Systematic Astrometric Errors on Schmidt Plates

1. Background

With the advent of highly accurate multifibre spectrographs covering between one to two degrees of sky and with fibre diameters down to 1.5 arcsec in size, the accuracy of positions from the input object catalogue is becoming a significant limiting factor in fibre throughput (e.g. Cannon 1993). Most input catalogues for fibre based observations are derived from measures of wide field Schmidt survey plates. With the imminent arrival of a one degree fibre field on the William Herschel Telescope (WHT) and a two degree fibre field on the Anglo-Australian Telescope (AAT) it is clear that it will not necessarily be the random measuring/recording error (0.1-0.2 arcsec on a modern emulsion) that limits the coordinate accuracy of the catalogue but perhaps more subtle non-linear systematic errors over the 10 cm or so of plate covered by the fibres. These might either be intrinsic to the telescope/plateholder/filter combination or introduced during the measuring/reduction stage.

To get the most out of the fibres the catalogue coordinates should ideally be accurate to better than 0.25 arcsec over the whole field. Naturally, even with accurate coordinates at the plate epoch it is still possible to go wrong, if, for example, the chosen guide stars have a non-negligible proper motion over the years between the plate being taken and the observations being made. However, let us concentrate only on systematic plate errors and in particular on those that are repeatable from one plate in a series to another, since in principle these should both be measurable and also removable.

The standard procedure for astrometrically calibrating Schmidt plates consists of two stages. First the astrometric standard stars from a suitable astrometric catalogue, for example PPM (Röser & Bastien 1988), are located on the plate and accurate x,y plate coordinates derived. Second a least-squares solution, with suitable iterations to reject outliers, is made between projected standard coordinates ξ, η relative to the plate centre for the astrometric standards and their measured plate x,y positions. It is also usual to fold into the least-squares solution a Schmidt radial correction term of the form tan(r)/r, where r is the distance from the plate centre in radians. This term is purely due to the optical geometry of a Schmidt telescope and as such is a fixed known quantity. The least-squares solution usually takes either a linear 6 plate constant form or sometimes a more general quadratic 12 plate constant model is used. Further refinements of this technique due to Taff and co-workers (1992) involve partitioning the plate into various virtual sub-plates and solving separately for each sub-plate in order to try and reduce systematic errors left over from the global plate solutions. (It is worth noting, however, that this latter procedure if not carefully controlled could introduce as much error across sub-plate boundaries as it was designed to take out.)

That there are significant systematic repeatable astrometric errors left over from global plate modelling, in at least some series of Schmidt plates, is clear from Fig. 1 of Taff et al. (1992). However, now that we have available on-line APM catalogues of large numbers of both POSS I O and E plates, UKST J and R survey plates and first tranche of POSS II J plates, it is convenient and timely to extend Taff's work to other plate series and see what the problems are.

2. Constructing Error Maps

If we assume the systematic errors are constant for a particular plateholder/filter/telescope configuration then we can effectively co-add many plates to beat down the random contribution and reveal the constant systematic component.

The method is simple. Start with a convenient astrometric catalogue; the PPM catalogue is ideal since it has between 200-300 stars per plate with positions accurate to 0.3 arcsec. Locate all the PPM stars on each plate. For each field a simple 6 plate constant linear model is computed using the standard Schmidt geometry radial correction term. This is the normal APM astrometric fit and basically takes out global scale errors, rotation and position of centre. This leaves any non-linear pattern intact. Furthermore, since there are typically 200 or so PPM stars per field and we are only fitting 6 constants, the deviations from fit are a genuine combination of random PPM catalogue errors (0.3 arcsec rms) + measuring errors (up to 0.3 arcsec rms for the brightest heavily saturated stars) + systematic errors on the plate.

In order to reveal repeatable systematic errors to an accuracy of 0.1 arcsec, with a spatial resolution of one to a few cm, it is necessary to stack around 100 or more plates to beat down the random errors enough to see the effect. After stacking, the residuals in PPM -v- fitted plate coordinates for each field are binned into 1 cm x 1 cm regions of plate, giving an average of 15 or more PPM stars per bin. Individual star residual errors are typically 0.5 arcsec. After averaging the residuals in each bin, 3 x 3 bilinear median and boxcar filters were used to lightly smooth the raw version thus ensuring that the final binned errors were less than 0.1 arcsec.

Figure 1 illustrates the end product of this process, a vector residual map of PPM stars for an 'averaged' UKST second epoch R survey plate. The map was constructed using 15000+ PPM stars taken from 120 UKST fields in the equatorial region. The plot essentially represents a picture of the 'average' plate taken from APM 5.8° x 5.8° scans with N at the top and E to the left. Bin coordinates are in cm from the plate centre. The SE corner has a few points missing due to the 16 level density wedge prominent on UKST plates. The residuals are scaled such that a 1 arcsec vector residual corresponds to 1 cm on the plate. It is immediately apparent that most of the systematic residuals are less than a few tenths of an arcsec in size and that the only seriously distorted region is at the S within 1 degree of the plate edge. Even here the largest residual is 'only' 1 arcsec. Further investigation is needed to decide on the cause of these systematic patterns but favoured candidates would be plateholders and/or filters.

We can easily rule out the filter causing the effect by constructing a similar diagram from the UKST J survey plates. This is shown in Fig. 2 and essentially shows identical systematic errors to those in Fig. 1, proving that it is not the filter causing the problem. It is worth noting too that the R plates measured were originals whilst the J plates were glass copies of originals, highlighting the fact that careful copying does not degrade the overall astrometry either.

Before further speculation as to other possible causes let us look at the Northern sky catalogue data. Figure 3 is a residual plot derived from APM 6.2° x 6.2° measures of POSS I E glass copies of the Northern sky survey. This plot was derived from 400 plates using some 75,000+ PPM stars (splitting the dataset into 3 groups sorted by various criteria also reveals exactly the same pattern). There is clearly a much more significant systematic component of typical size 0.5 to 1 arcsec, with significant variations over regions a few cm in size. The mainly radial/square symmetry of the pattern strongly suggests that this is likely to be a function of the telescope/plate holder. This global pattern of systematic errors is very similar (bar sign) to that shown by Taff et al. (1992) in the DOSS II workshop (Fig. 1). Since Taff's data were taken from the quick V survey also done on the Palomar Schmidt in the 1980s this also points to a telescope/plate holder problem.

3. A Possible Cause

I am grateful to Neill Reid for pointing out that both the POSS I and quick V survey were carried out using the same design of plate holder and that before commencing POSS II the plateholder assembly was redesigned. He suggested that this might be the cause of the systematic errors.

The original Palomar plateholder system was a straightforward mechanical design with the plate directly clamped into the mandrels. This should be contrasted with the UKST J and R surveys which both made use of a vacuum clamp system. As part of the upgrades prior to starting the POSS II survey a vacuum clamp system was installed in several iterations starting May 1987. Initially this started out as a four hole system but later grooves were added connecting the holes to give better clamping over the whole plate. Moreover, the mandrels had originally been ground to the wrong

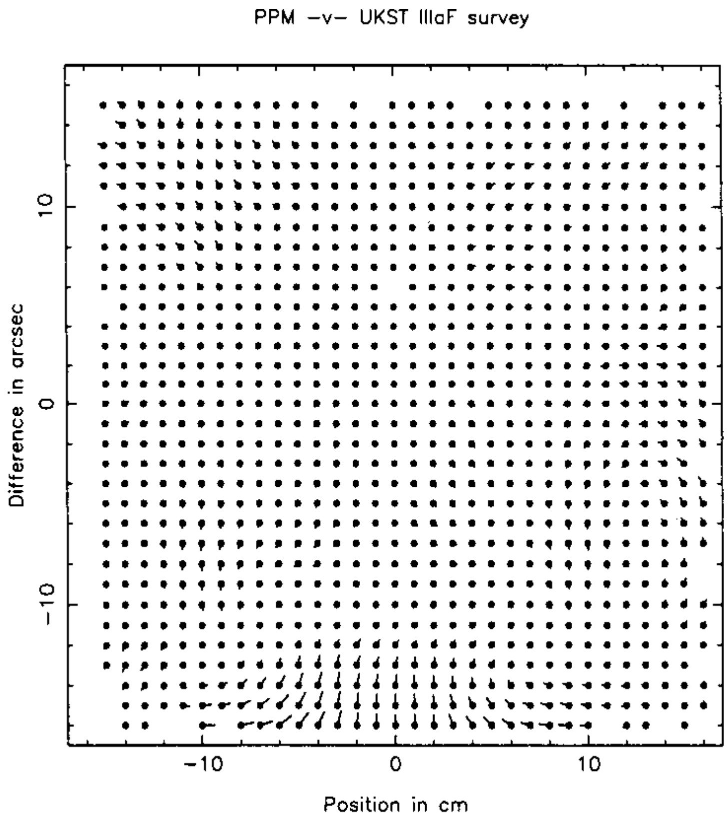

Figure 1. A vector residual map of PPM stars for an 'averaged' UKST second epoch R survey plate with N at the top and E to the left. Bin coordinates are in cm from the plate centre. The SE corner has a few points missing due to the 16 level density wedge prominent on UKST plates. The residuals are scaled such that a 1 arcsec vector residual corresponds to 1 cm on the plate (see text for more details).

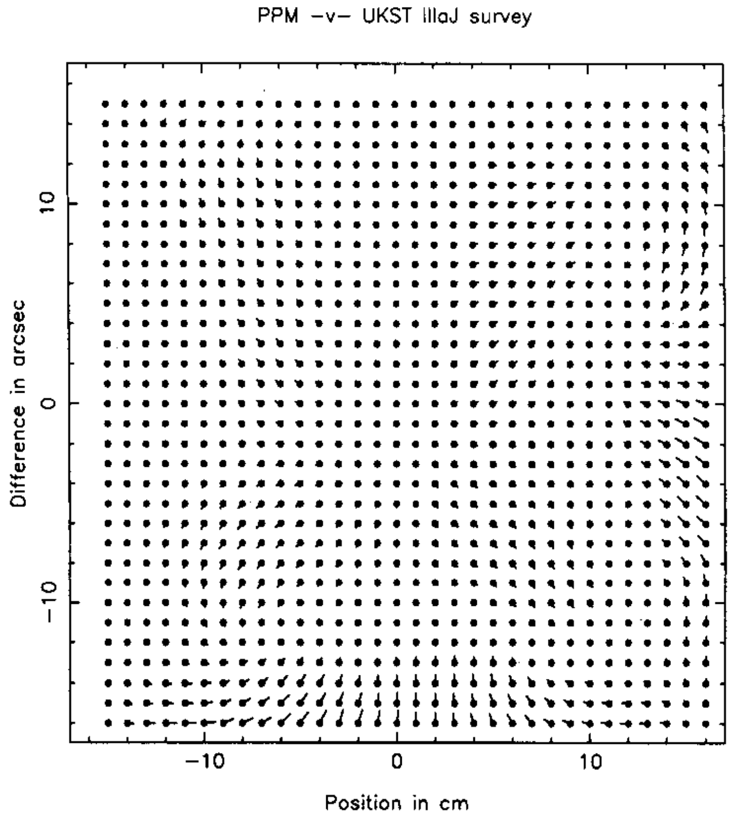

Figure 2. A vector residual map for an 'averaged' UKST J survey glass copy plate.

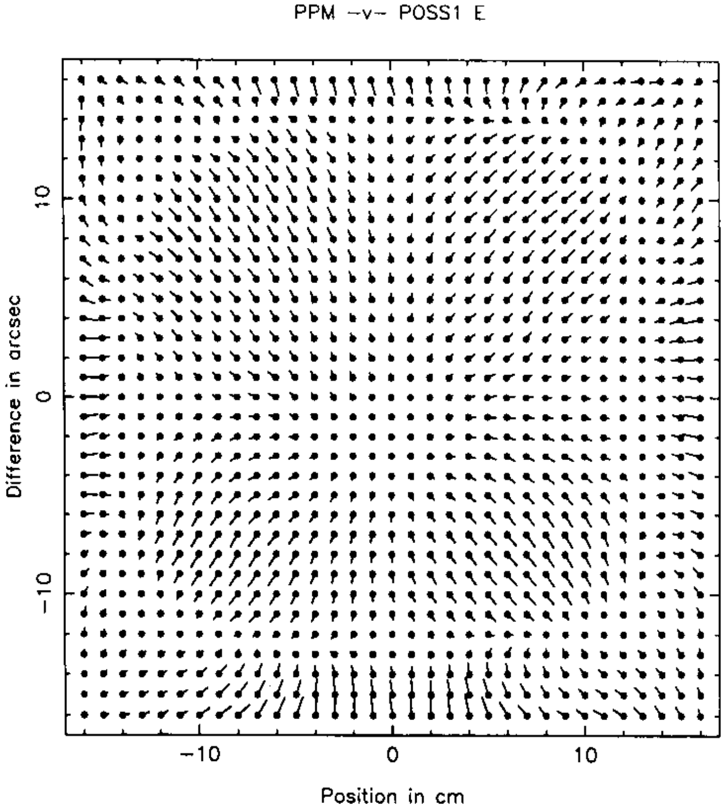

Figure 3. A vector residual map for an 'averaged' POSS I E survey glass copy plate.

radius of curvature — presumably to compensate for bulging air pockets in a mechanically clamped plate assembly. These were reground during early 1989. Since then the plateholder system has remained stable.

It is relatively straightforward to calculate the expected astrometric distortion for an incorrectly clamped plate. Altering the radius of curvature of the mandrels from 120.1 inches to 120.9 inches has a negligible effect on the derived astrometry if the plate surface is everywhere smoothly matched to the mandrels. However, if for example a plate contours the surface in some parts but clears it by, say, 1 mm in other parts with typical scale length 10 cm, then differential non-linear systematic astrometric errors of order ±0.5 arcsec will result. It seems quite plausible that this was the cause of the problem on the E, O and quick V plate series. The plates were clamped such that their focal surface reflected the symmetry of the clamps rather than the mandrel surface and this is reflected in the symmetry of the systematic errors.

With the recent changes in plateholder design we would predict that the POSS II survey plates should not show the same systematic error pattern and should have a much smaller residual error.

Although we currently have only scanned around 50 plates from the POSS II J survey it is sufficient to see that the systematic error pattern of Fig. 3, typical of pre-POSS II Palomar plates, has now almost vanished. Figure 4 shows a preliminary vector residual map for the POSS II J plates. At the moment we do not have enough plates scanned to know if the systematic errors have been completely eliminated but it is already clear that the modifications to the plate holder assembly seem to have both identified and significantly reduced the problem. Note also that some of the plates used in the series were taken whilst the plateholder modifications were still ongoing. Unfortunately we do not yet have enough plates measured that were taken after the final modification date to unambiguously say whether the systematics have completely vanished.

Given that plateholder problems seem to be a good candidate for the systematic astrometric errors, it is worth considering the possibility that the systematic errors seen at the centre of the Southern edge

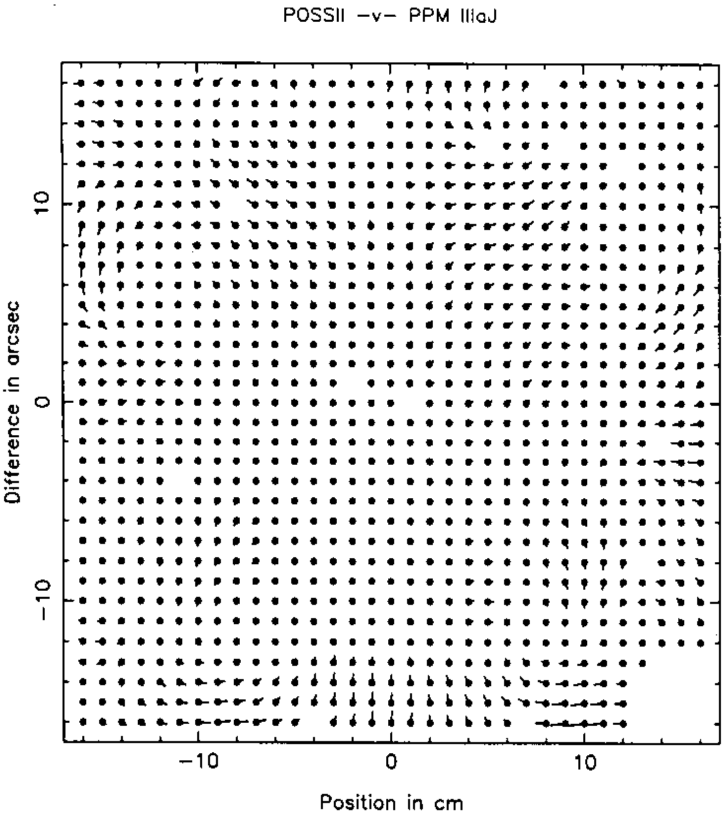

Figure 4. A preliminary residual map for an 'averaged' POSS II J survey glass copy plate (some plate holder modifications were still being made in the series coadded to form this map).

of UKST plates are caused by the plate surface not being correctly vacuum clamped onto the desired focal shape near this region.

4. Correcting for the Repeatable Systematic Errors

Since the shape of the repeatable systematic errors has a rather complex non-linear structure the most straightforward method to remove the effect is simply to subtract/add the appropriate correction derived directly from the table of errors making up the smooth vector residual plots. Bilinear interpolation from the table suffices to estimate the error correction at any desired plate coordinate. After applying this correction to UKST plates the residual between PPM positions and derived positions drops from 0.50 arcsec to 0.43 arcsec for a global linear 6 plate constant model; whilst POSS I plates show a significant improvement with the residuals falling from 0.79 arcsec to 0.59 arcsec. In all cases the residual error was calculated by fitting a Gaussian independently to the x and y error distributions and taking the average Gaussian sigma as the measure.

Considering that the PPM catalogue errors are of order 0.3 arcsec and the photographic errors can be at least as large for heavily saturated stars this suggests that any remaining systematic component in the global plate solution is now well below 0.5 arcsec. However, without independent external coordinates, such as VLA radio positions for faint sources accurate to 0.1 arcsec or better, it is difficult to know if the 0.25 arcsec level has been achieved. Work to do this external check for the Northern sky is in progress. In the south we already know from matching UKST plates taken on the same field that differential systematic effects between plates are generally small, and certainly less than 0.25 arcsec, over the central 5° x 5° field.

References

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Wide-Field CCD-Imager on the Burrell Schmidt Telescope at Kitt Peak

Kitt Peak National Observatory has had a CCD-imager on the 0.6 m Burrell Schmidt Telescope of Case Western University since 1989. This telescope is located on Kitt Peak and half of its observing time is allocated by the Kitt Peak Time Assignment Committee in the same way as for other Kitt Peak telescopes. The deadlines for proposals on the standard forms are March 31 and September 30.

Currently the imager has a thick STIS/Tektronix 2048 x 2048 CCD with 21 micron pixels. The CCD has been coated with Metachrome II to extend its blue sensitivity. The scale is 2.0 arcsec per pixel. A wide variety of broad and narrow-band 2 x 2 inch filters are currently available which with the present shutter assembly give an unvignetted field that is 63 arcmin in diameter. We will very soon be installing a new 4 x 4 inch filter wheel and shutter assembly which will increase the size of the unvignetted field.

Data is acquired using a Sun SparcStation and Kitt Peak's ICE CCD acquisition software. The focus is motor controlled and an automatic guiding system is available on an auxiliary refractor. The system has primarily been used for direct imaging but some work using objective prisms has also been done. Please get in touch with either of the undersigned for further information or telescope or instrument manuals.

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