RESULTS OF JOINT PROJECT ON LINKING OPTICAL–RADIO REFERENCE FRAMES

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Results of international co-operation between observatories from China, Russia, Turkey, and Ukraine on refinement of linking optical and radio reference frames are discussed. About 300 fields around extragalactic radio sources in the selected fields of extragalactic radio sources from −40 to +70 degrees in declination were observed with CCD ground-based telescopes. The catalogue of optical positions of more than 200 ERS with average accuracy 30 mas in ICRF by using of secondary reference stars from the UCAC2 and USNO-B1.0 catalogues was obtained as a result of this cooperation. The intermediate internal estimation of link between optical and radio reference frames was shown the angle values near zero within an accuracy of about 6 mas by using of secondary reference stars from UCAC2. A comparison of presented results with those of other investigations was made.

INTRODUCTION

The link between optical (Hipparcos) and radio (ICRF) reference frames was realized in position within ±0.6 mas at the mean epoch 1991.25 and in rotation within ±0.25 mas per year [4]. However, the accuracy of Hipparcos–ICRF link degrades over time owing to error in the HC proper motion determination. It is a reason for verification and refinement of frame's link by different methods and telescopes [9, 15].

The task of the Joint Project (JP) between astronomical observatories from China, Turkey, Russia and Ukraine is the refinement of optical / radio linking with collaborated CCD telescopes [7, 13].

PROGRAM AND INSTRUMENTATION

The final co-operative program list includes about 300 ERS in the selected fields of celestial sphere in declination zone from -40° to $+75^\circ$ and magnitude range from 12^m to 20^m.

Several CCD telescopes of collaborated observatories which were taken part in the Joint Project are shown in Table l.

OBSERVATIONS AND REDUCTION

Observations

Up to day positions of 300 ERS optical counterparts were obtained by CCD direct imaging mainly on the 1.0-m Yunnan and RTT150 telescopes, with secondary reference stars mainly 14–18 magnitudes. More than 2000 CCD frames were obtained during 2000–2003. Every ERS field was observed on average 5–6 times.

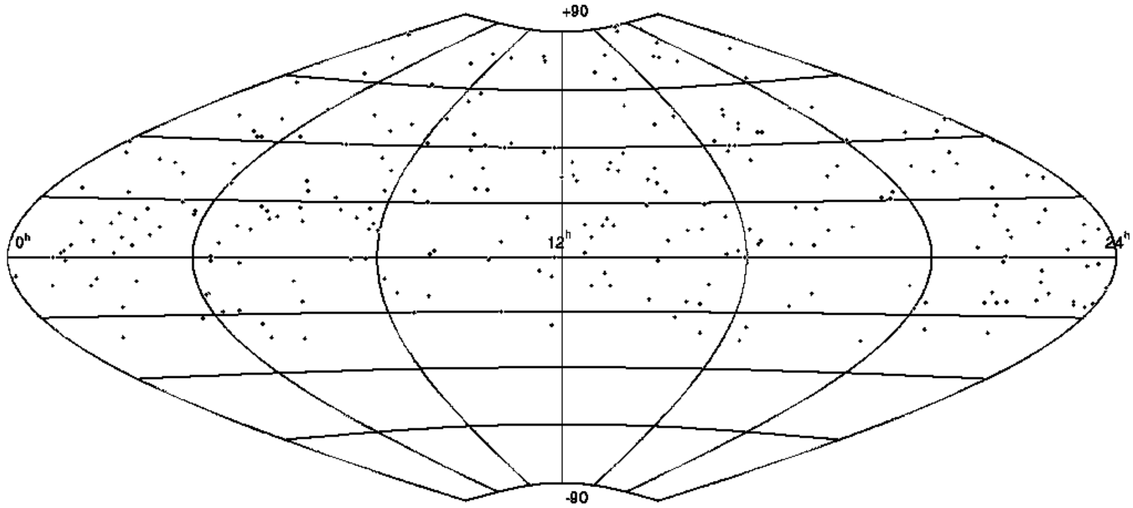


Figure 1. Distribution of the ERS in right ascension and declination

Table 1. Collaborated telescopes

Telescope	RTT150, Antalya, TUG (Turkey)		1.0-m Yunnan AO (China)	MCT, Nikolaev AO (Ukraine)
φ	+36°		+31°	+47°
Type	Reflector		Reflector	Refractor
D (mm) / F (mm)	1500 / 11700		1000 / 13000	160 / 2044
CCD	ST-8	Andor DW436	TI	ISD017A
Size, pixel	1530×1020	$2K \times 2K$	1024×1024	1040×1160
Pixels, mkm	18×18	13.5×13.5	24×24	16×16
arcsec/pixel	$0.16''$	$0.24''$	$0.37''$	$1.6''$
FOV	$4' \times 3'$	$8' \times 8'$	$6.5' \times 6.5'$	$28' \times 31'$
Mode	Stare	Stare, Drift scan	Stare	Stare, Drift scan
Magnitude	$19^m \div 21^m$	$19^m \div 23^m$	$17^m \div 19^m$	$12^m \div 14^m$
$N1$	131	55	116	10
$N2$	21	41	82	2
Period of observations	2000–2002	2003	2000–2003	2000–2003

Reduction methods and results

Processing of the CCD images including dark, flat, and defect fields corrections, digital image filtration, identification of objects and determination of coordinates for star-like objects' in CCD were made using the PUMA astrometric package [8]. The measured $(x,\ y)$ centers of images was derived using two-dimensional spherically symmetric Gaussian fit model.

The linear 6-parameter plate model has been adopted for reduction of measured CCD coordinates $(x,\ y)$ to tangential (standard) coordinates (ξ, η)

$$\xi = c + a \cdot x + b \cdot y,$$
$$\eta = f + d \cdot x + e \cdot y.$$

The primary optical reference stars from HC are too bright and sparsely distributed in the sky. On the reason of a small field size of CCD frames of collaborated telescopes (see Table 1) the first processing approach was made using the USNO-A2.0 and USNO-B1.0 catalogues [5, 6].

Secondary reference stars from USNO have similar magnitudes (16^m–18^m) in comparison with selected ERS optical counterparts (Fig. 2). So, correction of brightness equation in $\Delta\alpha_{O-R}$, $\Delta\delta_{O-R}$ are expected negligible.

Differences $\Delta\alpha_{O-R} \cdot \cos\delta = \alpha_O - \alpha_R$ and $\Delta\delta_{O-R} = \delta_O - \delta_R$ were calculated from ERS optical and radio coordinates, respectively, and their distributions are shown in Fig. 3a. It is to be noted that some differences in

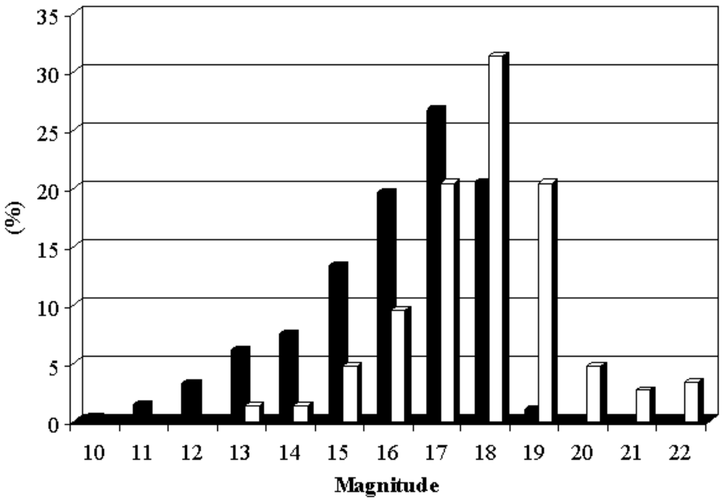
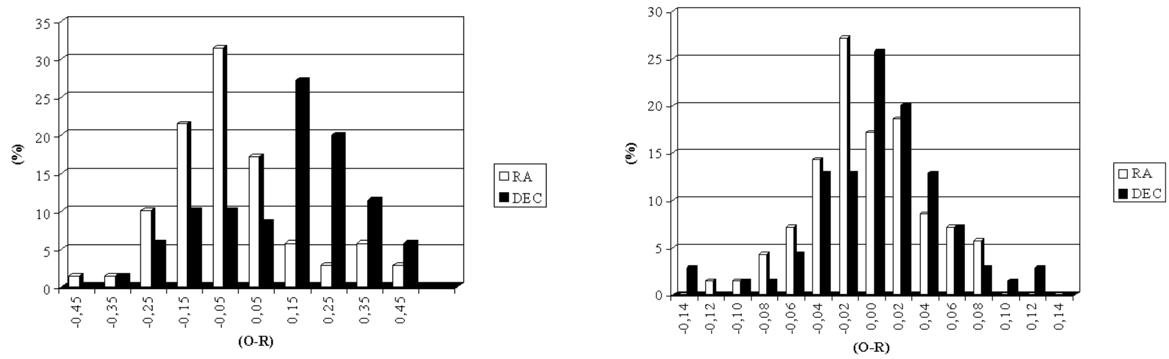


Figure 2. Distribution of secondary reference stars from USNO-B1.0 (dark) and selected ERS (light) with magnitudes



a) the USNO-B1.0 catalogue

b) the UCAC2 catalogue

Figure 3. Distribution of differences between ERS coordinates in optical and radio range $\Delta\alpha_{O-R} \cdot \cos\delta$ (light) and $\Delta\delta_{O-R}$ (dark)

the positions between ICRF and USNO-B1.0 are available on the reason of some errors: the regional differences in positions between ICRF and USNO-B1.0; some errors of CCD frames reduction and possible structure problems of some separate ERS.

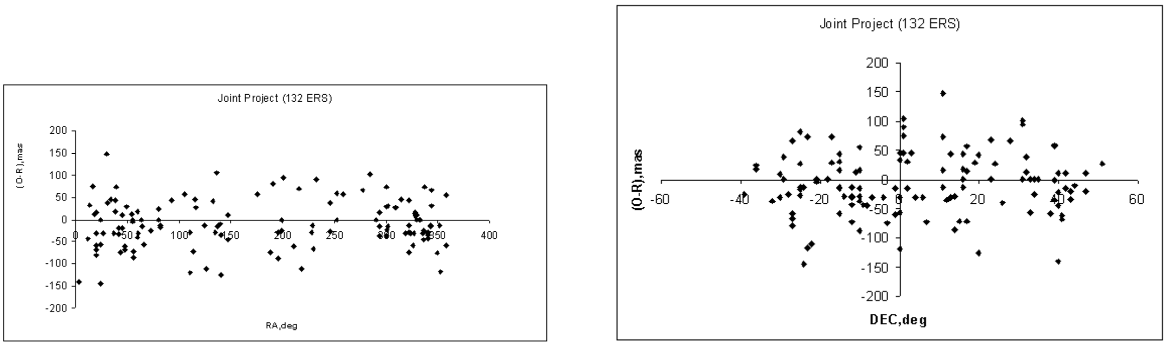
Despite enough of reference stars of similar brightness to the researched objects, the received differences have shown impossibility to use the USNO catalogues for determination link parameters owing to low accuracy positions and proper motions.

In autumn 2003 the UCAC2 catalogue became available in separate areas of a zone of declinations up to $+52°$. A processing of received material was made using the reference stars from the UCAC2 [14]. Unfortunately, the version UCAC2 we used has allowed us to process less half of available fields on reason of small field and absence of high declination zone.

A distribution of differences $\Delta\alpha_{O-R} \cdot \cos\delta = \alpha_O - \alpha_R$ and $\Delta\delta_{O-R} = \delta_O - \delta_R$ with the UCAC2 catalogue is shown in Fig. 3b. Only four optical counterparts out of 136 lie beyond 150 mas. There are no dependence of the optical minus radio position differences as a function of right ascension and declination (see Figs. 4 and 5).

DETERMINATION OF PRELIMINARY ANGLES BETWEEN OPTICAL AND RADIO REFERENCE FRAMES

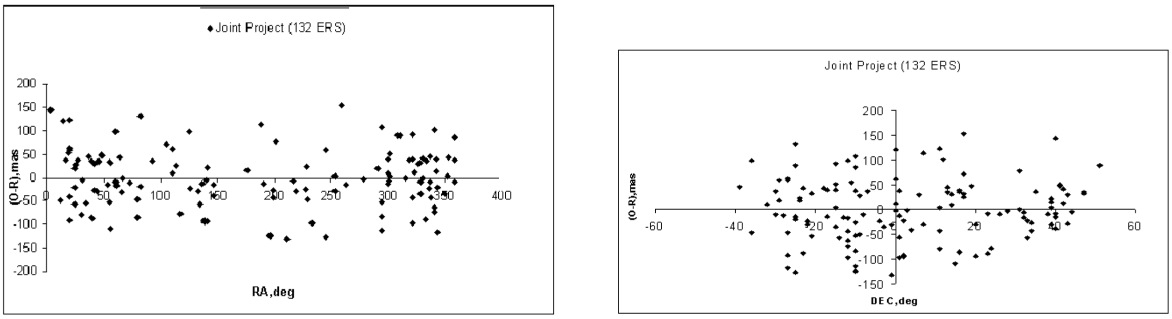
In accordance with available observations the values of the angles between optical and radio reference frames were calculated by known formulas:



a) as a function of right ascension

b) as a function of declination

Figure 4. Optical minus radio differences $\Delta\alpha_{O-R}\cdot\cos\delta$ for the ERS observed in Joint Project



a) as a function of right ascension

b) as a function of declination

Figure 5. Optical minus radio differences $\Delta\delta_{O-R}$ for the ERS observed in Joint Project

$$\begin{aligned} \Delta\alpha_{O-R}\cdot\cos\delta &= \omega_x\cdot\sin\delta\cdot\cos\alpha+\omega_y\cdot\sin\delta\cdot\sin\alpha-\omega_z\cdot\cos\delta, \\ \Delta\delta_{O-R} &= -\omega_x\cdot\sin\alpha+\omega_y\cdot\cos\alpha, \end{aligned} \tag{1}$$

where $\Delta\alpha_{O-R}=\alpha_O-\alpha_R$ and $\Delta\delta_{O-R}=\delta_O-\delta_R$ are the ERS coordinate differences in optical and radio reference frames; w_x, w_y, w_z are the rotation angles about the x, y, z axes, respectively.

Taking into account all remarks shown above the angles' values were determined from available observations (Table 2). For comparison, the angles obtained by various authors are given [3, 10, 11, 15]. At last the Joint Project results which were determined recently with the new UCAC2 catalogue are shown in Table 2.

Table 2. Optical-radio rotational parameters

Source	ω_x, mas	ω_y, mas	ω_z, *mas*	N	σ_1, mas
Andrei *et al.* (1995), FK5 [2]	-30 ± 20	30 ± 30	20 ± 20	29	170
Kumkova *et al.* (1995), FK5 [3]	38 ± 18	22 ± 16	-17 ± 16	78	–
FASTT (1997), FK5 [10]	3 ± 5	25 ± 5	16 ± 4	689*	104
FASTT (1998), HC [11]	-2.2 ± 3.3	-2.2 ± 3.4	3.3 ± 2.9	689**	–
Zacharias *et al.* (1999), ERL [15]	-0.2 ± 3.9	-5.4 ± 3.9	-2.5 ± 3.9	318	58
Joint Project (2003), UCAC2	-1.3 ± 7.2	9.3 ± 6.7	6.1 ± 5.7	132	59

The column N gives number of ERS sources in the solution, 689*, 689** gives number of FK5 and HC stars, respectively, determined in the ICRF using CCD observations with the FASTT; ω_x, ω_y, ω_z are the rotation angles with their standard errors; σ_1 is the weight unit error.

It is to be noted that results obtained with the UCAC2 are similar to best. They have higher accuracy due to good secondary reference star positions of the UCAC2.

The USNO-B1.0 is a convenient and perspective catalogue for reduction of CCD frames with a small size of fields. It is necessary to complete investigations by processing of available observations using the USNO-B1.0 catalogue.

CONCLUSIONS

- At present, the observations of about 200 ERS obtained using the telescopes collaborated in Joint Project are available for reduction.
- The best rotation parameters has been obtained in the system of a more precise catalogue like the UCAC2 on the accuracy level of ±6 mas.

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