SCHMIDT PLATE ASTROMETRY: NEW PRACTICAL TOOLS FOR THE PREPARATION OF A GAIA INPUT CATALOGUE

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ABSTRACT

We present a concept for an optimized reduction scheme for large sky surveys with Schmidt plates, e.g. POSS II. These methods have been tested successfully in a new reduction of GSC 1.0. We propose this to be applied in the construction of Guide Star Catalogue II (GSC II). GSC II is the ideal reservoir of objects from which an observing list for the proposed ESA space interferometry mission, GAIA, can be constructed. Experience with the new reduction of GSC 1.0 gives us confidence that an absolute accuracy of 0.1 arcsec per coordinate and plate can be reached, especially if TRC (Tycho with proper motions derived from a combination with the Astrographic Catalogue) is used as reference catalogue.

Key words: Schmidt-plate astrometry, GSC II, GAIA

1. INTRODUCTION

The needs of having an input catalogue for the proposed ESA space interferometry mission, GAIA, have clearly been expressed in the discussions during this workshop, but exact specification for it have not yet been designed. Even if GAIA will survey the entire sky, and no *a priori* selection of targets will be necessary, Lindegren & Perryman (1994) underlined the needs of having a reservoir of objects with accurately known positions, which can be given by GSC II (Lasker 1995). GSC II is presently expected to provide absolute position accuracies better than 0.5 arcsec for 2×10^9 objects on the whole sky down to $V = 18$ mag and two-passband photometry with an accuracy better than 0.2 mag.

Experience with GSC 1.0 (Lasker et al. 1990) showed that a classical single-plate polynomial reduction scheme is not appropriate to fully exploit the astrometric potential of a Schmidt survey, see e.g., Taff et al. (1990a). In this paper we propose a reduction scheme, which will improve the positional accuracy of GSC II to about 0.1 arcsec. This makes GSC II and a possible GAIA input catalogue an important astronomical source available well before the launch of GAIA.

2. REDUCTION OF SCHMIDT PLATES

As starting point of our considerations we assume that the x, y-coordinates of objects on a plate are already determined; we do not discuss how they are derived from the digitized plate scans. Several parameters influence the position of an object on a plate: telescope, plate holder, colour filters, measuring machine, centroiding algorithm, and so on. Changes in any of these parameters will, in general, modify the plate coordinates of the objects in a systematic way. The case of a sky survey with a series of plates where these parameters can be kept nearly constant allows us to carefully investigate common distortions and to remove them before the final reduction of individual plates is started.

2.1. Global Reduction Model

The first step in the whole reduction scheme is a classical single-plate adjustment. This can be achieved by a simple polynomial-fit, but we propose to use the stepwise regression model (Hirte et al. 1990). With stepwise regression only significant coefficients in a plate model will be kept.

Figure 1. Example of a reseau correction. Shown are the residuals between GSC 1.0 and PPM after a filtering to PPM has been applied (see text for further explanation). The residuals are averaged over all plates in the +30° zone of GSC and are plotted as a function of the plate coordinates.

In the case of a sky survey, with some 1000 plates taken with the same instrument and similarly processed afterwards, the application of stepwise regression may possess an additional advantage discussed below. After a first single-plate reduction we can study common residual distortions with respect to the reference catalogue adopted. This kind of investigation dates back to the early times of photographic astrometry, and has successfully been applied in some zones of the Astrographic Catalogue. We call it 'reseau correction', as it was used to correct distortions of the reseau imprinted on the plates of the Astrographic Catalogue. As an example we refer to Wood (1971). The principle is quite simple: the plate is partitioned like a chess-board, and the residuals—after the single-plate reduction—are grouped within the individual fields of the chess-board and averaged over a number of plates.

Fig. 1 shows an example of a reseau correction. It displays the residuals between GSC and PPM in the +30° zone of GSC. Similar patterns are found by Taff et al. (1990b) and by Lopez Garcia et al. (1994). From Fig. 1 one finds that the systematic distortions in the plate corners may amount to 1 arcsec and more. Again, let us emphasize that the size and shape of the pattern strongly depends on all the parameters mentioned in the beginning and the model chosen for single-plate reduction. The selection of plates with common signature is a critical item for the application of the reseau correction. This selection is not given *a priori*; parameters like exposure time, filters, emulsions etc. can be chosen as selection criteria. Though not yet applied in investigations of GSC 1.0, we are convinced that the method of stepwise regression gives us another clue to find plates with common signatures. Of course, it would be desirable to have the common reseau-like distortion removed before applying the single-plate reduction model. So, it is promising to iterate these two processes once.

2.2. Reduction of Individual Plates

The measures described in the previous chapter are well-suited to remove systematic distortions common to a large number of plates in a survey. On individual plates, however, systematic deviations from the reference catalogue still may exist which have scale-lengths smaller than the plate size and may be of a more stochastic nature. They cannot be treated by a global plate-model. Reasons for the existence of these distortions are, in general, the conditions of exposure, and also the individual treatment of the plates in plate-holder and measuring machine. To adequately model these effects, Röser et al. (1994a) proposed the technique of numerical filtering.

In an application to GSC 1.0, Röser et al. (1994a) chose a simple numerical filter with equal weight. They also fixed the number of reference stars in the filter to 25 stars, guaranteeing that the spatial scale of the filter automatically adjusts to the density of the net of reference stars. Röser et al. (1994a) applied this technique to the −30° zone of GSC 1.0. The results are shown in Fig. 2. The top part presents the distribution of angular distances between the original GSC 1.0 and PPM Supplement (Röser et al. 1994b). Stars of the PPM Supplement are chosen to avoid any correlation with the stars of the main PPM catalogue active in the filter. An example on the southern hemisphere is chosen, because the present-day accuracy of the positions in PPM and PPM Supplement is about 0.1 arcsec. The maximum of the distribution of the two-dimensional angular differences corresponds to the standard deviations (if they are equal) of the differences in right ascension and declination. So, we find an rms-difference between GSC and PPM Supplement of about 0.6 arcsec per coordinate. The corresponding distribution after the application of the filter is shown in Fig. 2 (bottom), and the rms-difference between the improved GSC and PPM Supplement went down to 0.25 arcsec. We suppose that this dramatic improvement in the case of GSC 1.0 arises from the fact that, in the original reduction, SAOC and CPC had to be taken as reference catalogues, and that systematic differences between these catalogues and the new PPM still are significant on scales of typically 2°. These results encourage us to study the filtering technique further in order to optimize the shape and size of the filter.

Figure 2. Angular differences GSC 1.0 – PPM supplement (top) in the −30° zone. The maximum of the distribution at 0.6 arcsec corresponds to the standard deviation of the differences in the coordinates. Bottom: The angular differences after application of the filtering technique. The improvement indicates the presence of sub-plate scale systematic errors in the original GSC 1.0.

2.3. Testing the Results by Use of Plate Overlaps

Usually, post-fit residuals to a reference catalogue serve as a measure for the quality of the plate reductions. This is true only to a certain extent. In photographic astrometry magnitude dependent effects are the most critical ones. They can be caused by an incomplete sampling of the actual point-spread function on the plate, and it is also conceivable that the centroiding algorithm is inadequately adapted to the large dynamic range of the images. Knowing the magnitude dependent errors is important, because one is interested in the positions of faint field stars which are outside the magnitude range of the reference stars.

There is no direct way of testing a magnitude effect as described above. But, in sky surveys with partially overlapping plates one has the opportunity of testing the adopted reduction scheme and search for magnitude effects in overlapping regions. This independent test is not restricted to reference stars, but probes the quality of the reduction for all the measured objects in the overlapping area. With this approach a magnitude dependent radial displacement of the measurements for GSC 1.0 was detected (Morrison et al. 1995).

3. DETERMINATION OF PROPER MOTIONS

When positions from two sky surveys made at different epochs are determined, proper motions can be derived in a straightforward way. There is, however, a much more rigorous solution to this problem: the plate-overlap adjustment procedure (Eichhorn 1960). In an iterative approach, positions and proper motions are determined alternatively. Here, we present the application of this method in the region of the Pleiades. We used 14 plates from the Astrographic Catalogue with epochs around 1900, 25 plates taken with the Tautenburg Schmidt telescope between 1961 and 1991.

Two different approaches have been followed. First, PPM was chosen as reference catalogue for positions and proper motions (case A). Fig. 3a shows the vector point diagram of the proper motions of 38 570 stars. Most of them are found only on Tautenburg plates, because these go much deeper than the limiting magnitude of the Astrographic Catalogue; on the Astrographic Catalogue plates there are 1231 stars. The members of the Pleiades cluster nicely separate from the field stars grouped around the origin. The shape of the field star distribution is discussed below.

Figure 3a. Vector point diagram of the proper motions of 38 570 *stars in the Pleiades region. PPM was used as reference catalogue for positions and proper motions.*

In a second approach, only the system of PPM positions was used, and we started the reduction by assuming that all proper motions are identically zero (case B). After some iterations the Pleiades stars separated from the field stars and proper motions as shown in Fig. 3b evolved. Different from case A, the shape of the field star distribution in Fig. 3b is perfectly circular.

Figure 3b. Same plot as in Fig. 3a, but calculations were started by assuming that all proper motions are identically zero.

To investigate this item further we plotted the proper motions in right ascension in case A as a function of right ascension (Fig. 4a). A slope of 3 mas/yr/deg was found. The corresponding plot for case B is given in Fig. 4b, and now the average proper motions are constantly zero. This difference can be caused by the system of PPM proper motions. In fact, Röser (1994) already found this behaviour for the Pleiades stars in PPM, but because of their small number it was only marginally significant.

Figure 4a. Plot of the proper motions in right ascension (mas/y) averaged in bins of 500 arcsec as a function of right ascension (in arcsec). PPM chosen as reference catalogue for positions and proper motions.

Such an increase of the average proper motions with increasing right ascension is artificial. It shows, however, that the underlying reference system, in this case PPM, carries its signature through the plate-overlap method. This means that no systematic changes are introduced by the method, and it underlines the importance of having a better reference system, Hipparcos.

At present, we are applying the method to a larger area of the sky, combining 180 Astrographic Catalogue plates and 9 GSC plates. This is a test case for the application of the method in a combination of POSS II with POSS I to derive proper motions for GSC II.

Figure 4b. Same as Fig. 4a, but calculations were started by assuming that all proper motions are identically zero.

4. CONCLUDING REMARKS

Most of the tools described above are presently being applied in a new reduction of GSC 1.0 and the determination of proper motions in combination with the Astrographic Catalogue (see Röser 1995). Although the reseau correction has not yet been applied, and the magnitude effect (Morrison et al. 1995) not yet removed, test samples were compared with observations from the new CCD-equipped Bordeaux meridian circle. These comparisons (Réquième 1995) indicate that, when our reduction scheme will be applied to GSC 1.0, an average accuracy of 0.1 arcsec per coordinate will be obtained. We can be even more confident to reach this accuracy, if TRC (Röser & Høg 1993), i.e., TYCHO combined with the Astrographic Catalogue, is used as reference catalogue instead of PPM. We expect to obtain the same accuracy for GSC II. On the northern hemisphere, for instance, proper motions will be derived with an accuracy of about 4 mas/year for all stars down to $V = 18$ mag from a comparison of POSS II and POSS I.

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