trackers instruments are widely used for high accuracy survey work in industry. They can be operated both in absolute and interferometric mode and require retro reflectors, e.g. corner cube reflectors, to reflect the laser beam.

For our project we used an instrument of type Leica LTD840. According to Leica is the 2σ absolute coordinate accuracy that is achievable with this instrument on the order of ± 10 ppm for distances up to 35 m. This includes both the uncertainty of the angular measurements (2 axis) and the absolute (or interferometric) distance measurements. The instrument has a rotating head that emits and receives a laser beam. Its rotation around two perpendicular axes is re-

Figure 1. The laser tracker in its standard operation mode where the tracker head can move ±235° in azimuth and ±45° in elevation.

stricted to ±235° and ±45° and usually the instrument is used with an orientation so that these axes are the primary and secondary axis, respectively, (Fig. 1). However, it is neither possible nor necessary to orient the instrument with one axis parallel to the local plumb line. The instrument's orientation is always derived with transformations based on overdetermined measurements in a network.

3 Determination of the VLBI reference point

The 20m radio telescope at the Onsala Space Observatory is of azimuth-elevation type and is enclosed by a protective radome that prevents any direct observation of the telescope structure from the outside. The telescope reference point does not exist as a material point and is the intersection of the right-angle projection from the elevation-axis onto the azimuth-axis. Neither of the two axes can be observed directly. However, it is possible to mount targets on the telescope structure, in particular on the elevation cabin that is movable both in azimuth and elevation.

The particular situation at Onsala complicates any survey work for reference point determination. A local network of geodetic markers exists outside the radome. Through windows and doors in the radome building this outer geodetic network can be connected to three markers in the concrete floor of the radome building. The three markers are placed symmetrically around the telescope tower and can be connected to five survey pillars that are located on the radome foundation. The radome foundation is a ca. 3 m heigh concrete wall with diameter of about 18 m and surrounds the telescope tower in about 7 m distance to it. The telescope elevation axis is at about 14 m height with respect to the floor of the radome building. Further details on the network of markers and pillars inside the radome building and the outside network of ground markers are described by Haas and Eschelbach (2005).

Due to the geometrical situation it was not possible to use the laser tracker in its standard operation mode (secondary axis with ±45° opening angle) from any point in the radome building to observe any target close to the elevation axis. We therefore constructed an adapter to mount the instrument horizontally on the survey pillars on the radome wall (Fig. 2), so that the telescope elevation cabin could easily be reached with the laser beam due to the ±235° opening angle of the primary axis. In this orientation the laser beam could also reach targets on at least three other survey pillars on the radome wall and targets on all three ground markers in the radome floor, due to the ±45° opening angle of the secondary axis.

Three different types of retro reflector were

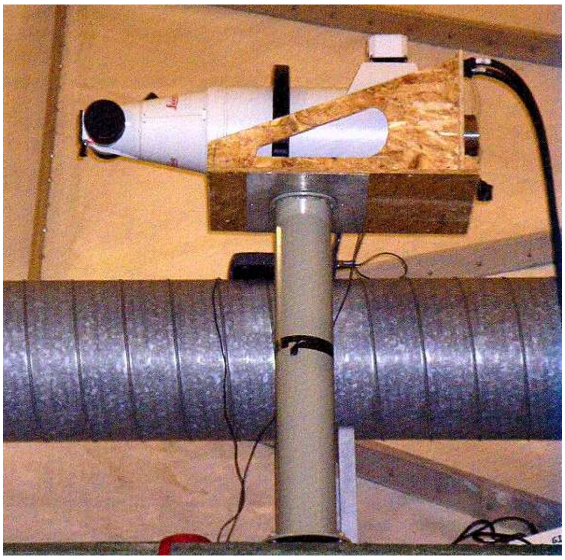

Figure 2. Laser tracker on a survey pillar on the radome wall. The tracker head can now move ±235° in elevation and ±45° in azimuth and thus targets close to the telescope elevation axis can be reached.

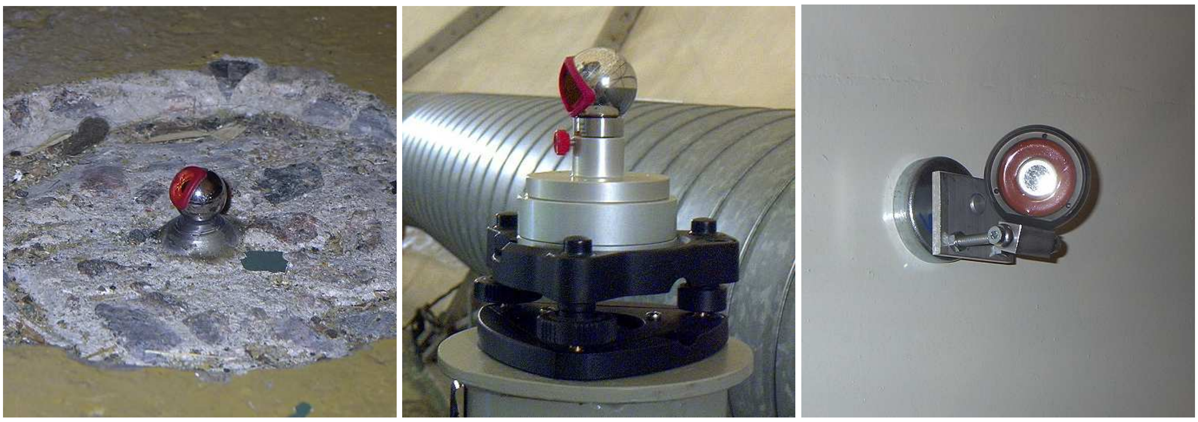

Figure 3. Three different types of retro reflectors used for the survey work: Left: 0.5" CCR used on ground markers; Middle: 1.5" CCR used on the survey pillars; Right: CER used on the telescope elevation cabin.

used for the survey work, see Fig. 3. On the ground markers we used 0.5" corner cube reflectors (CCRs), on the survey pillars 1.5" CCRs, and on the telescope elevation cabin cat eye reflectors (CETs). The latter were mounted with magnets and have an opening angle of 60°, while the CCRs have an opening angle of only 30°.

Measurements were performed from each point of the small network inside the radome building to all other visible points in this network. Two CETs were attached with magnets on each side of the telescope elevation cabin symmetrically at about 1 m distance from the elevation axis. They were observed from each survey pillar at different azimuth and elevation positions of the telescope. A series of tracker measurements was performed in each azimuth position while running the telescope up and down in elevation. Two measurement campaigns were observed with the CETs mounted in two different constellations on the elevation cabin. In total the telescope was positioned in 10 different azimuth positions and in 18 different elevation positions per azimuth position, resulting in 720 coordinated points (Lösler, 2009a).

During the laser tracker measurements the tilt of the instrument was monitored by a levelling device Nivel210. A long-term monitoring of the instrument tilt over 48 hours revealed that the survey pillars were slightly tilting with time when the laser tracker was mounted. However, since the actual tracker measurements did not take more time than about 30 minutes per standpoint, were the tilt changes during this short measurement period negligible. Short term tilt changes due to the movement of the laser head were also detectable, but small in magnitude and negligible, too. Further details on the survey work are given in e.g. Lösler (2009a) and Lösler and Eschelbach (2009).

The analysis of the data was done with two different approaches, performing a one-step analysis with an advanced model (Lösler and Hennes, 2008; Lösler, 2009b), and performing a two-step analysis with constrained circle-fitting (Eschelbach and Haas, 2003). Besides the actual coordinates of the telescope reference point, also the offset between the azimuth and elevation axis and axis tilt parameters were part of the model. The results of the two different approaches agree very well, better than 0.05 mm for the three coordinate components and the axis offset. The advanced one-step analysis has the big advantage that the whole covariance information is available while the two-step circle-fitting approach applies a reduced stochastic model and neglects correlations between various parameters.

4 Local-tie determination

To determine the local-tie between the VLBI and GNSS reference points, additionally a traverse was measured. The network inside the radome building could be connected to the outside network of ground markers by observations through windows in the radome building. Due to dry weather conditions the laser tracker could be used out-doors (Fig. 4). For the traverse, small tripods equipped with 1.5" CCRs were placed on the bed rock (Fig. 5), and a 0.5" CCR could be placed directly on the reference point of the GNSS monument (Fig. 6).

Figure 4. The laser tracker outdoors during the measurement of the traverse between the radio telescope enclosed by the white radome in the background and the GNSS monument in the foreground.

Figure 5. A small tripod equipped with a 1.5" CCR, placed on the bedrock for the traverse measurements.

The advanced analysis model (Lösler and Hennes, 2008) was extended to allow a one-step network analysis that included both the VLBI and GNSS reference points. The analysis gave results in a local true cartesian system since the laser tracker was not oriented with respect to the local plumb line.

The results for the coordinates of the VLBI and GNSS reference points in the local cartesian coordinate system are given in Table 1 and the corresponding complete covariance information in Table 2.

Figure 6. The 0.5" CCR on the reference point of the GNSS monument.

Table 1. Coordinates of the VLBI and GNSS reference points and their standard deviations in the local true cartesian coordinate system.

	X	Y	Z
VLBI	90.12325 m	35.94974 m	22.75947 m
	± 0.10 mm	± 0.10 mm	± 0.08 mm
GNSS	12.75551 m	23.39043 m	9.06529 m
	± 0.21 mm	± 0.25 mm	± 0.27 mm

A direct comparison with the results derived by Eschelbach and Haas (2003) is not possible on the level of coordinates, since the two local networks differ slightly from each other. However, coordinate system invariant results can be compared. These are the distance d between the two

Table 2. Fully populated covariance matrix for the VLBI and GNSS reference points in the local true cartesian system. The order of elements left to right and top to down is X_{VLBI}, Y_{VLBI}, Z_{VLBI} X_{GNSS}, Y_{GNSS}, Z_{GNSS}, and the units are 10^{-9} m^2.

10.34	1.73	1.53	−2.71	0.37	−0.44
	9.52	−0.79	0.17	−1.69	−3.34
		7.22	−0.35	1.12	5.85
			45.82	2.88	−12.96
				60.30	38.42
					72.97

Table 3. Distance d between the VLBI and GNSS reference points and axis offset e of the VLBI radio telescope for two epochs.

epoch	d (m)	e (mm)
2002	79.5685	−6.0
2008	79.5678	−6.2

reference points and the axis offset e of the radio telescope. Table 3 compares these two results for the two epochs. A statistical hypothesis test showed that no statistically significant deformation between the two epochs can be detected.

5 Conclusions and outlook

The 2008 local-tie survey at Onsala was very successful. From our experience we can draw important conclusions both for for local-tie surveys at geodetic fundamental stations in general and the Onsala Space Observatory in particular.

The application of a laser tracker allows to derive the local-tie results in a local true cartesian system. Levelling observations are not necessary and the local-tie results are not influenced by the plumb line of the local gravity field. The local-tie results in the local true cartesian system can easily be related to a global cartesian system, e.g. the International Terrestrial Reference Frame (ITRF) (Altamimi et al., 2007).

The use of a laser tracker provides highly accurate local-tie results on the sub-mm level.

Using a laser tracker allows fast survey work and short station downtime.

The advanced analysis approach (Lösler and Hennes, 2008) gives the complete covariance information that is required for the ITRF.

For the Onsala Space Observatory we can conclude that the local-tie between the VLBI and GNSS reference points is stable, comparing the 2002 and 2008 results. The local-tie information is now available with the complete covariance information required for ITRF combinations. We also could confirm the previously derived axes offset of 6 mm (Eschelbach and Haas, 2003; Haas and Eschelbach, 2005).

Acknowledgements Michael Lösler was supported by DFG-project HE5213_2-1. We thank Hexagon Metrology Nordic AB, Göteborg, for providing the laser tracker.

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