Centroiding Planetary Camera Stellar Images

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Abstract

The Space Telescope Astrometry Team is investigating the astrometric capabilities of the Planetary Camera. Our primary motivation for establishing an astrometric calibration of the PC is a long-term proper-motion study, the goal of which is to determine the internal velocity distributions of several globular clusters. The ultimate astrometric accuracy of the PC will be determined by 1) the accuracy to which the aberrated images can be “centered”, and 2) the accuracy to which the distortions across the PC field can be modeled. Here we address the first issue and summarize our progress including results from a study of the use of maximum likelihood image reconstruction to improve the image center determinations. We are investigating the benefits to be gained by performing the image restoration on a grid which is finer than the actual PC pixel size by using subsampled synthetic PSFs from Tiny Tim and replicating a PC exposure of the globular cluster NGC 6752 for test purposes.

I. Motivation

Even with its aberrated images, the *HST* Planetary Camera allows imaging of individual main-sequence stars very near the cores of globular clusters. It is our goal to use the *HST* PC as an astrometric instrument to determine stellar proper motions within six globular clusters. The proper motions would yield:

- internal velocity dispersions for these six clusters,
- virial mass estimates for these clusters,
- kinematic distance estimates (statistical parallax),

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- and, for a subgroup of the more nearby clusters –

  (i) the radial and azimuthal velocity dispersions as a function of distance from the cluster center, and
  (ii) the degree to which energy equipartition exists between various stellar mass groups within the clusters

Instrument: Planetary Camera = 4 x 800 x 800 CCD, Scale = 0.043 arcsec/pixel

Desired astrometric accuracy:

- positions to ± 1 mas, (1/40 pixel)
- second epoch exposures after 5 years ⇒
- proper motions to ± 0.2 mas/yr (~5 km/s for d = 5 kpc) ⇒
- σ_v to ~ ± 1 km/s for d = 5 kpc
- Note: σ_v ~ 6 to 10 km/s for globular clusters)

III. Non-Reconstructed Images

Previous tests, (Girard and van Altena, 1990), using synthetic PC frames and a limited number of early-observation frames of the R136 region showed that 2 mas positional accuracy could be achieved for well-exposed images using Gaussian fitting of the raw intensity profiles. The accuracy quickly fell off for fainter images and in crowded regions.

Although we are interested in an application involving crowded fields with low signal-to-noise images, (the globular cluster program), it is worth noting the centering precision we have recently achieved with a set of high signal-to-noise, isolated PC stellar images. This series of PC frames, taken in conjunction with FGS observations intended to monitor the long-term stability of the FGS instrument frame, was taken with the same pointing on consecutive orbits. The PC fields contain from two to three well-exposed stars. We have fit the raw intensity profiles of the stars with our 2-D Gaussian centroider and estimated the centering precision from the deviations in the separation of star pairs. Based on 22 separation measures, the single-coordinate centroiding precision is 0.6 mas, (0.014 pixels)!

It must be stressed that this high level of repeatability is thus far demonstrated only over consecutive *HST* orbits and with nearly identical pointing, (the individual star positions varied by ~ 0.06 to 0.20 pixels).

IV. Reconstructed Images

Two PC frames of the globular cluster NGC 6752, (a 40-sec and 500-sec exposure with F675W), were used to test if image reconstruction could improve the positional accuracy. Approximately 55 (uncrowded) stars from PC-5 were used. The entire 800x800 pixel frame was restored using a maximum likelihood image reconstruction code, (Nez and Llacer, 1990). Reconstructions were based on a synthetic PSF, generated by the Tiny Tim software package, and were halted after 100 iterations. The reconstructed intensity profiles were centered using the two-dimensional, Gaussian fitting routine. The long exposure positions were transformed into those of the short exposure to determine the unit weight measuring error. The results are presented in Table 1.

Table 1: Long-to-short exposure reduction results

	unit weight error (mas)		No. stars	Mag range
	x	y		
raw[a]	1.4	2.1	33[b]	2.3
PSF @ (200,600)	1.4	1.2	39	2.9
PSF @ (400, 400)	1.3	1.0	38	2.8
PSF @ (600,200)	0.8	0.8	42	3.3

a. This solution required the removal of many “outliers” both bright and faint, thus the unit weight errors may be underestimated in this solution.
b. The original target list consisted of 55 stars. Several of these were so saturated they did not center in any reductions. In addition, 8 to 10 very bright stars were eliminated due to a non-linear magnitude effect present.

These results suggest that 1 mas positional accuracy may be obtained with image reconstruction, for an uncrowded field of relatively well-exposed images. We do not consider these results conclusive, however. There are indications that the image positions were biased toward the center of the brightest pixel of each image, (i.e. the fractional pixel coordinates were not evenly distributed from 0.0 to 1.0). If this is the case, the effect would appear in both the long and short exposure reconstructions and the error estimates based on the above reductions would be invalidated.

V. Subsampled Reconstructions

Synthetic PSFs may be generated on arbitrarily fine grids, allowing the reconstruction to be performed on a grid spacing smaller than that of the detector, one that better samples the PSF. A subsampled reconstruction should be much less affected by the centering bias discussed above. We have used subsampled reconstructions, at subsampling factors of 1 through 5, to explore its effect on the final centered positions.

Two additional PC exposures of NGC 6752 have been used for this part of our study – the first, a 100 sec, F555W exposure; the second, a 100 sec, F785LP exposure. A 128 x 128 subframe containing roughly 40 faint stellar images was extracted from PC 5. Tiny Tim PSFs were calculated, in both filters, at the center of the subframe, and for each subsampling factor from 1 to 5. The subframes were then processed through 80 iterations of the reconstruction code.

Twenty-five stars successfully centered on each of the 1x processed frames. The differences between the fractional pixel coordinates from the 1x and 5x reconstructions for these stars are shown in Figure 1. There is no indication of a systematic bias in the 1x fractional pixel coordinates, relative to the presumably accurate 5x coordinates, giving us somewhat more confidence in the error estimates quoted in Table 1.

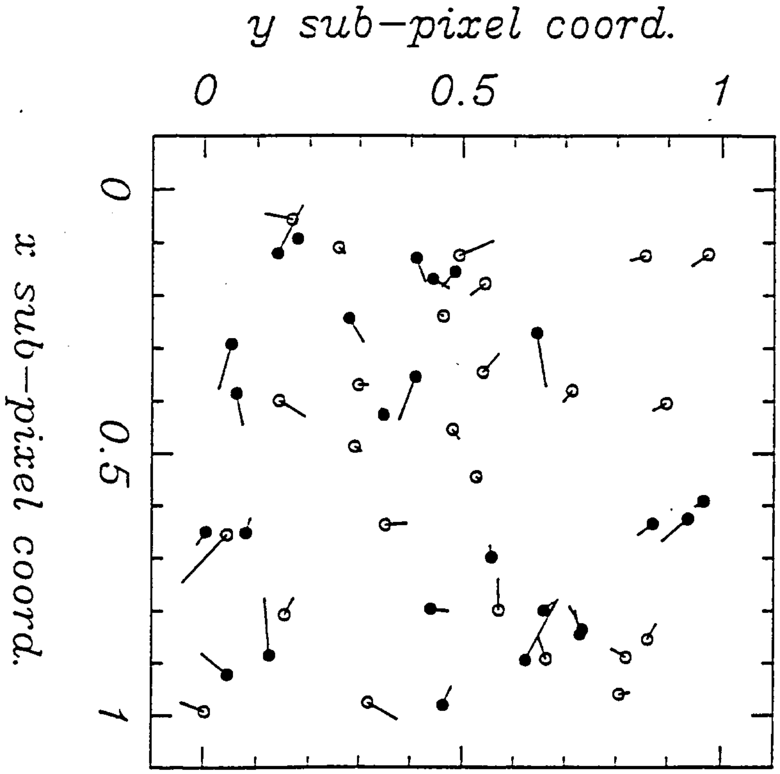

Figure 1: Fractional pixel coordinates based on the 5x subsampled reconstructions on the F555W (filled circles) and F785LP (open circles) frames. The vectors indicate the difference between the 5x and 1x sub-pixel positions. There is no evidence for a systematic bias toward the center of the pixel in the 1x data. The pixel size is 0.043 arcseconds.

In an attempt to determine just how the image coordinates "converge" from their 1x to their 5x values, linear transformations of the Nx positions were transformed into the 5x positions. The standard error of each transformation is plotted in Figure 2. Unexpectedly, the error does not decrease monotonically but is a minimum for the 3x transformation, (the error at 5x has been artificially plotted as 0.0). If instead the transformations are performed into the 4x coordinates, also shown in Figure 2, the minimum appears for the 2x data! Clearly there is an artifact of the subsampling/reconstruction process rearing its ugly head here. This effect is currently being explored. It is encouraging to see, however, especially in the F555W data, a quick convergence at small subsampling factor.

The Gaussian centering algorithm performs better as the number of iterations through the reconstruction process increases, not surprisingly. Positions based on 0 raw, 20, 40, 60, and 80 iterations were transformed into positions derived from a 100 iteration reconstruction of the 4x subsampled frame. The transformation standard errors are plotted in Figure 3. The 0 iteration, raw, results are deflateddue to the fact that only the 11 brightest stars centered in the raw frame reduction, whereas the processed frames centered from 30 to 40 stars.

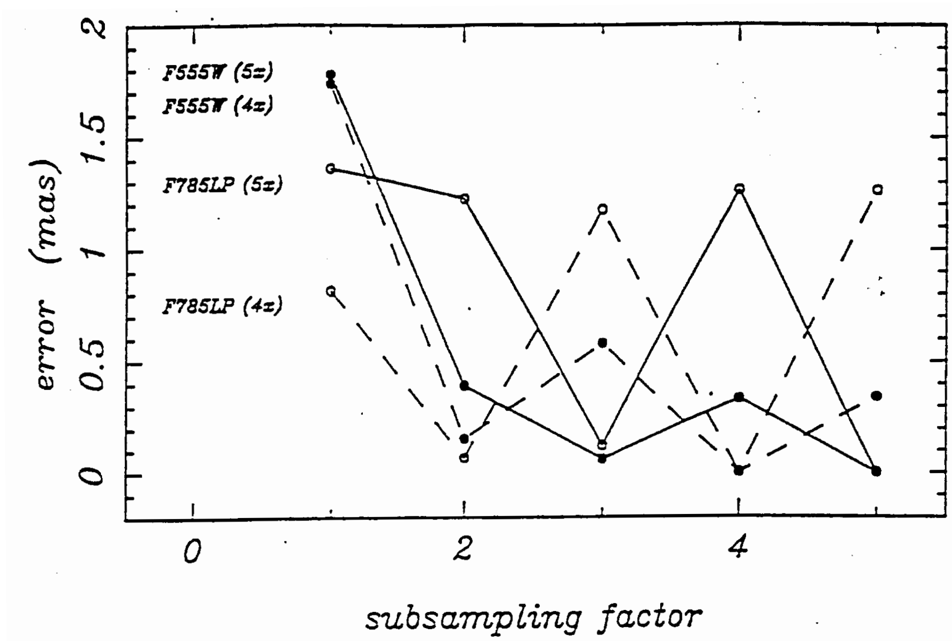

Figure 2: Single-coordinate standard errors of linear transformations between the Nx reconstructed positions and the 5x based positions (solid line) and the same for transformations between the Nx and 4x positions (dashed line). The 5x into 5x and 4x into 4x errors have been artificially set to 0.

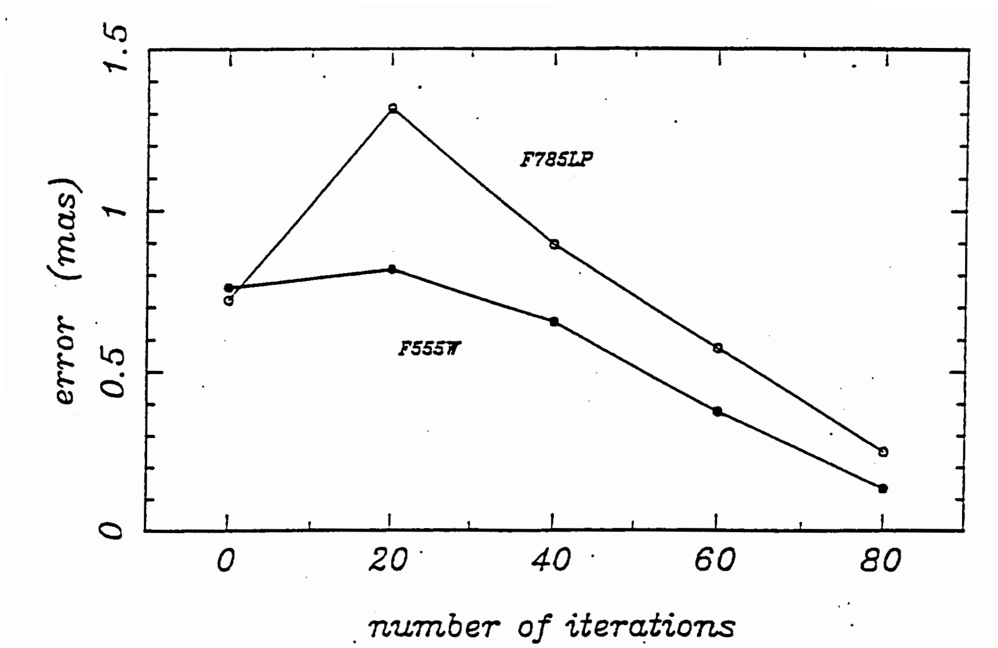

Figure 3: Single-coordinate transformation errors for the 4x based reconstructed frame as a function of the number of iterations through the reconstruction routine. The positions are transformed (linear spatial terms) into those derived from the 100 iteration frame.

VI. Summary

- image reconstruction allows more robust image centering, (in terms of number of stars centered and their magnitude range)
- preliminary indications are that positions based on reconstructed images are of higher accuracy, approaching 11 mas for well-exposed images
- subsampling before reconstruction qualitatively improves the final image and aids the centering routine in detecting faint images, although possible systematics introduced by the reconstruction process require further study
- a repeatability of 0.6 mas has been found for well-exposed images, although only for consecutive *HST* orbits with nearly identical pointing
- the important problem of modeling the distortions across the field of the PC remains to be addressed

References

Girard and van Altena, 1990, BAAS 22, 1277
Nez and Llacer, 1990 Astrophys. and Space Sci. 171, 341