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Photogrammetry, Laser Scanning, Holography and Terrestrial Surveying of the Noto VLBI Dish

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Abstract

Since the late 90's, different surveying approaches have been independently applied to the Noto VLBI antenna. In particular, holography, photogrammetry, triangulation, trilateration, GPS and laser scanning have been used for determining the shape, the deformation and the position of the radiotelescope, its dish and its components. These datasets represent an interesting source of independent information that must be compared, combined, processed and used for validation with a comprehensive approach. We briefly summarize the experiments carried out at the antenna by different groups that are active within the Institute of Radioastronomy, explicitly referring to their work and highlighting the potentials of a combination of these methods and their results.

1. Introduction

In 2001 an active surface system was implemented on the Noto antenna [1]. It has been realized through 244 electromechanical actuators under computer control. They ensure that the paraboloid is maintained at each elevation. The actuators were mounted underneath each convergence panel forming the primary mirror (Figure 1). The main goal of the active surface is to recover the misalignment of panels induced by gravitational effects. If the active surface is properly working, a flattening of the antenna gain curve over elevation is expected.

Figure 1. Actuators of the active surface installed in Noto.

Figure 2 shows a comparison between measurements made at 43 GHz (Cassegrain focus) with and without enabling the active surface. Other antenna efficiency measurements performed at different frequencies can be found at: http://www.ira.inaf.it/actsurface/index.html.

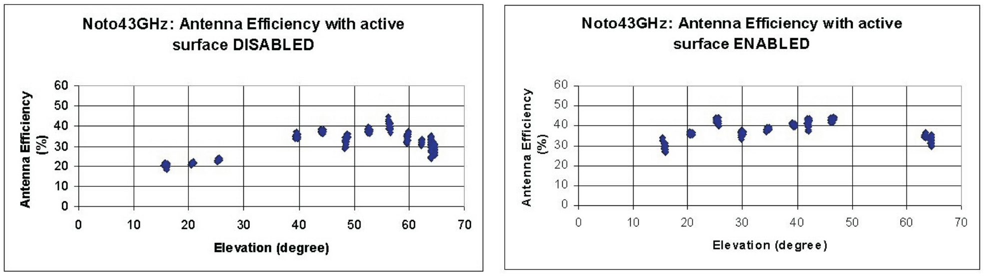

Figure 2. Antenna efficiency at 43 GHz not using (left) and using (right) the active surface.

Photogrammetry, terrestrial measurements, holography, and laser scanning, among other techniques, can be applied in a comprehensive investigation of the shape of the dish, thus improving the antenna's performance and the accuracy of the technique itself.

2. Photogrammetry

Photogrammetry is a three-dimensional coordinate measuring technique that is based on processing of images, its main products being Digital Surface Models (DSMs), orthoimages and 3-D reconstruction of the objects. Processing is usually made by an analytical plotter or a Digital Photogrammetric System (DPS). By taking photographs of an object from at least two different locations, the overlapping part of each stereopair can be mapped in 3-D. Photogrammeric surveys of Noto's antenna surface were performed in December 2000 and April 2002 [2] using a large format (230mm x 230mm) terrestrial metric camera CRC1 (Geodetic System Inc.). Figure 3 shows the differences between the theoretical shape of the VLBI parabola and the real shape as determined in 2000.

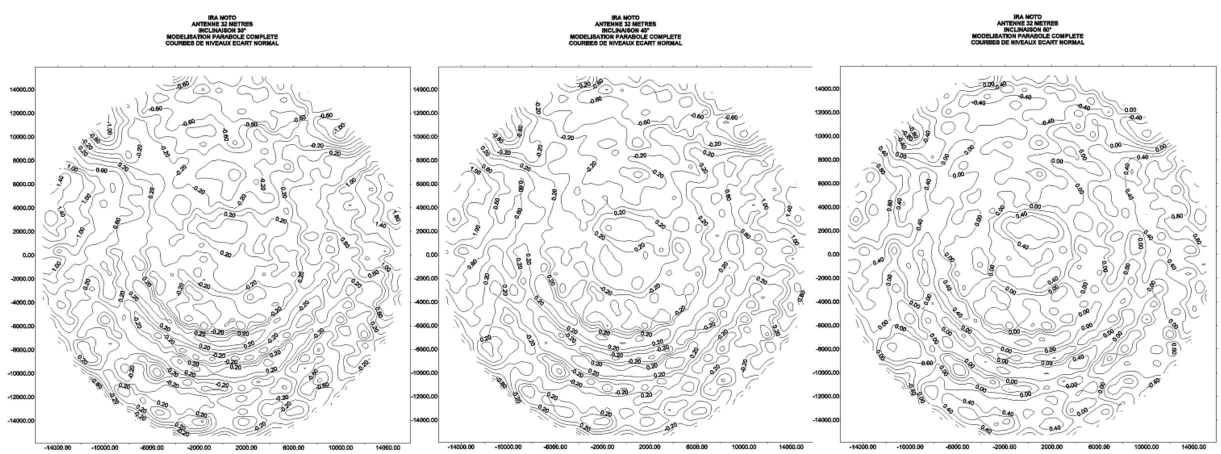

Figure 3. Difference with respect to the theoretical shape of the parabola (mm), at 30, 45, 60 of elevation (focal lengths: 10256.21mm, 10257.23mm and 10257.74mm respectively).

3. Holography

Holography is a very promising technique to evaluate the real profile of the radiotelescope mirrors. System requirements for performing holographic surveys can be easily satisfied at a well-equipped radio astronomical observatory. A holographic survey of the Noto antenna has been performed [3] and results obtained using this approach can be compared to the other surveying approaches here described. The holography technique is based on the Fourier transformation between the antenna beam pattern, $P(u,\nu)$, and the field distribution over the aperture plane, $E_{ap}(x,y)$: $E_{ap}(x,y) = \text{FT}\ [P(u,\nu)]$ as shown in Figure 4. In particular, the factor of interest is the phase distribution on the surface map, which gives the surface alignment errors.

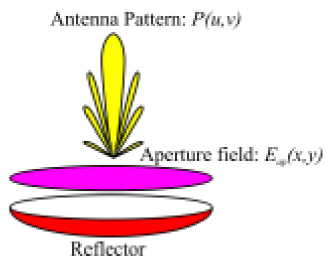

Figure 4. Scheme of antenna beam pattern $P(u,\nu)$, and field distribution over the aperture plane $E_{ap}(x,y)$.

A numerical result obtained by an antenna simulator is plotted in Figure 5. An antenna pattern produced by a parabolic reflector with several deformations corresponds to a phase of the aperture field not constant, as expected for an ideal parabolic profile. Hence, the holography technique consists of measuring the antenna far-field pattern. This step can be done by observing a source with a stable and well-known position in the sky. Several alternatives are available: geo-stationary satellites, strong astronomical sources (like masers) and, finally, local transmitters. In order to map the antenna pattern in a $u\nu$-plane, several measurements need to be performed around the source position: the wider the $u\nu$-plane, the higher the deformations space resolution.

Since both amplitude and phase of the antenna pattern are necessary, a coherent receiver is requested. There are two main methods to determine the phase pattern: one, called phase retrieval method, based on recovering it through power measurements performed with two receiver placed close to each other. The other, the interferometric method, consists of having two coherent measurement systems: the target antenna, usually the radio telescope, and the reference reflector antenna, usually a small satellite dish. The advantages of the interferometric method are its high accuracy and fast computation; on the other hand it needs an additional receiver for the reference antenna. Then, to obtain the phase difference, the two antenna signals are processed by a cross-correlator. Restricting the measurement to N beamwidths, the profile shape is determined with a spatial resolution of approximately D/N, D being the antenna diameter. Moreover, a good accuracy is assured when the signal is characterized by a high signal to noise ratio. Holography receiver and data acquisition system must have a large dynamic: the power level for on-source can be 105 times stronger than that of N beamwidths off-axis.

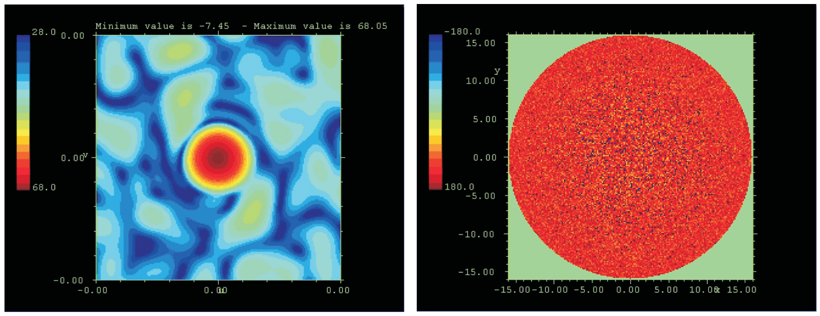

Figure 5. Antenna pattern produced by a parabolic reflector with deformations (on the left) corresponds to a phase of the aperture field not constant (on the right), as expected for an ideal parabolic profile.

4. Topographical Local Survey

In September 2005 high accuracy topographical surveys were realized at Noto and Medicina observatories in order to monitor the stability of ground control networks and to perform a rigorous estimate of the VLBI-GPS eccentricity vectors. For a detailed and comprehensive description of the survey method adopted in the field operations, see [4]. In addition, triangulation has also been used to locate, within the topocentric frame, the positions of the spheres used as targets during the laser scanning survey, thus realizing common points in the two surveying approaches.

5. Laser Scanning

In September 2005, the two INAF VLBI antennas (Noto and Medicina) were surveyed for the first time with the laser scanning technique. Our aim was to realize a 3-D model of the dish and to position it with respect to the local ground control network. The instrument used in this experiment was a TRIMBLE-MENSI GS200 which can store the position of about 5000 points per second with a resolution in range of about 1.5 mm @ 50m. The GS200 uses a laser pulse, which can determine the distance between the scanned points and the instrument itself by recovering the double-way travel time of the signal. The acquisition of the three-dimensional coordinates of the points belonging to the VLBI antenna is performed using an auto-focus laser with a spot size of 3 mm @ 50 meters. The grid step is fixed by the user taking into account the resolution and the amount of data; Figure 6a shows an example of surveyed points clouds. Both Noto's and Medicina's antenna surfaces have been scanned at different elevation angles of the radiotelescopes. In order to use the instrument within the inner dish surface, ad hoc supports were realized and fixed to the primary mirror (Figure 6b and 6d). The raw data acquired with laser scanning systems intrinsically define a cloud of points expressed with respect to an instrumental reference system; the different parts of the surface (clouds) are connected in a common reference system by means of common points (these points have been observed with total stations, too). In this survey, the connecting points have been physically materialized through appropriate spheres placed on the external border of the VLBI antenna dish (Figure 6c): their centers can be recognized by the laser system. Through an ad hoc terrestrial survey, the positions of the spheres' centers have been determined with respect to the topocentric reference system.

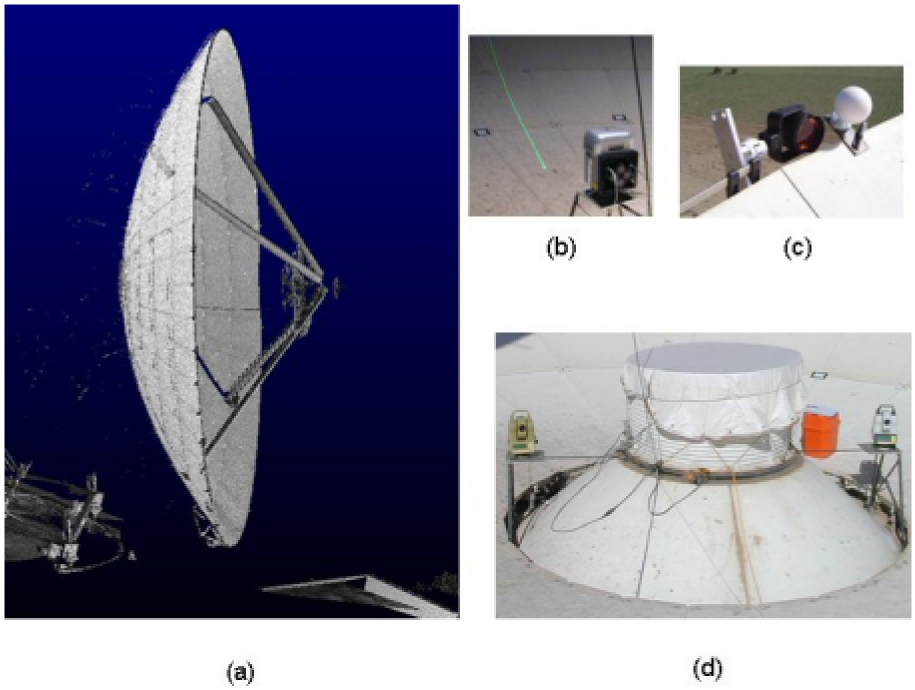

Figure 6. (a) Example of laser scanning derived cloud of points, (b) laser scanner during the acquisition of the inner part of the VLBI dish, (c) sphere used to align the laser scanner acquisition in a topographical local frame, (d) high accuracy total stations occupying the same points as the laser scanner in order to connect the spheres' centers positions to the local topographical network.

6. Outlook

The measurements collected applying these different approaches now form a comprehensive set of information that must be carefully handled and comprehensively combined for recovering and validating relative and absolute gravitational deformations of the antenna. Both geodetical and astronomical applications of VLBI will greatly benefit from this information.

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