An experimental scanning of the Metsähovi radio telescope dish

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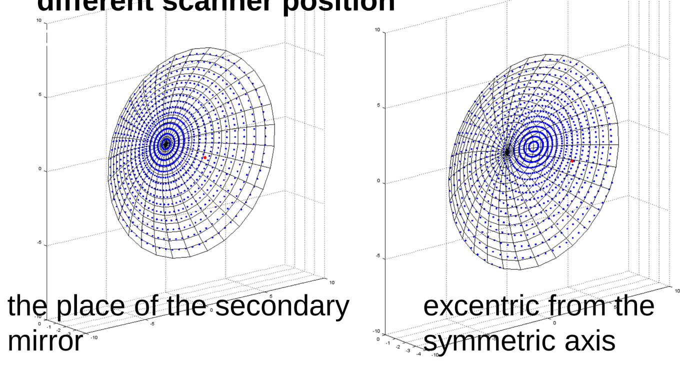
Abstract

An experimental scanning of the Metsähovi radio telescope dish was carried out in August 2014. We investigated a possibility to detect and estimate the elevation angle dependent deformations of the dish using terrestrial laser scanner. In this presentation we describe the practical organization of the experiment, instrumentation, measurements and quality of the data. We also describe the functional and stochastic model and algorithms which were used in data processing, paraboloid fitting, and the analysis of the solutions.
The experiment shows that the terrestrial laser scanner is suitable for the focal length estimation. The analysis of the results reveals also possible deformations of the quadrapod structure. For investigating the surface of the dish we would like to repeat the measurements with more high accuracy

Preparation of experiment

There are not too many possible places for the scanner. We made some simulations with different realistic scanner position keeping in mind the geometry, point cloud symmetricity, point density and possibility to scan in different elevation positions, repeat the measurements afterwards, angles between the back scattered light and the normal of the surface, and possibility for georeferencing the scanner and the dish during the scanning.
We knew that the intensity and the quality of the data is bad if the incident angle (the angle between the back scattering light and the surface normal) is too big. The possible places to mount the scanner are: the place of the secondary mirror, excentric of the symmetric axis of the paraboloid on the structure of the quadrapod , or to install a long bar holding the scanner trough the vertex of the paraboloid.

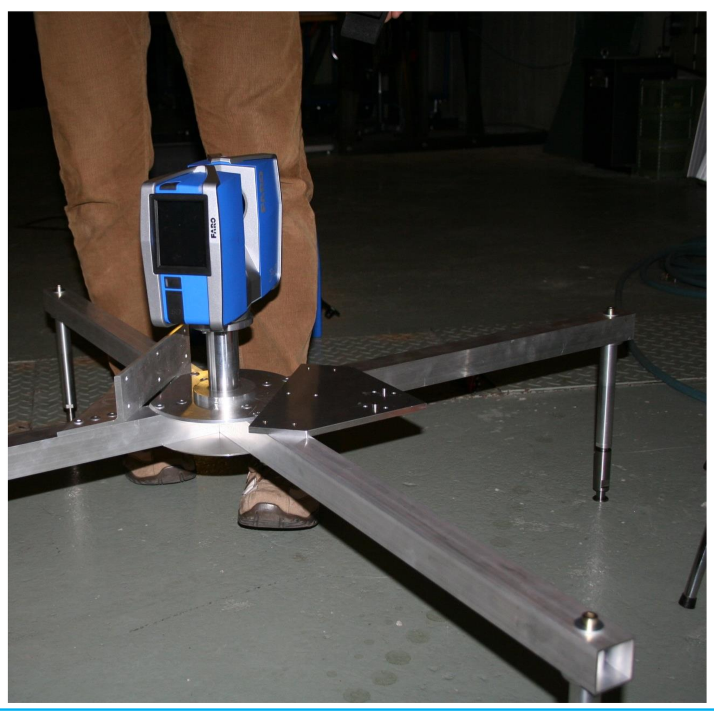
Point cloud geometries with different scanner position



Measurements

Instrumentation

We used Faro Focus 3D terrestrial laser scanner. Its weight is about 5 kg and it has a possibility to remote control. We used an adapter dedicated for the purpose. During the measurements the scanner was attached on the position of the secondary mirror. Laser scanner was adjusted on the adapter on the ground level. The instrument was switched on after the adapter with the scanner was adjusted on the position of the secondary mirror of the telescope. Measurements were started remotely on ground level. The progress of the measurement can be followed on the Windows pad which was used as a remote control unit.



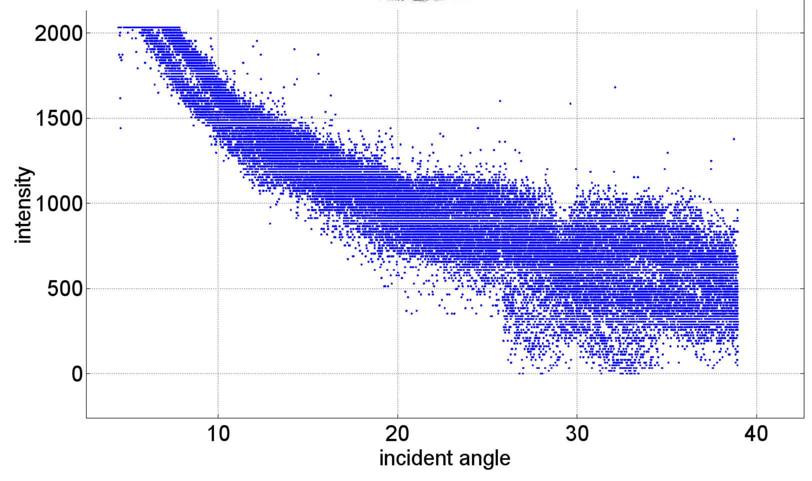
Data quality

Intesity

Intensity of the back scattered light is a good indicator of the data quality. In the case of Metsähovi dish the intensity picture shows that the dish painting is not equal in every panel or there are cleaner and dirtier parts of the dish. Panels and even screws are visible.

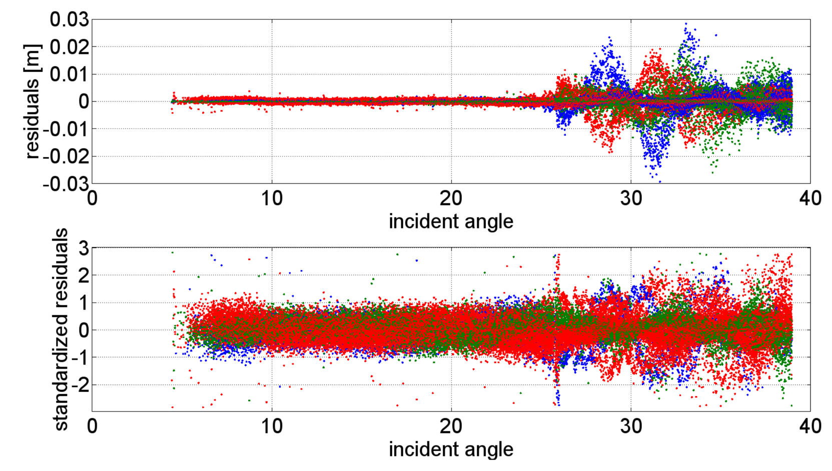
Incident angle

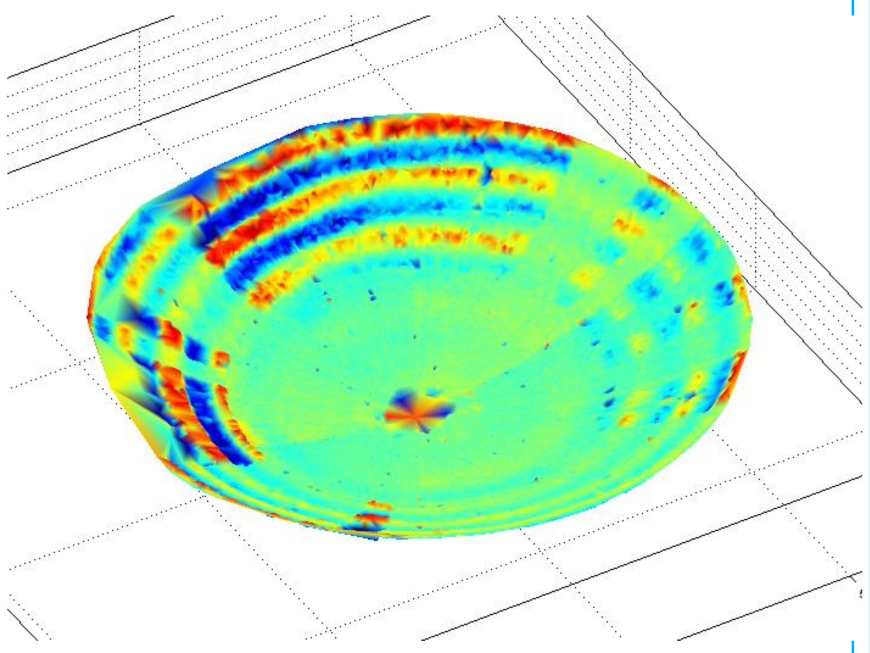
Incident angle increase from the bottom of the dish to the edges. If we survey the intensity as a function of incident angle we see that in 26º there is a jump of the intensity distribution



Residuals

Residuals after fitting the paraboloid indicate bad data if the incident angle is more than 26º. There seems to be a peculiar periodical effect. This is most probably due to properties of the scanner (modulating frequency in distance measurement) and the properties of the surface. The VLBI dish is almost too reflective for the scanner. It is not reasonable to remove all data with incident angle more than 26º because it covers almost a half of the dish surface.
We removed the points iteratively if residuals of some coordinate component was more than 0.1m and then more than 0.02m. After that we rejected outliers using standardized residual limit 2.8.
Covariance matrix of angles and distance measurements were converted to covariance matrix of coordinates. The variances of distance and angles with incident angle more than limit 26 were multiplied by four and by the factor based on the intensity and limit intensity 1000. It guaranteed that the peculiar behaviour effected minimal on the parameters. The standardized residuals show how we managed in our weighting.





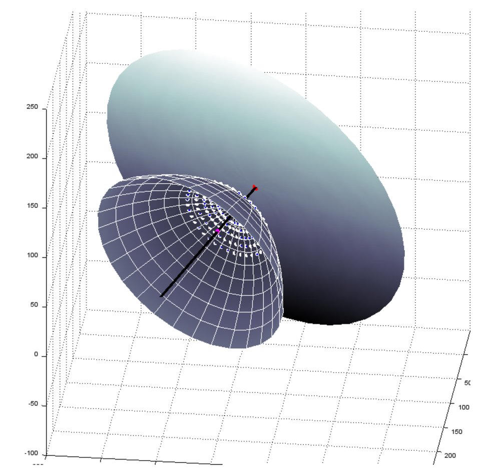
Paraboloid fitting

$$g(X_O, X_F, X) = \sqrt{(X - X_F)^T (X - X_F)} - (X - X_O)^T \frac{(X_F - X_O)}{\sqrt{(X_F - X_O)^T (X_F - X_O)}} = 0$$

Focal length:

$$f = \frac{\sqrt{(X_F - X_O)^T (X_F - X_O)}}{2}$$

A point on the rotational paraboloid surface has an equal distance to the focal point F and to the plane where the point O lies on the symmetric axis of the paraboloid. The direction of the paraboloid is same as the direction from O to F. These two points are sufficient to determine the rotational paraboloid in an arbitrary attitude (right)



The coordinates of the vertex point V of the paraboloid is the mean of X_F and X_O. For solving the parameters the iterative linearized least squares mixed model was used.

$$A = \begin{pmatrix} \frac{\partial g}{\partial X_F} & \frac{\partial g}{\partial X_O} \end{pmatrix}$$

$$B = \frac{\partial g}{\partial X}$$

$$y = -g(X_O, X_F, X)$$

$$N = A^T (B C_l B^T)^{-1} A$$

$$t = A^T (B C_l B^T)^{-1} \left(y + B v_{0_i}\right)$$

$$Q = N^{-1}$$

The corrections of the parameters:

$$dx = Qt$$

The corrections of observations

$$v = C_l B^T (B C_l B^T)^{-1} (1 - AQA^T (B C_l B^T)^{-1}) y;$$

$$v_{0_{i+1}} = v_{0_i} + v$$

Corrected observations are:

$$X_{i+1} = X_{i,original} + v_{0_i}$$

Point vise covariance matrices C_l were used. The covariance matrix of coordinates were based on the geometry of the observations and the variances of angles and distance observations and the intensity of the back scattered light. We rejected outliers iteratively using limits for residuals and standardized residuals.

Five different elevation positions were scanned. We got about 17 000 000 points in every elevation position. In order to manage all the points in paraboloid fitting adjustment we needed to develope an algorithm with sparse matrices for covariance matrix of observations and the B-matrix. The other choice which we tried was to stack the point vice normal equations in loop, but it makes the procedure in Octave interpreter all too slow. To handle the whole data was still impossible: memory exhausted. Our solution for that was partitioning the data and stacking normal equations of the parts.

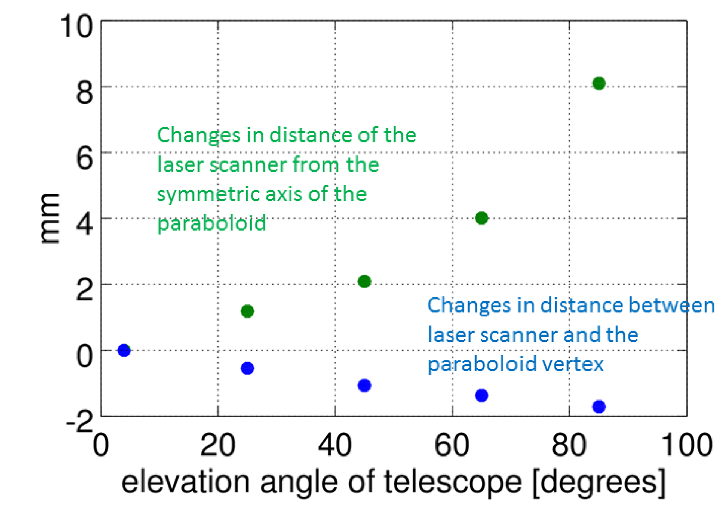
Effect of deformation on VLBI results

Sarti et al. (2011) and Artz et al. (2009) have studied the impact of signal path variations (SPVs) caused by antenna deformations on geodetic VLBI results for Medicina and Noto (Italy), and Effelsberg (Germany) telescopes.

Elevation-dependent models of SPV for Medicina and Noto telescopes were derived from a combination of terrestrial surveying methods to account for gravitational deformations. After applying these models in geodetic VLBI data analysis, estimates of the antenna reference point positions were shifted upward by 8.9 and 6.7 mm, respectively. Applying the model of antenna gravitational deformations caused changes in height estimates in the range [−3, 73] mm (Sarti et al (2011)).

Artz et al. (2014) saw a huge impact on the height position estimates in their data analysis. The position estimate was improved by applying the correction model to geodetic VLBI observations of the Effelsberg radio telescope. Their results indicate that the ITRF2008 position of Effelsberg is wrong by several centimeters.

Results and conclusions



Changes in position of the laser scanner relative to the paraboloid vertex

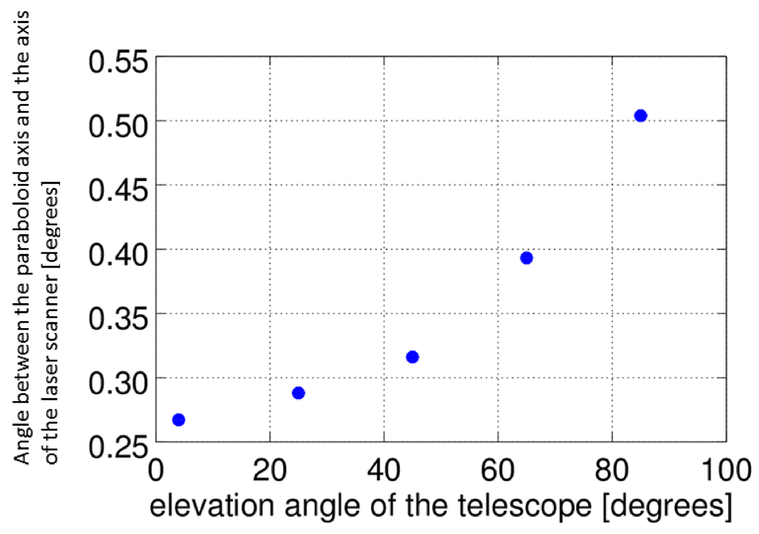
The position of the measuring instrument changes with respect of the vertex as a function of elevation angle (above) . We calculated the distance of the scanner from the vertex of the paraboloid and the distance of the scanner from the symmetric axis of the paraboloid

Conclusions

The reasons for the movement and changes in orientation of the measuring instrument may be in deformations of the quadrapod structure, deformations of the adapter of the scanner or changes in the attitude of the mirrors (prisms) inside the scanner. The scanner was terrestrial laser scanner and intended to use in normal position and it is possible that its ability to measure in inclined attitude is restricted.
The accuracy of the scanner used in this experimental work is not adequate for investigating the changes in paraboloid surface. When in the future the accuracy of this kind of instrument reach reasonable level to study accurate surfaces, the orientation of the instrument must be solved for with known points outside the object under the study because of the changes in orientation and position of the measuring instrument. It is also important to calibrate the scanner not only radiometricly but also geometricly.

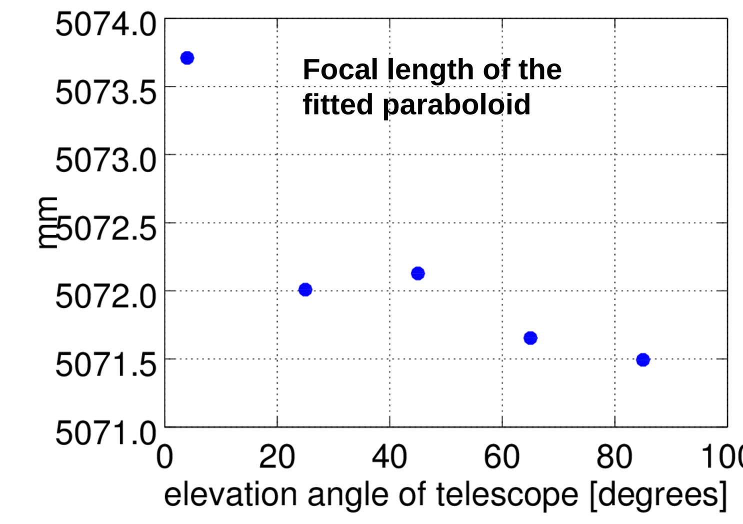
Changes in orientation between the laser scanner and the telescope dish

The angle between the symmetric axis of the paraboloid and the "vertical" axis of the scanner changes systematically when elevation angle of the telescope increase (below). It can be seen when calculating the angle between v=[0,0,-1] of the instrument and the direction of the symmetric axis of the paraboloid in scanner coordinate system in each elevation position. It indicates the bending of the quadrapod or adapter of the scanner. It may also come from the scanner inside orientation of the mirrors or the deformation of the dish.



Changes in focal length

Against all odds the focal length shortened when the elevation angle increased. An explanation might be that the diameter of the dish is small and the support of the quadrapod makes the edge of the dish not flattened but curved and that makes the focal length to be shorten.



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