COMPARING THE TYCHO CATALOGUE WITH CCD ASTROGRAPH OBSERVATIONS

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ABSTRACT

Selected fields around radio–optical reference frame sources have been observed with the U.S. Naval Observatory CCD astrograph (UCA). This telescope is equipped with a red-corrected 206mm 5-element lens and a 4k by 4k CCD camera which provides a 1 square degree field of view. Positions with internal precisions of 20 mas for stars in the 7 to 12 magnitude range have been obtained with 30 second exposures. A comparison is made with the Tycho Catalogue, which is accurate to about 5 to 50 mas at mean epoch of J1991.25, depending on the magnitude of the star. Preliminary proper motions are obtained using the Astrographic Catalogue (AC) to update the Tycho positions to the epoch of the UCA observations, which adds an error contribution of about 15 to 20 mas. Individual CCD frames have been reduced with an average of 30 Tycho reference stars per frame. A linear plate model gives an average adjustment standard error of 46 mas, consistent with the internal errors. The UCA is capable of significantly improving the positions of Tycho stars fainter than about visual magnitude 9.5.

Key words: CCD astrometry; Tycho Catalogue; improving Tycho positions.

1. INTRODUCTION

Wide-field CCD images have been taken from selected areas in the sky. Positions of Tycho Catalogue (ESA 1997) stars have been used for astrometric reductions of those CCD frames. The total error budget in this reduction consists of at least 3 contributions:

1. the error of a Tycho Catalogue star position at the Tycho mean epoch (1991.25)
2. the proper motion error for the (1997 − 1991) epoch difference
3. errors from the CCD observations

For bright Tycho stars the error contributions from the proper motions and CCD observations dominate, while for the fainter Tycho stars a meaningful external position error can be estimated from our observations.

Table 1. The UCA telescope and camera.

clear aperture	206	mm
focal length	2057	mm
plate scale	100	arcsec/mm
number of lens elements	5	
spectral bandpass of lens	550–710	nm
usable flat field of view	≈ 9	degree
number of pixels	4096×4096	
pixel size	9.0	μm
pixel scale	0.9	arcsec/pixel
spectral bandpass used	579–642	nm
filter replaces window	λ /4	optical quality
readout	14	bit
readout noise	13	e^-
full well capacity	85 000	e^-

2. OBSERVATIONS

In January 1997 the U.S. Naval Observatory CCD Astrograph (UCA) was equipped with a 4k by 4k CCD camera for a new astrometric Southern Hemisphere project (Gauss et al. 1996, Zacharias et al. 1997). This project is designed to observe all stars in the 7 to 16 magnitude range with an expected positional accuracy of 20 to 70 mas. With a scale of 0.9 arcsec/pixel, the field of view (FOV) is over 1 square degree. Details about the telescope and the camera are given in Table 1. Earlier observations with a 1k CCD camera at the same telescope have not been used for this investigation due to the smallness of the FOV.

CCD frames within an area of 3° by 3° centered on extragalactic reference frame sources have been taken with 30 seconds exposure time. The raw data have been corrected for dark current. Stellar images have been fitted by 2-dimensional, circular symmetric, Gaussian model profiles. Figure 1 shows an example of the internal profile fit precision, $\sigma_{\rm pf}$, as a function of the instrumental magnitude, which is between V and R. Saturation occurs at about 7.5 mag and $\sigma_{\rm pf}$ is about constant at 20 mas up to 12 mag.

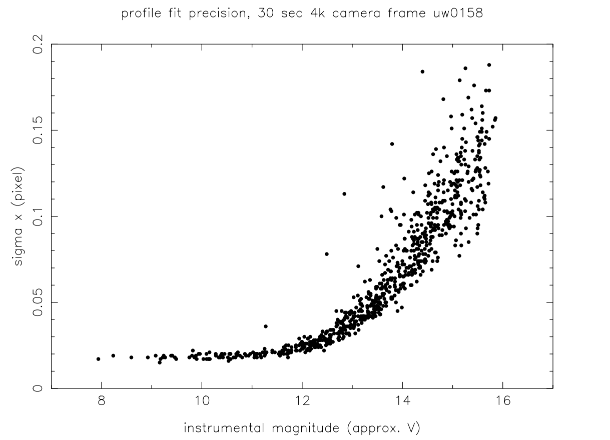

Figure 1. Image profile fit precision as a function of magnitude. This example shows data from a single 30 second CCD frame taken close to the galactic plane.

The accuracy of the UCA observations has been estimated to be about 15 mas (Zacharias et al. 1997) for the previously used 1k CCD camera in a 20 arcmin field of view and 150 second exposure time. Figure 2 shows an example of the error, $\sigma_{\rm CCD}$, of the UCA x, y data from centre-in-corner overlap frames taken for this investigation. This error includes the repeatability precision as well as errors due to the geometry of the detector. The dominating error contribution for these short exposures is the turbulence in the atmosphere. Based on these frame-to-frame comparisons, we adopt $\sigma_{\rm CCD} = 30$ mas for an individual observation of a Tycho star (per coordinate).

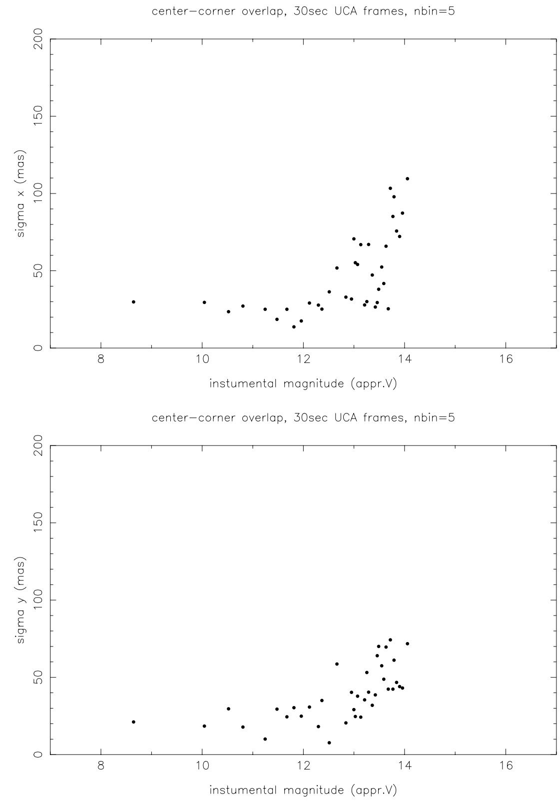

Figure 2. Frame-to-frame transformation error versus magnitude for 2 center-in-corner overlapping frames of 30 second exposure time. One dot represents the rms mean of 5 individual residuals.

3. PROPER MOTIONS

The difference between the mean Tycho epoch (1991.25) and the epochs of the individual CCD observations (about 1997.25) has been bridged by proper motions derived from Astrographic Catalogue (AC) data. Positions from new USNO reductions of the AC (Urban & Corbin 1996) have been used in combination with the Tycho Catalogue data to derive proper motions and errors. Systematic differences between the AC, which is in the FK5/J2000 system, and the Tycho Catalogue, which is in the International Celestial Reference System (ICRS) are considered negligible to change over the small areas investigated here.

Table 2. AC error statistics for proper motions.

field name	$\sigma_{\rm AC}$ mas	mean AC epoch	$\sigma_{\rm pm}$ mas/year	$\sigma_{\rm pmc}$ mas
0642+449	200	1896	2.2	13
0743−006	200	1898	2.3	14
0906+015	200	1908	2.5	15
1830+285	300	1900	3.3	20

The estimated error for an AC position is an average for the corresponding declination zone. The values for $\sigma_{\rm AC}$ as given in Table 2 have been used for all stars of a given field because the few images per AC star do not allow derivation of a meaningful error for individual stars. To a good approximation, the AC position error does not depend on magnitude over the range of magnitudes (7.5 to 11.5) considered here. Table 2 also gives average values for the AC epoch, the estimated proper motion error, $\sigma_{\rm pm}$, and the error contribution due to proper motion errors $\sigma_{\rm pmc}$ to our 1997 epoch data. Individual observational epochs and Tycho Catalogue data have been used for each star for the following reductions and error statistics.

4. ASTROMETRIC REDUCTIONS

Currently our CCD camera has a problem with the charge transfer efficiency (CTE). Corrections based on a preliminary model have been applied to the raw data on a pixel by pixel basis to compensate for this CTE effect. Only one axis (CCD x-coordiante = right ascension) is affected and residual systematic errors depending on x and magnitude might be present in the data on a 20 mas level.

For this investigation only those stars recommended as astrometric reference stars in the Tycho Catalogue have been used. Proper motions as described above have been used to update the Tycho positions to the individual epochs of the CCD observations. A conventional plate adjustment (CPA) has been made for each individual CCD frame using from 9 to 45 Tycho reference stars in a weighted, least-squares fit.

A small, but significant, plate tilt has been derived from a pilot investigation and the x, y data were corrected for this effect in the final plate adjustment, with a linear model. Field distortion errors are negligible. The data have been corrected for differential refraction and aberration but not for differential color refraction which is not required here due to the narrow spectral bandpass (65 nm) used.

5. RESULTS

Table 3 gives the results for each individual CCD frame. On average 30 Tycho reference stars per CCD frame have been used. The observed standard errors of the conventional plate adjustment, σ_{CPA}, are mostly in the range of 30 to 60 mas. An estimate for σ_{CPA} from internal errors, σ_{theory}, is derived from the rms sum of our three individual error contributions: the formal Tycho position errors, the assumed errors from the proper motions and the CCD x, y data. The last two columns in Table 3 give the ratio observed/theory for the error budget for the x and y axis, respectively. On average, the errors observed in this external comparison exceed the predicted internal errors by about 5 per cent and 7 per cent for the right ascension and declination component, respectively.

Figure 3 shows the corresponding position differences (UCA−Tycho) for both axes as a function of the Tycho V magnitude. The increased scatter towards the fainter magnitudes is dominated by the Tycho Catalogue position errors. This shows the success of a meaningful external comparison of the Tycho Catalogue with our observations. For stars brighter than about magnitude 9.5, the dominating error contributions are our observations in combination with the AC proper motion errors. No significant systematic error as a function of magnitude can be seen. Figure 4 shows the rms standard error for the (UCA–Tycho) position differences as a function of magnitude, averaged over 10 data points.

Table 4 gives a summary by magnitude. In this table the observed average coordinate differences are slightly too 'optimistic' due to the correlation with the Tycho stars used as reference stars, while for the CPA estimates (see above), the proper number of degrees of freedom have been taken into account.

6. CONCLUSIONS

- The observed error budget in this external comparison is in agreement with the estimated internal errors to better than 10 per cent.
- The positional errors as given in the Tycho Catalogue are consistent with our observations (for stars in the 9.5 to 11.5 magnitude range).

Table 4. Standard errors of UCA−Tycho differences in position as a function of magnitude class.

V = Tycho Catalogue V magnitude
σ_{ty} = median standard error in position for Tycho stars at mean epoch 1991.25
σ_{ref} = rms error of reference stars, contrib. from Tycho and AC proper motions
σ_{dif} = rms observed position diff. (UCA−Tycho)

V	mag	7 – 8	8 – 9	9 –10	10–11	>11
σ_{ty}	mas	4.0	6.7	12.9	27.9	39.2
σ_{refx}	mas	17.9	18.9	25.2	33.1	38.8
σ_{refy}	mas	17.0	18.2	22.6	31.2	39.8
σ_{difx}	mas	45.1	25.7	30.8	50.4	64.2
σ_{dify}	mas	28.6	28.2	32.5	48.8	65.3
n_{stars}		7	38	128	327	89

- Our data do not allow a meaningful estimate of the Tycho position errors for bright stars (≤ 9.5 mag).
- The observational errors for a single 30 second exposure CCD frame are in the order of 30 mas per coordinate.
- The dominating error contribution for our CCD observations is the atmosphere for these short exposures. For the UCAC–S project 120 second exposures are planned and the expected 20 mas accuracy for well exposed stars seems very realistic.

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Table 3. Error budget for individual CCD frames.

field name	CCD frame name	numb.of Tycho stars	σ_{CPA}		σ_{theory}		$\sigma_{\text{CPA}}/\sigma_{\text{theory}}$	
			$x = \alpha$ (mas)	$y = \delta$ (mas)	$x = \alpha$ (mas)	$y = \delta$ (mas)	$x = \alpha$	$y = \delta$
0642+449	150	12	29.6	43.1	43.9	42.1	.67	1.02
0642+449	151	18	42.0	32.9	42.0	39.7	1.00	.83
0642+449	152	14	46.9	54.8	44.9	41.7	1.04	1.31
0743−006	153	35	51.5	37.6	44.7	42.3	1.15	.89
0743−006	156	19	57.3	35.7	46.5	39.5	1.23	.90
0743−006	157	30	58.3	52.1	46.3	40.5	1.26	1.29
0743−006	158	37	48.7	51.9	49.3	44.5	.99	1.17
0743−006	160	32	28.6	48.7	47.8	42.9	.60	1.14
0906+015	161	14	65.5	42.4	46.9	40.3	1.39	1.05
0906+015	162	14	62.8	52.9	46.9	40.3	1.34	1.31
0906+015	163	9	29.8	34.6	41.7	38.9	.72	.89
1830+285	175	37	33.6	52.3	40.7	42.0	.82	1.25
1830+285	176	32	40.1	39.5	41.4	42.9	.97	.92
1830+285	177	32	42.9	36.9	41.4	42.9	1.04	.86
1830+285	178	43	40.5	38.7	41.7	43.3	.97	.89
1830+285	179	43	38.6	48.4	41.9	43.5	.92	1.11
1830+285	180	45	47.5	34.1	42.3	43.5	1.12	.78
1830+285	181	45	49.6	44.2	42.3	43.5	1.17	1.02
1830+285	182	39	44.5	54.3	42.1	43.7	1.06	1.24
1830+285	183	40	39.4	52.2	42.1	43.7	.94	1.19
average		30	46.1	45.0	43.9	42.1	1.05	1.07

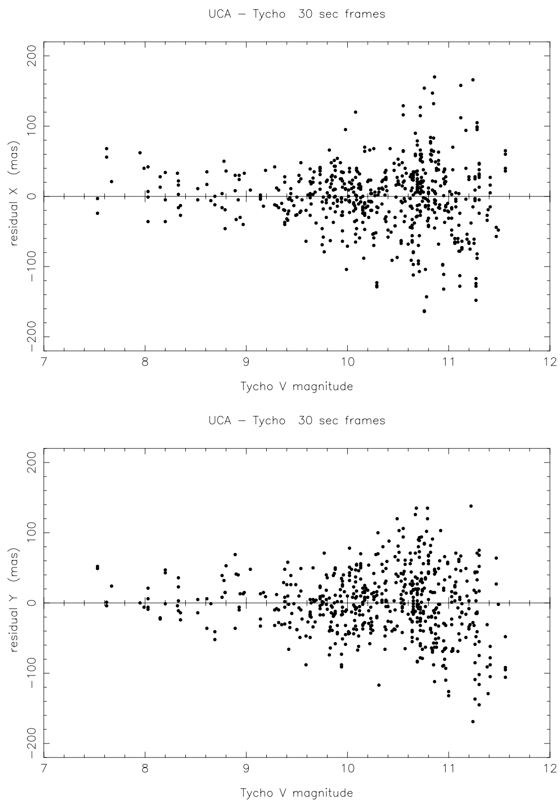

Figure 3. Plate adjustment rediduals (UCA−Tycho) versus Tycho V magnitude.

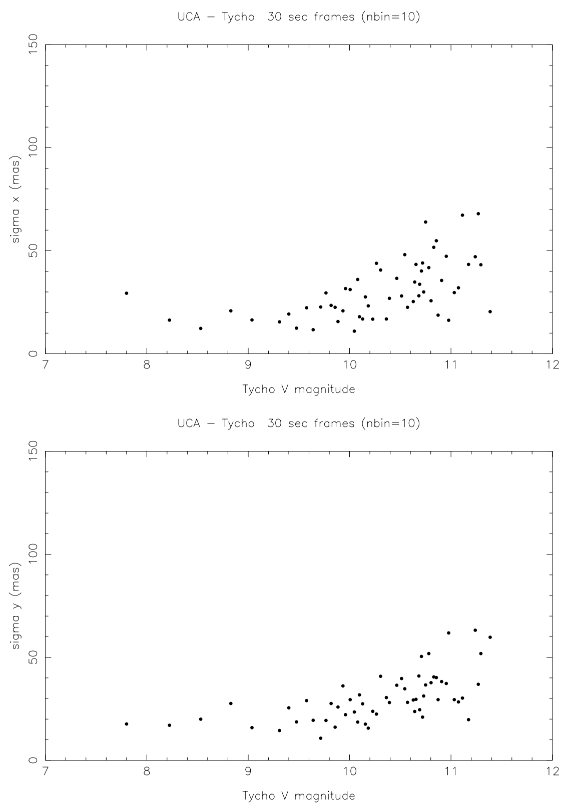

Figure 4. rms average of observed position differences (UCA−Tycho). One dot represents the mean over 10 individual residuals.