INDIRECT LINKING OF THE HIPPARCOS CATALOG TO EXTRAGALACTIC REFERENCE FRAME VIA EARTH ORIENTATION PARAMETERS

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Abstract. The indirect method of linking the Hipparcos reference frame to the frame defined by extragalactic sources is described. To this end, two independent time series of Earth orientation parameters observed by two different techniques with respect to the two reference frames are used: a) Optical astrometry observations (referred to Hipparcos stars), b) VLBI observations (referred to extragalactic objects). The parallel use of both techniques during the last decade enables to determine the orientation of the two reference frames at a fixed epoch and their mutual slow rotation with precision of at least 1mas and 1mas/year, respectively. In order not to raise confusion, the potentiality of the method is demonstrated on the example based on the star catalogues originally used at the participating observatories, not on any of the existing preliminary versions of the Hipparcos catalog.

1. Introduction

It is well known that the original reference system of the Hipparcos Catalogue has six degrees of freedom; its orientation and rotation with respect to conventional extragalactic reference system must be determined from other observations than Hipparcos project itself. The overview of the methods to be used is published by Lindegren & Kovalevsky (1995). The prevailing majority of these methods is based on more or less direct observations of the positions of the Hipparcos stars with respect to extragalactic objects.

Here we describe an indirect method, based on comparing two independent Earth Orientation Parameters (EOP) referred to the two reference systems (optical and extragalactic). The Earth provides an intermediary

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(rapidly rotating) reference system whose orientation, with respect to the two aforesaid systems, is monitored by two distinct methods using completely different instruments.

The new global adjustment of the EOP from optical astrometry observations since the beginning of the century is presently being prepared by a Working Group set up by IAU Commission 19 (Vondrák, 1991). Its final goal is to derive the EOP in the Hipparcos reference frame; the expected accuracy of the prepared solution is, for the last decades, at the level of 10mas per 5-day value (Vondrák *et al.*, 1992). In the absence of the final Hipparcos Catalogue, a set of preliminary test solutions has been made based on the original local star catalogues used at the observatories, the most recent one being published by Vondrák *et al.* (1995). EOP are regularly monitored with respect to extragalactic objects by Very Long-Baseline Interferometry (VLBI); the results obtained by different analysis centers are combined into a single solution at the Central Bureau of the International Earth Rotation Service (IERS). The nominal precision of these observations is less than 1mas, the adopted positions of the observed extragalactic sources define the extragalactic celestial reference frame (Carter & Robertson, 1993).

2. The Earth Orientation Parameters

There are five EOP that define the position of the spin axis of the Earth, both in the terrestrial and celestial reference systems, and the phase of the spin around the axis. They are as follows:

1. The two components of the axis in the Earth x, y (polar motion),
2. The two components of the axis in space *wrt* standard Celestial Ephemeris Pole $\Delta\psi, \Delta\varepsilon$ (celestial pole offsets in longitude and obliquity),
3. Universal time offset from the International Atomic Time UT1–TAI.

When determining these parameters from optical astrometry observations, the diurnal part of the observed variations is substantial for determining celestial pole offsets, while longer periodic part is used to determine polar motion and UT1. The first two parameters are thus practically useless for linking the two reference frames, being sensitive only to terrestrial reference frame changes. On the contrary, the celestial pole offsets are insensitive to terrestrial reference frame changes (these changes can produce only diurnal variations in $\Delta\psi, \Delta\varepsilon$) but any change in the celestial reference frame orientation is fully reflected in these values. The most 'problematic' component is the Universal time UT1 – it is fully sensitive to both terrestrial and celestial reference systems.

3. Orientation of Optical and Extragalactic System

The relative orientation of the two reference systems and their mutual rotation can be described by six parameters. Here we use the notation introduced by Lindegren & Kovalevsky (1995) – the transformation of a column vector given in the Hipparcos system as $\vec{H} = (x_H, y_H, z_H)^T$ into the extragalactic system $\vec{E} = (x_E, y_E, z_E)^T$ at the epoch t_0 is given by the formula

$$\vec{E} = \begin{bmatrix} 1 & \varepsilon_{0z} & -\varepsilon_{0y} \\ -\varepsilon_{0z} & 1 & \varepsilon_{0x} \\ \varepsilon_{0y} & -\varepsilon_{0x} & 1 \end{bmatrix} \vec{H} \tag{1}$$

and the time derivatives of the angles ε define the rate of mutual rotation of both systems: $\omega_x = \dot{\varepsilon_x}, \quad \omega_y = \dot{\varepsilon_y}, \quad \omega_z = \dot{\varepsilon_z}$.

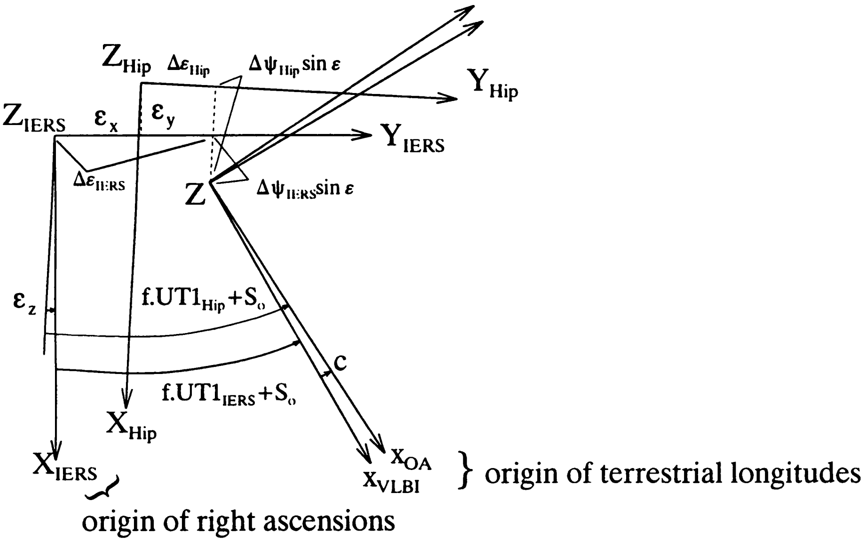

Figure 1. **Relation between celestial pole offsets and the orientation of the Hipparcos and extragalactic reference frames**

The relation between the EOP and the angles defining the orientation of both celestial reference systems is explained at Fig. 1. It shows the position of the axes X, Y, Z of both celestial reference frames and the position of the axis x (origin of longitudes of the terrestrial reference frames used by VLBI and optical astrometry) as seen from the north pole. Z_{Hip} and Z_{IERS} denote the positions of the north pole of Hipparcos and extragalactic reference frames, both moving with standard precession-nutation, Z is the position of the actual celestial pole. The offsets between Z and Z_{Hip}, Z_{IERS} are measured by optical astrometry and VLBI and expressed by means of celestial pole offsets $\Delta\varepsilon_{\rm Hip}, \Delta\psi_{\rm Hip}\sin\varepsilon$ and $\Delta\varepsilon_{\rm IERS}, \Delta\psi_{\rm IERS}\sin\varepsilon$. They contain not only the misalignments of the two systems of reference, but also the deviations of actual nutation from the standard model used. Provided the same model is used for optical astrometry and VLBI, the latter deviations disappear in the difference. Universal time is calculated from the measured angle between the plane of zero meridian of the terrestrial reference frame and the XZ plane of the corresponding celestial reference frame. In this case, these are the angles $\angle x_{\rm OA}X_{\rm Hip}$ and $\angle x_{\rm VLBI}X_{\rm IERS}$; they are equal to $f.{\rm UT1}_{\rm Hip} + {\rm S}_0$ and $f.{\rm UT1}_{\rm IERS} + {\rm S}_0$, respectively, where $f = 1.0027\ldots$ and S_0 is the standard expression for GMST of 0^h UT1, including the equation of equinoxes (Seidelmann, 1992). Since the origins of terrestrial longitudes for optical astrometry instruments (defined by their adopted longitudes) and for VLBI (defined by the adopted directions of the baselines) are not generally identical, there is no possibility of independent determination of ε_z and c. The formulas for calculating the ε values then read

$$\begin{aligned} \varepsilon_x &= \Delta\varepsilon_{\rm IERS} - \Delta\varepsilon_{\rm Hip} \\ \varepsilon_y &= (\Delta\psi_{\rm Hip} - \Delta\psi_{\rm IERS})\sin\varepsilon \qquad (2) \\ \varepsilon_z + c &= 15.041({\rm UT1}_{\rm Hip} - {\rm UT1}_{\rm IERS}). \end{aligned}$$

Having the two sets of EOP observed in the same time interval, we can interpolate them for the same time arguments and calculate the values ε using eq. (2) at various epochs. The time interval of common observations of both techniques being sufficiently long, the time derivatives of these values (defining the values ω) can also be obtained. In doing so, one should also take into consideration all possible correlations of the input data. Since the precision of VLBI is much higher than that of optical astrometry, we consider here only the correlations coming from our optical astrometry solution. It is a result of a rather complicated system of normal equations with about 30 thousand estimated parameters. The only significant correlations exist between the values obtained at the same 5-day interval – the adjusted values of EOP for different epochs are practically de-correlated. Consequently we treat the values calculated from eq. (2) as observed correlated quantities, taking the weight matrix from optical astrometry solution in which only certain non-diagonal elements have non-zero values.

4. Example of Linking Quasi-FK5 System, Conclusions

Before the Hipparcos catalog is available, let us demonstrate the potentiality of the proposed method on the example of a quasi-FK5 catalogue. The solution for the years 1900.0–1991.0 presented in (Vondrák *et al.*, 1995), based on more than 3 million of observations made with 30 instruments located at 19 observatories, is referred to local catalogues partially homogenized into a system that is very close to FK5. The last decade of the solution is parallel to VLBI observations; here, we take the IERS combined solution C 02 (5-day values with epochs close to optical astrometry solution) in the years 1980.3–1991.0. In order to calculate the differences on the *rhs* of eq. (2) we interpolated the IERS values for the epochs of optical astrometry solution using cubic splines. The differences are graphically displayed in Figs. 2 and 3. The trends in all three components are obvious, especially the one in UT1. Also remarkable is a quasi-periodic character of the differences; it seems to prompt that there might be some systematic differences in certain nutation terms (very probably in annual term) as detected by optical astrometry and VLBI.

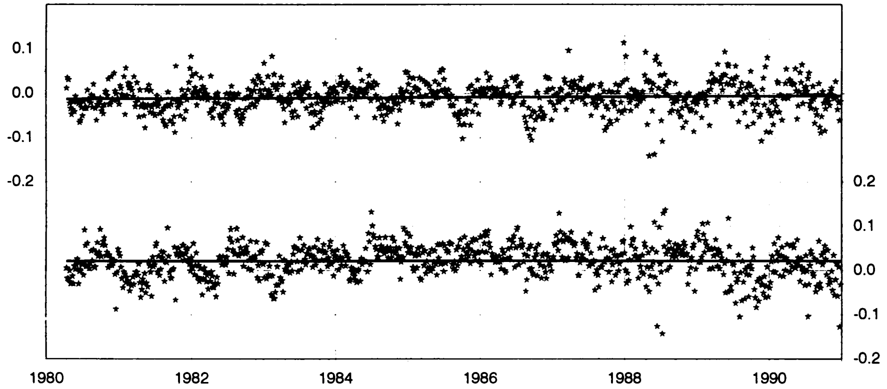

Figure 2. Differences of celestial pole offsets (in arcseconds) $\Delta\varepsilon$ (upper part) and $\Delta\psi \sin\varepsilon$ (lower part) in the sense optical astrometry minus VLBI.

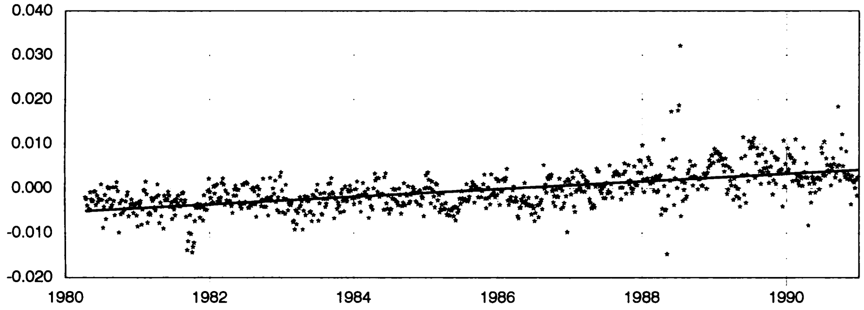

Figure 3. Differences in UT1 (optical astrometry minus VLBI) in seconds of time.

The resulting six parameters of the mutual orientation between optical and extragalactic reference frame, their standard errors and matrix of correlation coefficients are given in Tab. 1. The values ε_0 (for the epoch

$t_0 = 1985.25$) and their standard errors (derived from the dispersion of 5-day values as seen in Figs. 2 and 3) are given in milliarcseconds, the values of ω and their standard errors in milliarcseconds per year. One can see that the standard errors in ε_{0z} and ω_z are nearly twice as big as for the other two angles. It clearly demonstrates the presence of larger systematic errors in UT1 observations than in latitude observations; the effect of higher latitudes of the observatories also plays certain role. Standard errors σ are three times bigger than one would expect from the formal precision of the global optical astrometry adjustment. The difference in terrestrial longitude systems used by optical astrometry and VLBI and their possible drift prevents us from determining the angles ε_{0z} and ω_z by this method.

TABLE 1. Example of orientation angles ε, ω, their standard errors σ (in milliarcseconds) and correlation coefficients, calculated for original star catalogs.

Orientation		σ	Correlations					
			ε_{0x}	ω_x	ε_{0y}	ω_y	$\varepsilon_{0z} + c$	ω_z
ε_{0x}	8.59	±1.11	1.000	0.063	0.012	-0.002	0.095	0.024
ω_x	-1.09	0.39	0.063	1.000	-0.002	0.017	0.023	0.090
ε_{0y}	23.00	1.11	0.012	-0.002	1.000	0.052	-0.066	0.007
ω_y	0.99	0.39	-0.002	0.017	0.052	1.000	0.006	-0.068
$\varepsilon_{0z} + c$	-19.59	1.65	0.095	0.023	-0.066	0.006	1.000	0.119
$\omega_z + \dot{c}$	9.82	0.60	0.024	0.090	0.007	- 0.068	0.119	1.000

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