REFINEMENT OF LINKING OPTICAL/RADIO REFERENCE FRAMES ON THE BASIS OF POSITIONAL OBSERVATIONS CONDUCTED IN UKRAINE, CHINA AND RUSSIA

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Preliminary results of cooperative programme for refinement of linking optical/radio reference frames are discussed. The instrumentation, methods of observations and reductions as well as preliminary results are presented. Optical positions of several extragalactic radio sources (ERS) are determined by using the CCD telescopes of China, Russia and Ukraine. The catalogue, which consists of 14000 stars selected from the USNO–A2.0 in the fields around 200 ERS is used as reference one. The positions of stars in this catalogue were obtained from observations with Mykolaiv Axial meridian circle (AMC) for declination zone from equator to +70° in the 11–14.5 magnitude range made during 1996–1998. It is estimated that an expected accuracy of the optical/radio linking in case of using about 200 ERS for northern declination zone is on the level of 5 mas provided the uncertainties ERS optical positions are not worse than 20 mas.

INTRODUCTION

The HC is considered as a best realization of the ICRF in optical frequency range. The equatorial axes of the HC have been satisfactory agreed relative to the ICRF at the epoch 1991.25 with an accuracy of ± 0.6 mas. However, the Hipparcos frame will lose this link progressively due to uncertainties of the Hipparcos proper motions. It is necessary to verify and check this link for variation with time. However, the link of HC to the ICRF in magnitude range above 10 mag is not easy. There are several ways for such check, and some of them could be realized by using the CCD astrographs and automatic meridian telescopes (AMT) (Argue, 1991; Kovalevsky, 1995; Stone, 1996; 1997). Proposed link programme could provide an intermediate system of reference stars in the HC system made with AMC in fields around ERS selected. Cooperative CCD telescopes with available FOV and sensitivities should guaranty a sufficient amount of intermediate reference stars for the determination of precise positions of faint ERS as well as to cover a magnitude range between intermediate stars and ERS optical counterparts. This cooperative programme is elaborated on the basis of joint research work in the field of optical/radio linking between Mykolaiv Astronomical Observatory (Ukraine) and Shanghai Astronomical Observatory (China) started in 1996 (Tang *et al.*, 2000).

The primary task of the proposed cooperative programme is establishment of optical/radio linking with accuracy better than 5 mas globally. It will be appropriate for enhancing a current link accuracy. From equations (1) it can be shown that for some available accuracy of ERS optical positions and for enough number of ERS it is possible to have a high accuracy of optical/radio linking (Fig. 1):

$$\begin{aligned} \Delta\alpha_{O-R} &= \mathrm{tg}\delta(u\cos\alpha + v\sin\alpha) + w, \\ \Delta\delta_{O-R} &= -u\sin\alpha + v\cos\alpha, \end{aligned} \tag{1}$$

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

It can be shown on the basis of equations (1) that rotation parameters accuracy of 5 mas will be reached by using of about 200 ERS with positional accuracy not worse than 20 mas (Fig. 1).

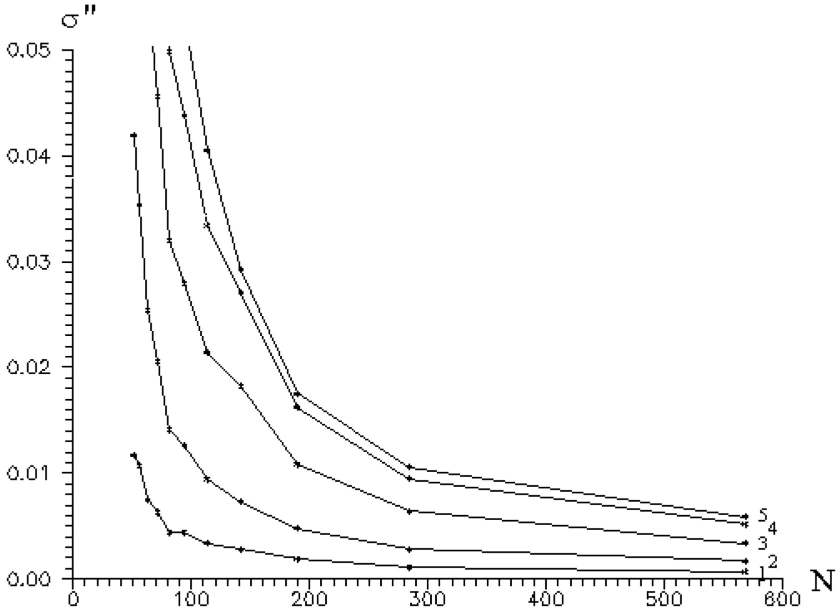

Figure 1: Rotation parameters accuracy (σ) in dependence of ERS number (N) and optical positions accuracy ($\epsilon_{\alpha,\delta}$: 1 – $\pm 0\overset{''}{.}01$, 2 – $\pm 0\overset{''}{.}02$, 3 – $\pm 0\overset{''}{.}03$, 4 – $\pm 0\overset{''}{.}04$, 5 – $\pm 0\overset{''}{.}05$)

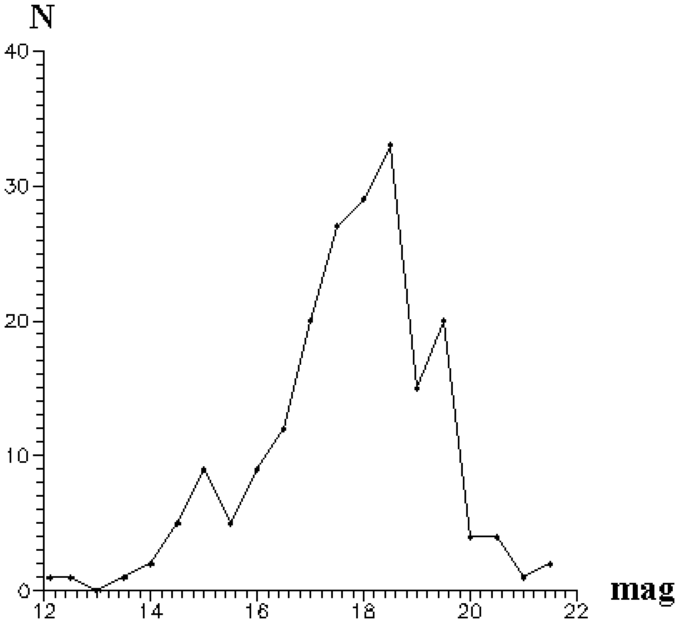

Figure 2: Distribution of selected ERS with the magnitudes in optical domain

PROGRAM AND INSTRUMENTATION

The cooperative program includes about 200 ERS for declination zone from equator to $+70°$. A distribution of selected ERS with the magnitudes in optical domain is shown in Fig. 2.

There are several cooperative CCD telescopes used in the program: AMC – Axial Meridian Circle (180, 2480) and Zone astrograph (160, 2044) of the Mykolaiv Astronomical Observatory (MAO) equipped by the similar CCD ISD017A (1040×1160, 16×16 mkm, $1''\!.6$/pix); AZT-8 astrograph (700, 2819)) of the Astronomical Observatory of the Kharkiv University (Ukraine) with the CCD ST-6 (375×241, 23×27 mkm, $1''\!.8 \times 2''\!.1$/pix); AZT-22 astrograph (1500, 11600) of the Engelghardt Astronomical Observatory of the Kazan University (Russia) installed in Turkey and equipped by the CCD ST-8 (1530×1020, 9×9 mkm, $0''\!.16$/pix) as well as 1.56 meter astrograph (1560, 15600) of the Shanghai Astronomical Observatory (China) with the CCD SONI (1024×1024, 16×16 mkm, $0''\!.25$/pix) (Maigurova *et al.*, 2000; Tang *et al.*, 2000) (see Table 1).

The Mykolaiv AMC was put into operation in 1995. AMC was equipped with CCD (256×288, 32×24 mkm) and computer control system. It permits to observe stars up to 14.5 limit magnitude. Observations of intermediate reference stars in the selected fields dimension $24' \times 60'$ around 200 north ERS and in the 11–14.5 magnitude range were made during 1996–1998. It was made about 120000 observations of 15000 stars including intermediate reference stars from USNO–A2.0 in selected fields, primary reference stars from HC and additional stars from TC. After installation on the AMC of a new CCD (ISD017A 1040×1160, 16×16 mkm, $1''\!.6$/pix) direct observations of bright counterparts of 24 ERS (up to 15 magnitudes) will be started in 2001.

Table 1: Cooperative telescopes used in programme

Telescope	AMC (Mykolaiv, Ukraine)	ZA (Mykolaiv, Ukraine)	AZT-8 (Kharkiv, Ukraine)	1.56 m ShAO (Shanghai, China)	AZT-22 (Antalia, Turkey)
Type	refract	refractor	reflector	reflector	reflector
Optical param D, F (mm)	180 2480	160 2044	700 2819	1560 15600	1500 11600
CCD	ISD017A 1040×1160 16×16 mkm $1''\!.26$/pix $23' \times 26'$	ISD017A 1040×1160 16×16 mkm $1''\!.6$/pix $28' \times 31'$	ST-6 375×241 23×27 mkm $1''\!.8 \times 2''\!.1$/pix $8' \times 10.5'$	SONI 1024×1024 16×16 mkm $0''\!.25$/pix $4' \times 4'$	ST-8 1530×1020 9×9 mkm $0''\!.16$/pix $4' \times 3'$
Mode	drift scan	drift scan, stare	stare	stare	drift scan, stare
Magnitude range	$10^m \div 16^m$	$12^m \div 15^m$	$15^m \div 17^m$	$17^m \div 19^m$	$19^m \div 21^m$
Observation program	24 ERS; refer. stars in selected fields (200 ERS)	20 ERS	65 ERS	75 ERS	50 ERS

By using some CCD astrographs direct observations of ERS for astrograph limiting magnitudes were started from 1998–99: with Mykolaiv ZA about 20 ERS in magnitude range $12^m \div 15^m$; with Kharkiv AZT-8 65 ERS in magnitude range $15^m \div 17^m$; with Shanghai 1.56 meter astrograph about 75 ERS in magnitude range $17^m \div 19^m$ and with AZT-22 astrograph of Kazan University about 50 ERS in magnitude range $19^m \div 21^m$.

3. REDUCTION AND RESULTS

3.1. AMC catalogue of reference stars

The intermediate version of AMC catalogue (AMC1B) is available via WWW:
http : //mypage.goplay.com/naom/amc1b.zip.
It contains about 15000 stars with catalogue accuracy on both coordinates:

$$\epsilon_\alpha \cos\delta = \pm 0''\!.079 \cdot (\sec Z)^{0.32} \cdot (\mathrm{mag} - 7)^{0.20};\ \epsilon_\delta = \pm 0''\!.093 \cdot (\sec Z)^{0.12} \cdot (\mathrm{mag} - 7)^{0.18}.$$

3.2. First estimation of ERS optical/radio differences

For small fields of view (FOV) of CCD telescopes one can consider influences of all distortions as negligible and, therefore, can adopt a linear model of reduction for:

a) the Kharkiv astrograph

$$X = ax + by + cxy + d,$$
$$Y = ex + fy + gxy + h, \tag{2}$$

where X, Y are standard coordinates; x, y are the measured coordinates.

Comparison between optical and radio positions is presented in Table 2 for several selected ERS. An accuracy of optical/radio ERS position differences obtained by using the AMC reference stars catalogue is given (in arcsec).

Table 2:

ERS	mag	number	$\Delta\alpha_{O-R}$	$\sigma_\alpha \cdot \cos\delta$	$\Delta\delta_{O-R}$	σ_δ
0735+178	16.2	5	0.87	±0.02	0.10	±0.04
0248+430	17.6	6	0.27	0.02	0.10	0.04
2200+420	14.7	7	–1.76	0.01	0.17	0.04
0738+313	16.1	6	–0.10	0.02	0.20	0.02
1749+096	16.8	6	1.02	0.10	–0.78	0.12
2145+067	16.5	5	0.60	0.07	–1.09	0.02

b) the Shanghai astrograph

$$X - x = a_1 + a_2 x + a_3 y,$$
$$Y - y = b_1 + b_2 x + b_3 y, \tag{3}$$

where X, Y and x, y are above mentioned for equations (2).

Comparison between optical and radio positions is presented in Table 3 for some selected ERS (in arcsec).

Table 3:

ERS	mag	$\Delta\alpha_{O-R}$	$\sigma_\alpha \cdot \cos\delta$	$\Delta\delta_{O-R}$	σ_δ
0552+398	18.0	–0.10	±0.22	+0.03	±0.15
0735+178	16.1	–0.50	0.14	0.29	0.13
0818–188	15.0	0.20	0.16	–0.16	0.12
0827+243	17.3	–0.78	0.19	0.98	0.23
0851+202	15.4	–0.01	0.12	–0.40	0.14
1652+398	13.9	–0.08	0.16	0.72	0.16
1727+502	16.0	0.11	0.17	0.24	0.18
2145+067	16.5	0.42	0.15	0.77	0.15
2200+420	14.7	0.01	0.23	0.05	0.25

c) Comparison between optical and radio positions for ERS0735+178 obtained with Shanghai, Kharkiv and Kazan astrographs has showed a good agreement within random errors. Among these telescopes the Kazan AZT-22 has negligible systematic errors.

It is to be noted that accuracy of optical/radio ERS position differences is determined mainly by accuracy of intermediate reference stars positions. It is a main reason for large dispersion of optical/radio differences and random error, especially in case of using faint reference stars. Also, the low accuracy of data given in Table 3 may be explained by existence of systematic errors. From another side when ERS observation number will be of about 10–16 the expected mean accuracy should be about $0.''02$.

CONCLUSION

1. Determination of optical/radio ERS differences with position accuracy of 20 mas by using the observations of 200 ERS permits to determine rotation parameters with accuracy of 5 mas and to refine the optical/radio reference frames linking.
2. The expected accuracy is possible by using the cooperative telescopes provided sufficient number of ERS observations (not less than 10–16) and final position accuracy of AMC catalogue of intermediate reference stars on the level of not worse than 50 mas.

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