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Reduction of the Astrographic Catalogue, zone of S. Fernando

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Abstract. The San Fernando Zone of the Astrographic Catalogue is reduced to the HIPPARCOS system in order to test a reduction model previously presented by Abad (1993). A new method for the determination of field distortion and magnitude or color dependent systematic errors on photographic plates is discussed.

Key words: astrometry — catalogs

1. Introduction

The photographic plates of the Astrographic Catalogue can serve two different purposes, namely: (1) They constitute the oldest epoch which covers the entire sky to a minimum limiting magnitude of 11.0 photographic magnitude, yielding accurate positions for about four million stars, and (2) They constitute a large set of plates of uniform characteristics which cover large areas of the sky with a generous overlap between plates and thus are ideal for testing plate reduction methods designed to determine and eliminate field distortion and other systematic effects in coordinates measured on the plates.

Theoretical considerations may lead to a mathematical formulation of the field distortion expected for a given telescope, but deformations or misalignments of the optical surfaces can lead to additional terms which are difficult or impossible to predict. The HIPPARCOS Catalogue greatly facilitates the test of any reduction method since from it accurate positions can be derived even for an epoch as remote as that of the Astrographic Catalogue. At the same time it provides information on the colors of the stars.

The Naval Observatory at San Fernando, presently the Royal Naval Institute and Observatory at San Fernando, Spain, was in charge of the observations of the zone of the sky situated between two degrees and ten degrees southern declination. The plates cover a field of 2×2 degrees approximately. Plates were taken along every full degree of declination, separating them in right ascension by a little less than two degrees. Thus a small overlap is obtained in right ascension between neighboring plates of the same zone, while a half-plate overlap is obtained between neighboring zones. The zones of even degrees in declination are displaced in right ascension by one degree with respect to the uneven zones. In this manner every star appears on at least two plates. A few stars may appear on as much as five plates.

The plates of the San Fernando zone have already been reduced by S. Urban (1996), who made the original measured coordinates available to us. His reduction is based on a second order polynomial in the coordinates X' and Y', the latter being the original measured coordinates X and Y corrected by an a priori known distortion correction (Zacharias et al. 1992). The ACRS catalogue (Corbin et al. 1991) was used as the reference system.

In this paper we make use of an improved method originally proposed by Abad (1993) to which magnitude and color dependent terms have been added. Here the HIPPARCOS Catalogue is used as the reference system.

The method makes full use of the plate overlaps, but we should point out here that under certain circumstances this may not lead to the best solution.

One of the reasons to chose the San Fernando zone for the test of the method is precisely that one of us (A.Z.) is a member of the San Fernando Observatory.

2. Method

The method to be used consists of two successive steps which can be repeated if necessary. First all plates are reduced simultaneously using a block method described by Stock (1981). Only linear terms are included in the process. At this point higher order terms or any other plate

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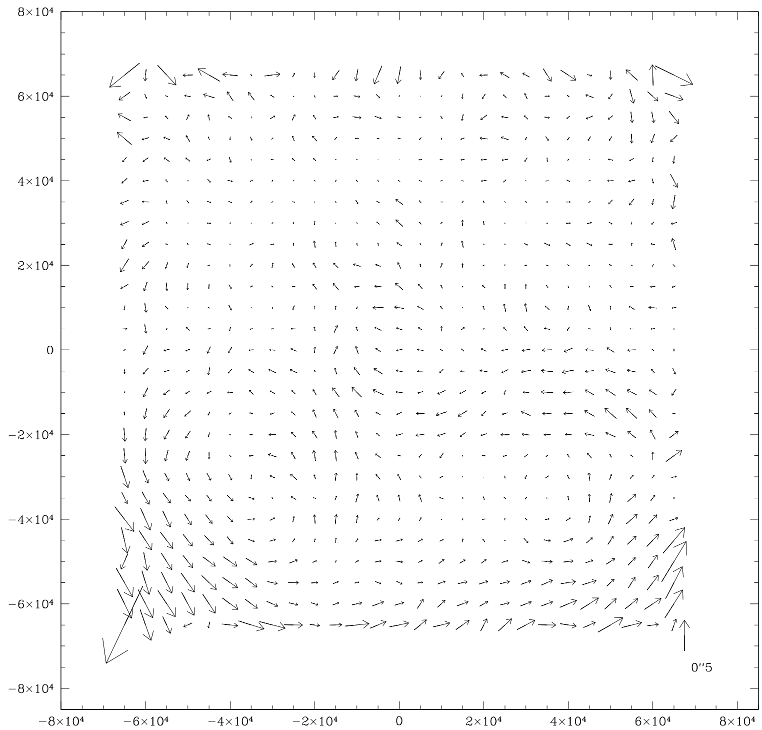

Fig. 1. Position residuals as function of the coordinates X and Y after the first step of the reduction process when block adjustment and a linear plate model were applied. Higher weights have been assigned to the residuals formed with the HIPPARCOS catalogue than to those formed with average positions from several plates

Table 1. Partial and final errors for the totality of the S. Fernando Zone Plates

	I			II			III		
Errors	after a lineal solution			corrected by distortion			corrected by mag. terms		
Magnitude	$\sigma_\alpha(s)$	σ_δ (″)	img.	$\sigma_\alpha(s)$	σ_δ (″)	img.	$\sigma_\alpha(s)$	σ_δ (″)	img.
2	0.000	0.17	2	0.004	0.04	2	0.002	0.10	2
3	0.019	0.27	6	0.021	0.28	6	0.016	0.36	6
4	0.028	0.49	53	0.028	0.42	51	0.025	0.35	50
5	0.033	0.48	218	0.031	0.40	208	0.029	0.37	207
6	0.023	0.34	1024	0.022	0.31	1020	0.019	0.29	1016
7	0.020	0.31	4362	0.019	0.29	4337	0.017	0.26	4333
8	0.019	0.28	17592	0.018	0.28	17549	0.016	0.25	17535
9	0.019	0.29	52858	0.019	0.28	52647	0.018	0.27	52647
10	0.021	0.32	81744	0.020	0.30	81164	0.019	0.29	81250
11	0.022	0.34	63405	0.021	0.31	62598	0.021	0.30	62754
total errors	0.021	0.32	221264	0.020	0.29	219582	0.019	0.29	219800
*'s Hipp.	0.028	0.42	6555	0.025	0.37	6528	0.024	0.34	6512

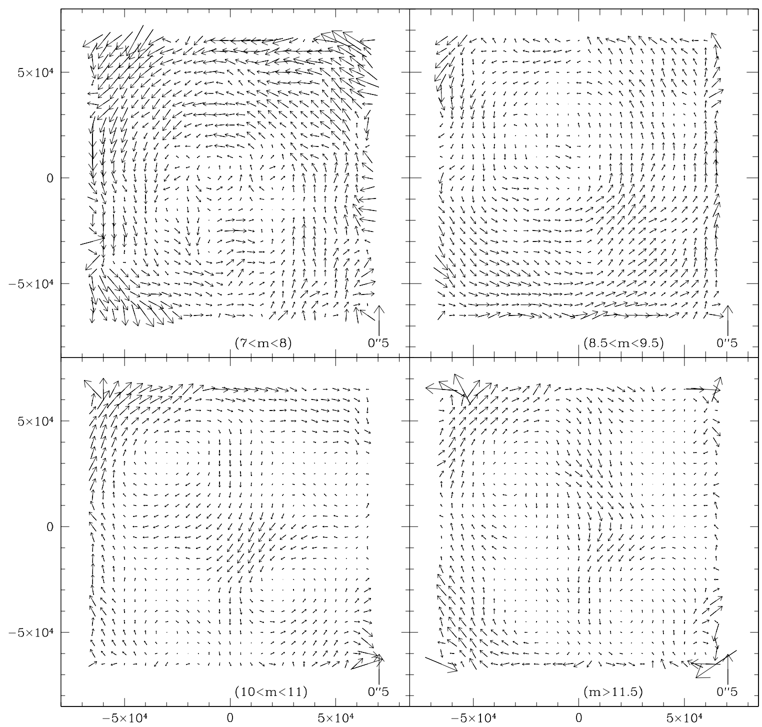

Fig. 2. Position residuals as function of the coordinates X and Y after correcting the measured coordinates by the pattern indicated in Fig. 1. The residuals are plotted for four different intervals of the apparent magnitude

model could also be included. Not much advantage is obtained with a more sophisticated model in the first step since what is not represented by the model will be discovered and determined in the second step. To get the process started stars common to overlapping plates have to be identified first. For this purpose provisional plate constants are derived, based on single plate solutions with the help of only a few stars. These provisional solutions are good enough to identify a large number of additional cross identifications, leading to a new and improved set of plate constants. Naturally, this step can be repeated if necessary. Star by star the coordinates coming from different plates are averaged, leading to a first catalogue.

Once the first catalogue is obtained residuals may be calculated in two ways. If a star is not in the reference catalogue the residuals are simply the differences between the individual positions and their average. If the star is contained in the reference catalogue instead we use the difference between the individual positions and the catalogue position. The reason is that a rigid overlapping scheme as it was employed for the entire AC plates can cause certain problems. If we consider for example the X-coordinates (i.e. right ascension measures) we find that their differences derived from pairs of images of stars common to two or more plates are practically constant, representing the displacement of the plate centers in right ascension from plate to plate. This means that distortion terms which are periodic with this displacement cannot be discovered from the coordinated differences. To detect these an external comparison is needed, for instance with the reference catalogue. Thus, in view of the high accuracy of the catalogue positions, higher weights are given to these residuals.

These residuals are then plotted as a vector field in a common diagram. Because of the large number of residuals and the dense coverage of the field covered by a plate, systematic patterns make themselves apparent quite easily. These patterns could in principle be represented by a polynomial or any other mathematical expression, but we prefer to average and interpolate the arrows in the vector field to obtain the desired correction function. This function is then applied to the original measured coordinates. Subsequently the first step, i.e. the block adjustment with only linear terms, is repeated, followed by averaging the positions and constructing a new vector field. A new correction function can then be applied if found to be necessary. For the interpolation we use a sliding weighted polynomial described by Stock & Abad (1988).

In order to determine a magnitude dependent field distortion the data are divided into several groups of fixed magnitude intervals and the above steps are carried out separately for each group. The correction to be applied is

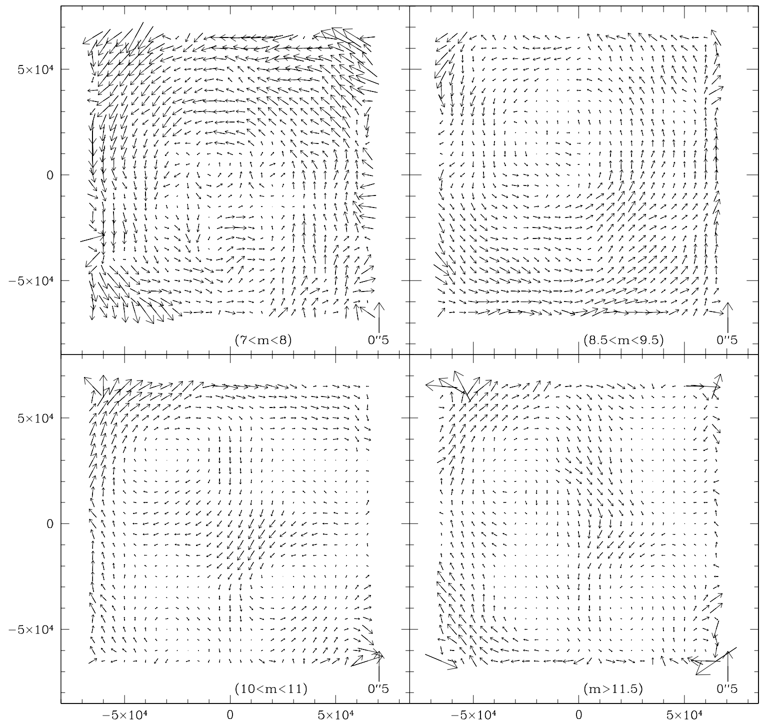

Fig. 3. Position residuals as function of the coordinates X and Y after correcting the measured coordinates by the pattern indicated in Fig. 1 and Fig. 2. The residuals are plotted for four different color intervals

obtained with a three-dimensional interpolation, the dimensions being the right ascension, the declination, and the magnitude. A similar process can be used for the determination of color dependent terms.

3. Reduction

In view of the large number of plates and of stars it was possible to subdivide the observational material for the purpose of determining the field distortion into several groups. For the general distortion the material was divided by right ascension into four groups of six hours each, with a certain amount of overlap. In view of the possibility of introducing a systematic error periodic with the displacement from field to field, as was pointed out in the previous chapter, a relatively high weight was given to the plate-catalogue links. This is even more justified because of the high accuracy of the HIPPARCOS positions which were used as the reference system. In the process we find:
1.- the exact coordinates of the plate centers,
2.- plate by plate the exact scale factor (i.e. focal length),
3.- four different and independent vector diagrams of the field distortion.

The vector diagrams for the four groups, of which one is shown in Fig. 1, are all very similar. Since the underlying data for the four groups are independent we may conclude not only that the field distortion is well determined, but also that is is independent of the season of the year, hence the telescope temperature.

It was found that the scale factors can be divided into two clearly distinct groups with the values 3460.0 and 3436.0 mm. This difference is clearly related to the declination zones. The different zones were observed mixed throughout the entire observing period which lasted for about two decades. The plates, however, were measured strictly in succession of declination zones. The mentioned discontinuity of the scale factor is almost certainly due to a change in the supposed scale of the reseau which was imprinted on the plates, as reported by the authors of the original coordinate measurements.

An analysis of the true plate centers shows that in the beginning of the series of observations insufficient attention was paid to the precession, a fact which is also pointed out by the authors of the original data.

For the determination of a magnitude-dependent systematic error the material was divided into several magnitude intervals (Fig. 2), with no subdivision by right ascension. The latter was justified since the general distortion, as was shown above, did not depend on the right ascension. It was attempted to use a similar process for the determination of a color dependent systematic error (Fig. 3).

Table 2. Final errors for the S. Fernando Zone AC, for different observing periods

Group	I			II			III			IV		
Epochs	1890 < *ep.* < 1894			1894 < *ep.* < 1900			1900 < *ep.* < 1910			1910 < *ep.* < 1918		
Magnitude	$\sigma_\alpha(s)$	σ_δ ('')	img.	$\sigma_\alpha(s)$	σ_δ ('')	img.	$\sigma_\alpha(s)$	σ_δ ('')	img.	$\sigma_\alpha(s)$	σ_δ ('')	img.
3	0.020	0.28	2	0.005	0.45	2						
4	0.019	0.17	15	0.015	0.17	10	0.008	0.06	2			
5	0.017	0.26	48	0.017	0.22	37	0.020	0.25	8	0.003	0.07	2
6	0.015	0.22	286	0.014	0.25	177	0.015	0.18	33	0.026	0.16	15
7	0.013	0.21	1111	0.014	0.22	847	0.014	0.20	145	0.019	0.25	52
8	0.014	0.23	4227	0.013	0.22	4192	0.014	0.21	515	0.023	0.25	152
9	0.016	0.24	11693	0.015	0.23	12879	0.015	0.23	1416	0.019	0.28	453
10	0.017	0.27	18068	0.017	0.25	18999	0.017	0.25	1704	0.021	0.31	611
11	0.018	0.27	17803	0.017	0.27	9152	0.020	0.28	1191	0.022	0.31	427
total errors	0.017	0.26	53253	0.016	0.25	46295	0.017	0.25	5014	0.021	0.29	1712
*'s Hipp.	0.020	0.30	4022	0.020	0.31	3603	0.020	0.29	1690	0.025	0.37	637

No reliable results could be obtained because information on the color is available only for an insufficient number of stars.

The average rms error of individual measurements in right ascension and declination was determined for different magnitude intervals after every step of the reduction. The results are given in Table 1. The first block of data contains the errors after the first linear block adjustment. As explained above, this solution led to the vector diagrams. Once these had been applied to the original X and Y coordinates, a new block adjustment was carried out, leading to the second block of data in Table 1. Finally magnitude dependent corrections are determined and subsequently applied to the already distortion corrected X and Y and a new block adjustment is carried out, leading to the third block of data in Table 1.

The total observing period covers almost three decades, from 1890 to 1918. The telescope performance, including its field distortion, may have changed during that time. A crude test of this possibility can be made by determining the above errors (after all corrections have been applied) separately for different plate epoch intervals, as shown in Table 2. No significant and well established change of the errors is observed between the first three intervals. A slight increase in the last interval may not be real because the number of data involved is considerably smaller.

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References

Abad C., 1993, A&AS 98, 1
Corbin T.E., Urban S.E., Warren W., 1991, Astrographic Catalog Reference Stars, NASA, NSSDC 91-10
García S., de Azcárate T., 1921, in: Introducción al Catálogo Astrográfico y Apuntes relativos a la Práctica de su Cálculo eds. Int. Publication of Real Instituto y Observatorio de Marina S. Fernando (Spain)
Stock J., Abad C., 1988, Rev. Mex. Astron. Astrofis. 16, 63
Stock J., 1981, Rev. Mex. Astron. Astrofis. 6, 115
Urban S.E., 1996, in CD: Astrographic Catalogue as Reduced to the ACRS eds. United States Naval Observatory (USNO)
Zacharias N., de Vegt C., Nicholson W., Penston M.J., 1992, A&A 254, 397