New Technologies For The Real 3D Reference Point Determination

Maria Hennes, Cornelia Eschelbach

GIK, Geodetic Institute of the University of Karlsruhe, Germany

Contact author: Maria Hennes, e-mail: `hennes@gik.uni-karlsruhe.de`

Abstract

For local tie determination accuracy the reference point determination is required. This paper discusses the advantages of new cinematic measurement techniques as robot tacheometers and laser trackers. Laser radar will be of advantage to detect reflector deformations.

1. Introduction

The availability of different space techniques on one observation site requires the establishment of local ties between the reference point of each observation method. Because sub-mm-accuracy is expected for space technologies in the near future, the positions of the reference points have to be determined with equal accuracy. In this contribution, new technologies for reference point determination in respect of the local tie realization and for deformation measurements of radio telescopes are presented, which, furthermore, aim at reducing the downtime of the telescope during local surveying.

According to the reference point definition the telescope's reference point as well as its defining elements are usually virtual, i.e. not materialized and not accessible. If a marker is mounted (e.g. magnetically) on the face surface of the elevation axis and the telescope is rotated azimuthally and vertically, in first approximation the marker's trajectories describe circles, which centers are dedicated to derive the reference point. For details see (Hennes et al, 2004 [6]; Eschelbach 2002 [2]). Efficiency of the trajectories determination can be achieved by the new technologies discussed below, which should replace the angular method.

2. Measurement methods

2.1. Angular method

The conventional method for reference point determination is the angular method using spatial intersection. The scale of the intersection network is derived from the local network, which connects the stations. Because the horizontal and vertical angles are measured with theodolites, this method is often referred to as theodolite method. For optimization of the network configurations see (Hennes et al, 2004 [6]). Because each target has to be observed from two stations and repositioning of the telescope is time-consuming and more inaccurate, it is highly recommended to observe the marker simultaneously from both stations. The observation data should be gathered in real-time using two electronic theodolites equipped with appropriate interfaces and connected to a central PC. At the same time, the data should be checked in respect of gross errors by appropriate software, which solves the spatial intersection or even the least squares circle adjustment (i.e.

IMKA (GIK, Karlsruhe), or Axyz (Leica Geosystems AG Metrology Division, Unterentfelden, CH)). Furthermore, observing simultaneously from two stations gives more reasonable information on axis wobbling. If the elevation axis is not accessible for the marker-adjustment-process and therefore elevation circles have to be observed, the survey takes up to seven days, even if using two theodolites and two experienced observers.

2.2. Polar Method

The major advantage of polar measurement systems in comparison to theodolite measurement systems is, that 3D-positions (e.g. 3D-coordinates) are determined in one step, because the polar measurements (distance and two angles) are measured (nearly) without delay. In respect of the observation schemes see (Hennes et al, 2004 [6]). Nowadays, most of these systems are able to track a moving target (reflector) and to determine the target coordinates quasi on-the-flight. Two instrument types have to be distinguished: Robot tacheometers were developed primarily for plain survey and laser trackers are appropriate for industrial measurement tasks.

A robot tacheometer consists of a motorized theodolite equipped with an EDM and a target recognition unit usually based on video techniques. The implemented software controls the motion of the tacheometer's telescope and delivers approx. three (in the future nine) 3D-coordinates per second at optimum. The position accuracy amounts up to 0.3 mm depending on instrument type for a non-moving target and decreases with target velocity (down to some cm @ some m/s). It is highly recommended, to correct the measured distances in respect of the addition constant, which is dependent from the angle-of-incidence, even if a 360°-reflector is used (Favre, Hennes, 2000 [4]). Furthermore, the line-of-sight should be calibrated for near-range-use (Hennes, 2003 [5]). The system performance for special properties are presented in (Hennes, 2003 [5]; Krickel, 2004 [7]). Further details on tracking performance will be examined at the Geodetic Institute (University Karlsruhe, D) using our motion simulator.

From the first, laser trackers are constructed for fast high-accuracy tracking. The maximum data rate is 1000 Hz. The laser trackers of Leica Geosystems have the best reputations among the trackers offered, although other manufacturer's specifications seem slightly better in particular cases (see also Faro Technologies Inc., Lake Mary, FL, USA and API, Rockville, MD, USA). The Leica LTD-series is specified with an accuracy of 0.1 mm @ 10 m, if the target moves slowly; the accuracy improves by factor two, if the target is fixed.

These new technologies enable observations even the VLBI-telescope is moving. Hereby, the point-uncertainty is negligible: For example, if the diameter of the elevation circle is 0.4 m and it is created within 10 minutes, the point-uncertainty due to the target motion becomes 2 μm for a laser tracker assuming a data rate of 1000 Hz or 0.6 mm for a robot tacheometer operating with 3 Hz. The azimuthal angular speed must be reduced due to the larger diameter of the azimuth circle (e.g. 2.5 h @ 6 m diameter). That means that within very short observation times the required reference point accuracy can be easily obtained. The personal effort as well as the telescope's downtime time decrease dramatically. Although the reflector's orientation due to an angle-of-incidence-dependent offset (and therefore varying with the telescope's orientation) has to be taken into account in the calculation, this is no limiting factor, because Leica's new T-Products for the LTD 700 and 800 announced for 2004 will solve this problem. Examinations at our institute will check the properties of the LTD 500 (see figure 1) in combination with 360°-reflectors on our motion simulator which are not specified up to now.

Figure 1. **Laser radar Leica LR 200 (left) and laser tracker Leica LTD 500 (right).**

2.3. Scanning

Scanning measurement systems should be preferred for the determination of the deformation of the telescope's reflector. The requirements can only be met by the so-called laser radar LR 200 (Leica Geosystems, see figure 1). The system works reflector-less and non-tactile. LR 200 reaches in the enhanced modus an accuracy of 10 μm producing a data rate of two measurements per second (Dold, 2002 [1]). Accuracy decreases with increasing data rate to 0.3 mm at 1000 Hz. For the definition of the six parameters of a surface patch in 10 m distance, the system needs approx. 1 s and achieves the required accuracy of 0.1 mm. The working range of the instrument covers typical main reflectors, if the sensor head (40 kg) is mounted close to the antenna focus. The sensor head may be tilted during the measuring process, so that measurements at each elevation are possible. For the determination of 1000 surface patches (panels), the survey should be done in less than one hour. If the laser radar is positioned externally, the connection of different stations can be achieved by scanning small spheres serving as fiducial points. Due to the fast data acquisition, the thermal deformation of the telescope elements can be determined.

2.4. Real-time capability and performance

The surveying time should be taken into account with high priority, especially when considering methods for surveying the geometry of a radio telescope. All methods, which allow performing its original tasks during the surveying process, should be preferred. So, the application of the classic angular method will decrease in future, even if two connected theodolites with simultaneous data acquisition and real-time calculation are employed. With robot tacheometers and especially with laser trackers, the requirement of time-reducing survey methods can be met, because they are capable to track a fast moving target and, principally, even to determine circle segments for the reference point determination simultaneously to the ordinary VLBI-operations. Furthermore, it must be guaranteed, that the employed instruments were calibrated beforehand. This is related especially to the tracking components of the instruments. Moreover, an efficient solution for the angle-of-incident-dependent addition constant has to be integrated.

Although potential deformations occur significantly slower than the movements generating the circle paths, in most cases the angular method is too time-consuming to detect thermal deformations. The most efficient method would be the scanning method. If the panel structure has to be adjusted, the integrated "build and inspect"-procedure of a laser tracker can be used most efficiently. Polar reference point determinations are capable to support the derivation of a model for describing thermal deformations based on temperature measurements of the basement.

3. Recent results

3.1. Angular measurement system

The conventional method based on angular measurements was tested in spring 2002 in a co-operation project between the Onsala Space Observatory, Chalmers University of Technology and the Geodetic Institute of University of Karlsruhe. For details see (Eschelbach, Haas, 2003 [3]) and (Eschelbach, 2002 [2]). The reference point's accuracy reached 0.3 mm (3D), and even the axis-offset could be determined to 6.0 mm $\pm$ 0.4 mm.

3.2. Performance of polar measurement systems

A typical elevation circle (diameter 0.5 m) was simulated by mounting a reflector on a motion simulator. A Leica laser tracker LTD 500 was positioned in a short distance to the circle and close to the center normal vector. Within 10 s a full circle with approx. 1000 points (3D-coordinates) was measured. The rms-value of the measured points in relationship to the best-fitting circle was 0.02 mm; due to the high data number, its center position could be derived with an uncertainty of 1 μm. To analyze the quality of circle segments with real data, the same data was divided into six circle segments. The center coordinates calculated now separately differ up to 0.09 mm. Therefore, it is recommended to observe segments, which are as large as possible and complementary. The center coordinates accuracy is approx. tenfold better than the manufacturer's specification for near range. Assigning this result to robot tacheometers capable to achieve point accuracy in slow motion of approx. 10 mm, a center point accuracy of 1 mm results, if the circle path is generated within more than 5 min. From this result, it can be assumed, that the required accuracy of the reference point can be achieved, if several circles are observed. In respect of the geometry of the telescope, the effect of steep sights (i.e. station far from the circle center normal vector) has to be analyzed for both instrument types. Suitable procedures to avoid systematical effects have to be developed. Both will be done using our motion simulator.

4. Resume

In respect of the increasing accuracy of the VLBI-techniques, the precise determination of the reference point location and of the geometric stability of VLBI-telescopes becomes more and more important. The proposed strategies and results of contemporary engineering and industrial measurement systems as theodolite measurement systems, robot tacheometers, laser trackers and laser radars demonstrate the potential of these systems and methods in respect of accuracy increase by new instrument developments, reliability increase by real-time computation and adjustment and last, but not least, by reducing the surveying time and therefore the downtime of the telescope. Especially recent developments as embedded system control, simultaneous reduction of reflector-orientation based offsets and the application of laser radar can and will make a significant step to an efficient procedure for generating local ties. The control software for these technologies ensures an approved data management, so that deformation effects could be analyzed, compared with results of other sites and, at least, modeled in dependence of its interference parameters.

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