Can Continuous Cartesian Connections realize local ties at 0.1 mm level?

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ABSTRACT

We present an approach to achieve continuous Cartesian connections at geodetic co-location stations. The concept builds on the classical idea of traditional local tie surveys and extends it to the needs of the 21st century. The objective is to provide the most accurate achievable continuous connection of the reference points of the various geodetic equipment in a local truly Cartesian coordinate system. This task appears to be a necessary pre-requisite for reach the objectives of the Global Geodetic Observing System (GGOS).

1 Introduction

The primary project of the International Association of Geodesy (IAG) in the coming years is to realize a Global Geodetic Observing System (GGOS) which will support the monitoring of the earth system and global change research (Rummel et al., 2005). The GGOS aims at a combination and integration of various geodetic techniques in order to benefit from all their advantages and to work around intrinsic shortcomings. An important ingredient of the GGOS are the geodetic co-location stations that host equipment for different geodetic space techniques (e.g. Satellite Laser Ranging (SLR) and/or Very Long Baseline Interferometry (VLBI) combined with Global Navigation Satellite Systems (GNSS)), geophysical sensors (gravimeters, seismometers, tide gauges, etc.), and atmospheric sensing devices (e.g. ground based microwave radiometers). A necessary pre-requisite for a meaningful combination and integration of the different observations and the derived results can only be achieved if the local geodetic relations at the geodetic co-location stations are accurately known. These relations or local ties are the coordinate differences between the reference points of the different techniques, including their temporal variations. To achieve the objectives of the GGOS it is required that the reference points are known with an accuracy better than 1 mm in a global reference frame (Niell et al., 2006) and that the full covariance information is available in both the temporal and spatial domains. This is also of major importance for the International Terrestrial Reference Frame (ITRF) (Altamimi et al., 2007) that combines the various techniques to derive a stable reference frame for the observations. Both GGOS and ITRF desire local tie information that is accurate on a level of 0.1 mm (Rothacher et al., 2009, Ray and Altamimi, 2005). In this article we briefly describe a possible way to establish a continuous Cartesian connection (3C) system that will facilitate full integration of separate techniques' observations at a co-location station to the currently highest achievable standard. Furthermore, we propose that a coherent 3C system is established at all co-location stations in order to reduce the uncertainties of future geodetic observations.

2 Local ties at geodetic co-location stations

Traditionally, the coordinate differences between the reference points of the different techniques at geodetic co-location stations are determined by so-called local tie surveys. These surveys are usually performed on a more or less regular basis every couple of years. This low repeat frequency is to a large extent due to the fact that local tie surveying is an engineering task that lies beside normal operations. In the local tie, the reference points of the various geodetic techniques are connected to a local survey network that is usually materialized by survey pillars that can be equipped with geodetic survey instrumentation to measure distance, angles, and height differences between them. An overview of available local tie techniques has been compiled by Pearlman (2008).

2.1 Local tie difficulties

In many cases the actual observation reference points cannot be observed directly, e.g. the axis intersections of radio telescopes used for geodetic VLBI, or the phase centers of antennas used for GNSS observations. In these cases indirect survey methods are usually applied. For radio telescopes the indirect methods make use of the instrument's symmetry properties, see e.g. Sarti et al. (2004). To perform the necessary measurements the radio telescopes then have to be positioned according to a predefined scheme. This is maintenance task that usually involves external expertise and means considerable and undesirable downtime from normal operation. Only recently has a new approach been proposed that shall allow reference point determination of a radio telescope while the instrument is in normal operation (Lösler, 2009). Traditionally, local tie surveys are often a combination of direction and distance measurements with tachymeters and height differences from spirit leveling. These survey instruments are oriented with respect to the local plumb line. The coordinates in the local coordinate system of the survey work thus dependent on the local gravity field and are not given in a local truly Cartesian (LTC) system, and hence add unnecessary uncertainties to the observations. Furthermore is the local tie information often incomplete, i.e. the covariance information is not available (Thaller et al., 2005). A transformation between results derived from space geodetic techniques that refer to global Cartesian systems (e.g. GNSS, SLR, VLBI) and such traditional local not-truly-Cartesian systems impose an increased loss of accuracy due to the uncertainties added in the transformation.

2.2 Desired properties of local ties

The accuracy of today's space geodetic techniques is on the order of 1 ppb and better on a global scale, and it is expected that 0.1 ppb will be approached in the near future. For example, the next generation geodetic VLBI system, VLBI2010, aims at an accuracy of 1 mm on a global scale (Niell et al., 2006, Petrachenko et al., 2009). To preserve this high accuracy and meet the requirements of the GGOS, it appears necessary to know the local coordinate differences between the reference points of the co-located techniques with even higher accuracy. Space geodetic techniques deliver coordinate results that refer to global Cartesian coordinate systems. Therefore, also the local coordinate differences need to be expressed in truly Cartesian local coordinate systems in order to avoid any accuracy losses in the transformation, and of course the complete covariance information must also be provided. It is desirable to monitor the local coordinate differences more often than in the past, and continuous monitoring will help to detect disturbances on the instruments and will aid to identify the reasons behind perturbations. Such disturbances could be of periodic or episodic character, e.g. air temperature, ground water column, or ground settling.

3 Continuous Cartesian connections

In the following we outline the 3C concept for geodetic co-location stations. These ideas could be realized at already existing geodetic co-location stations, and they are highly relevant for new stations to be established, e.g. in connection with the ongoing VLBI2010 efforts (Behrend et al., 2008). The initial step of the 3C concept is to establish an LTC coordinate system at the station. Subsequently, the reference points of the various different geodetic techniques and sensors are to be determined in this coordinate system. Since not all reference points can be observed directly, indirect methods usually need to be applied. Additionally, a number of targets with a stable geometric relation with respect to the reference points can be deployed; these targets can be used to represent the specific space geodetic equipment in a monitoring situation. In the following, the whole network shall be monitored in an automated fashion without disturbing the normal operations at the co-location station. Statistical analysis can be used in real-time or close to real-time to check the stability of the network. Post-processing data analysis will be used to derive the necessary transformation information for combination and integration purposes. Furthermore, any disturbances of the reference point locations can be investigated in detail in post-processing, too.

3.1 Local truly Cartesian coordinate systems

As mentioned earlier are local tie surveys traditionally often a combination of direction and distance measurements by e.g. tachymeters and height differences from spirit leveling. This implies that the local coordinate system is not truly Cartesian since the instruments are oriented with respect to the local plumb line. This effect is on the order of 3 mm for the z-component in survey networks with an extension of 200 m and need to be accounted for by local geoid and ellipsoid models. However, an LTC coordinate system that facilitates a direct transformation between different coordinate systems can be established e.g. by a laser tracker instrument. This type of instruments allows accurate distance measurements in interferometric and absolute mode as well as direction measurements. These instruments have many applications in e.g. industrial measurements (Juretzko and Hennes, 2008) and do not require any particular orientation with respect to the local gravity field.

An example for the application of a laser tracker is described in (Lösler and Haas, 2009) where such an instrument was used to determine the reference point of the 20 m radio telescope at the Onsala Space Observatory and the local tie between this reference point and the reference point of the GNSS monument. By using a laser tracker, an LTC coordinate system can be established and the reference points of the individual techniques and all survey pillars can be surveyed and expressed in this system. Additional retro-reflecting targets that are eccentrically mounted at some of the sensors can be included in the network. This is particularly important for sensors that have not-easily accessible reference points. These eccentric targets should be mounted in a way that the geometrical relation with respect to the sensor's reference point is known, and a continuous monitoring of these eccentrically mounted targets can be used to indirectly monitor the sensor's reference point. For example can GNSS antennas be mounted coaxially on top of 360° retro-reflecting prisms that allow surveying and monitoring from all horizontal directions within about ±30° elevation angle. At VLBI or SLR telescopes, such retro-reflecting prisms could be mounted at representative positions of the telescope structure.

3.2 Continuous monitoring

Once the LTC coordinate system has been established and all reference points as well as additional reference targets have been determined directly or indirectly in this system, the continuous monitoring may commence. The complete local survey network has to be equipped with suitable targets. A motorized total station is needed that can be computer controlled to perform angular and distance measurements following a predefined monitoring cycle. Near-real-time checks can be done already on the level of raw observations with simple statistical tools, e.g. histograms. Post-processing analysis needs to take into account the meteorological situation in order to do the corresponding corrections of the distance measurements. Time series of target coordinates and their uncertainties is one of the post-processing products, and the post-processing should include the determination of coordinates of all targets with their complete covariance information. Another product is the complete information needed for the transformation between the different geocentric Cartesian systems.

3.3 Experience from monitoring projects

The ideas of the 3C concept have emerged from the experience gained in a set of local tie monitoring campaigns where the temporal behavior of reference points have exceeded the GGOS specifications by more than an order of magnitude (Haas and Bergstrand 2010, Lösler et al. 2010, Haas et al. 2011). An example of movement patterns for four differently designed GNSS antenna monuments is displayed in Figure 1.

4 Conclusions and outlook

We presented a proposal to achieve continuous Cartesian connections between the reference points of different space geodetic techniques at geodetic co-location stations. Results from initial studies at different co-location stations indicate that there might be differential deformations on diurnal time scales with signatures on the order of 1 mm or larger. We are convinced that the information from the 3C is necessary to achieve the objectives of the GGOS and that co-location stations to be established e.g. in connection with the GGOS efforts should utilize the 3C-concept from the beginning. Furthermore can the 3C-concept be established on existing co-location stations in order to reduce uncertainties in coordinate transformation between different techniques, and if made in a standardized manner also included in the analysis.

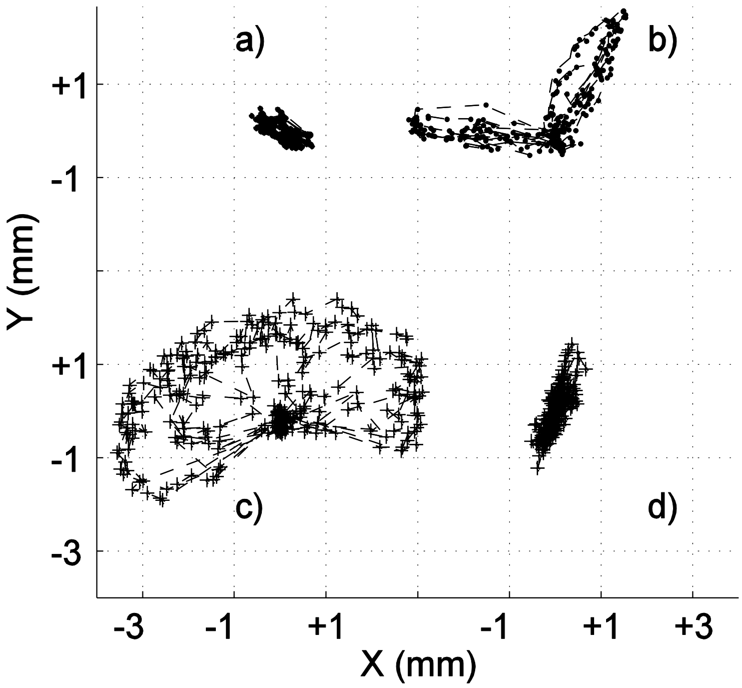

Figure 1 Variability of the horizontal position of four different GNSS monuments. The movement patterns reflect the interaction of solar radiation on monuments with different cross sections and are considerably larger than 0.1 mm for all the evaluated monuments.
(From Haas et al., 2011)

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