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An Investigation on a GPS-based Approach to Local Tie Computation

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Abstract

The estimation of eccentricity vectors at co-location sites represents a crucial aspect in order to combine reference frames stemming from different space-geodetic techniques. We investigate the possibility to pursue a thorough eccentricity vector estimation via a GPS Survey. Unlike terrestrially estimated eccentricities, the GPS derived ties have the following qualities: they are easy to perform—not requiring very highly specialized manpower and fatiguing surveys—and save time, thus allowing to speed up the whole process (from survey to computation). Here we examine the local tie derived from a GPS Survey that was conducted at the Astronomical Observatory of Medicina (Italy) in 2002, the proper geometrical modelling of the tie computation and the correct fitting into an ITRF frame. In the case at hand, the GPS derived tie is checked through a comparison with the terrestrial local tie performed at the same co-located site of Medicina.

1. Introduction

This investigation elaborates on the possibility of determining the local tie through a **purely GPS-based survey** performed at the ITRF co-located site of Medicina (Italy). Each local tie is characterized by an intrinsic precision not only related to the way it has been surveyed but also to the proper geometrical modelling and, consequently, to the conditions applied during the least-squares estimation in a rigorous, statistically-based procedure. Furthermore, if a terrestrial survey is executed, the eccentricity vector components, finally aligned to ITRF, seem to depend on the transformation performed in order to carry out the transition from the local topocentric reference frame, where the tie was classically surveyed, and the final realization of ITRF [1]. Processing and obtaining local eccentricities vectors via GPS-based surveys could allow to overcome the difficulties related to the aforementioned RF transition. In fact, since GPS directly operates in a geocentric reference frame, the transition to ITRF is automatically achieved avoiding the difficulties related to measuring the deflections of the vertical. The local ties computation has been done so far using CLEMeNT (Co-Location Estimation Model et Network Transformation), a in-house software, which showed satisfactory results in least-squares estimations both for highly precise terrestrial datasets [2] and for simulated and intrinsically noisy ones [3]. The accuracies reached in processing noisy datasets have inspired the possibility to perform GPS based local ties by means of a new release—**GPS-CLEM**— modified *ad hoc* in its structure in order to include a brand new ensemble of constraints which are going to strengthen the definition of the tracking points of the local tie.

2. GPS Datasets Used in the Analysis

The datasets here analyzed were acquired in September 2002 using 5 GPS receivers, in a survey context usually defined as *rapid-static*. Three out of five GPS antennae were fixed on three ground reference pillars, while two roving receivers were installed on the external part of the VLBI dish, thus describing circular arcs during the rotations of the radiotelescope. The GPS data processing has been executed by means of the Bernese GPS software V4.2 [5]. The data collected during the aforementioned campaign have been processed along with data acquired by the permanent IGS station installed at the same co-located site. Unfortunately, a failure in the power supply due to a thunderstorm brought about an interruption of the planned schedule. The VLBI antenna was moved in elevation and azimuth in such a way that the two mobile GPS antennae acquired observations at a given position for 15 minutes. The data were processed using a rapid static approach [4], utilizing two different phase center variation models: the IGS and NGS relative PCV (elevation-dependent models). As shown later, the choice of a PCV model considerably impacts the eccentricity vectors estimation.

3. The GPS Based Local Ties Estimation Procedure

The eccentricity vectors represent the geometrical connections between the reference points, each of them belonging to a specific space-geodetic technique. Regarding the case of Medicina, the *local tie* can be reckoned as the vector bridging the VLBI tracking point and the GPS *ARP* (Antenna Reference Point). A rigorous, statistically based estimation of the local ties has been performed so far using CLEMeNT, an in-house software implemented in Matlab environment and developed by a French-Italian Joint Research Group. It provides a **LSE** (Least-Squares Estimation) of the eccentricity vectors of co-located techniques performing, at the same time, a Network Transformation in order to align the local tie into a specific ITRS realization; for more details the interested reader is referred to [2]. The set of condition and observation equations, translated into a LSE context, creates the stochastic kernel of **CLEMeNT**; in fact, it executes an estimation process based on an approach performing a Mixed Model Least-Squares Adjustment (see e.g. [6]). The GPS points' coordinates, resulting from the Bernese v.4.2 GPS processing, are treated as new unknowns in the estimation process and, at the same time, they play the role of observations, each of them provided with an *a priori* statistical information (the complete variance-covariance matrix). Furthermore geometrical constraints which define the tracking points of the involved space-geodetic techniques are properly translated and included into the same estimation context, playing the role of condition equations that the cloud of points must strictly comply with.

4. The New Software Release: GPS-CLEM

The core of **GPS-CLEM**, in the stochastic structure itself, has remained unchanged, but unlike the former release it is a GPS focused one. New features have been introduced, extending the software's capabilities: an additional module has been added, which performs statistical testing focusing on the standardized observational residuals (Data Snooping) and allows to identify and localize potential blunders affecting the observations. The introduction of new geometric conditions on the surveyed set of points entails the possibility to extract further geometric parameters strictly related to the space-geodetic technique involved in the tie computation (for instance, the axis offset of the VLBI antenna).

5. A Deeper Look into GPS-CLEM: The New Ensemble of Implemented Conditions

Here we summarize the conditions applied:

1. **Intra-group parallelism of elevation and azimuthal surfaces** As the VLBI radiotelescope moves, the mobile GPS receivers register the points' positions occupied in the rapid static survey so that they theoretically describe canonical planar curves. During the rotation in elevation, the mobile GPS receivers describe a group of elevation circles: they are simultaneously surveyed and have to be parallel to each other. Similarly during the rotational motion in azimuth, the GPS receivers describe horizontal circles; the circles pertaining to this group must be parallel to each other.
2. **Inter-axial orthogonality** The condition refers to the two principal axes involved in the radiotelescope rotations imposing the two representative VLBI axes to be mutually orthogonal.
3. **Equivalence of elevation circles' radius** The elevation circle arcs traced out by the same GPS antenna and belonging to different elevation axis realizations must have the same radius.
4. **Axis offset estimate** This condition leads to define the VLBI axis offset valid for a radiotelescope, e.g. as in the Medicina case. Since the axis offset can be regarded as the Euclidean distance between one of the moving axis and the fixed axis, we can compute an offset from each realization of the elevation axis. As the axis offset is an intrinsic geometrical feature for the radiotelescope, it has to be univocally defined; hence we can set the axis offsets computed from different realizations to a unique value in the estimation procedure.

6. Running GPS-CLEM

The procedures involved in a typical GPS-CLEM run are as follows: 1. Reading input data coming from the **BERNESE 4.2** GPS postprocessing software; 2. Application of **Geometrical Conditions** to the sets of points described by the GPS antennae; 3. Building of the **Normal Conditioned Linear System** implied by the **MMLSA** (Mixed Model Least-Squares adjustment); 4. Estimation in a least-squares sense of the VLBI radiotelescope Invariant Point; 5. Recursive **Data Snooping** procedure in order to erase the points' coordinates burdened with blunders; 6. Insertion of additional points involved in the local tie computation; 7. Extraction of the SINEX file which contains the local tie estimate including its variance-covariance (vcv) matrix.

7. Performing the Solutions through GPS-CLEM

The Medicina eccentricity vector has been measured within a local ground control network during four different terrestrial surveys (2001, 2002, 2003 and 2005). In this investigation we compare the results obtained during the 2002 terrestrial campaign and the purely GPS-based survey carried out in the same period. The solution criterion we have adopted provides different tie estimations gradually increasing the applied constraints from a low degree of conditions to a high one, so displaying the effects of the conditions over the eccentricity vectors. Here the performed solution types are reported, in association with the name tags used during the processing: **(cum1)** applies the *Loosely Constrained Solution* provided with the former release of CLEMeNT; **(cum4)** adds to the previous approach the intra-group parallelism condition; **(cum5)** applies the conditions of intra-group parallelism and interaxial orthogonality; **(cum2)** adds the univocal estimate of the axis offset; **(cum3)** furnishes the further condition of radius' equivalence.

8. Analysis of GPS Derived Tie Solutions

The analysis of the performed solutions relies on two different aspects: first, a comparison between the terrestrial-classical tie and the GPS tie, both aligned to ITRF aimed at evaluating the agreement of the GPS tie to the classical one. Because of the effects of the alignment procedure of the classical tie from the topocentric system to the ITRF, great attention must be paid to the Euclidean norm of the eccentricity vector, which is invariant for the reference system changes. Secondly, an evaluation of the accuracy reached in the tie computation in the terms of vcv components. It has to be emphasized that the 2002 Medicina terrestrial tie has been determined by means of a loosely conditioned solution. This is the reason why, as shown in Figure 1, an excellent agreement between the **(cum1)** GPS based local tie and the terrestrial one in the terms of modulus has been achieved. Furthermore the solutions display a relevant dependence on the chosen PCV antenna model, both in the eccentricity vector moduli and in their accuracy. Best results have been obtained with the NGS PCV model performing a Data Snooping. Figure 2 points out the differences coming from the PCV model choice for solution **(cum2)**.

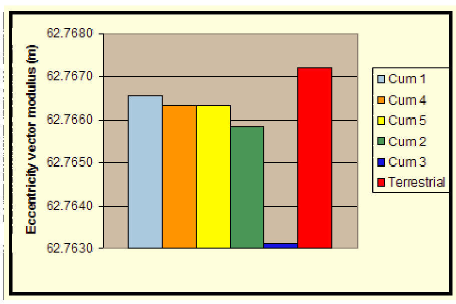

Figure 1. Local tie modulus variation (NGS PCV)

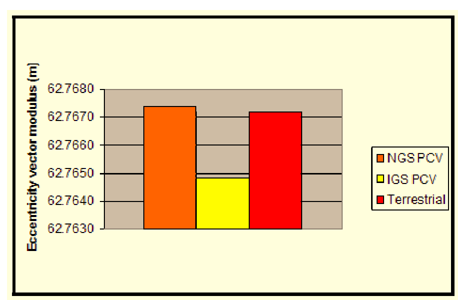

Figure 2. Influence of PCV over local tie modulus (**cum2**)

It has to be pointed out that, as the number of applied conditions increases, the tie accuracy generally improves, with the exception for the **(cum3)** case (Figure 3). Best agreement and accuracies have been achieved in the case of NGS PVC model with a (cum2) solution. Figure 4 shows the differences of the geocentric components between the terrestrial local tie and the GPS derived one.

9. Conclusions and Future Developments

The GPS local tie survey has great advantages if compared with the terrestrial survey: it is time-saving and easy to perform, there is no need of high precision topographic survey skills and, in principle, local ties could be performed regularly at all VLBI co-location sites. At the same time,

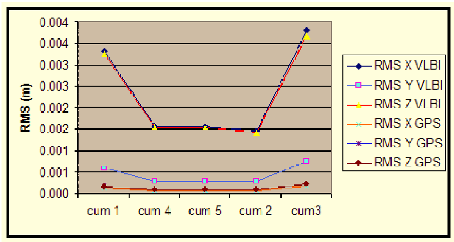

Figure 3. RMS of geocentric components of the tie

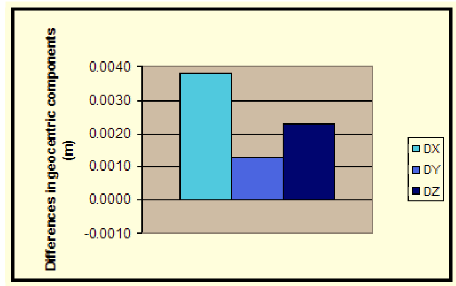

Figure 4. GPS based minus classical tie

this approach to computation provides encouraging results, which suggest further investigations. The ensemble of computed solutions displays a relevant dependence on the Phase Centre Variation modelling. This is the reason why an absolute PCV model will be tried out in the forthcoming future. Furthermore the differences in the geocentric components between the terrestrial local tie and the GPS derived one have to be carefully investigated, for the terrestrial local ties, in the attempt of isolating the effect of reference system transformation. The accuracies achieved with this approach, regarding that the analyzed datasets are quite critical from the geometrical point of view. As a matter-of-fact, beyond the shortcomings strictly related to the GPS technique which strongly affect the solution—multipath effects, satellite constellation not uniformly accessible as the radiotelescope moves—the employed datasets show a geometrical weakness as a consequence of a black-out that occurred at the observatory during the survey. Considering the scarcity in the number of involved surfaces, it could be of interest to strengthen the geometrical robustness by adding surveyed points, which results in an increased overall redundancy in the estimation process.

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