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TITLE: **Simulation of Aperture Finding Using the HSP Onboard Target Acquisition Application Processor**

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ABSTRACT

This report describes the results of studies to determine the adequacy of the HSP onboard target acquisition application processor (AP) for determining the offsets in deflection coordinates of HSP apertures from their nominal locations. This use has been proposed in conjunction with a new deflection control AP (VFBANANA) to allow onboard correction of the aperture motion in deflection coordinates which is introduced by thermal bending of the HSP (the "banana mode").

Two studies have been done. First, a Monte Carlo simulation has been carried out, including the effects of Poisson statistics for the number of counts in each pixel and a random location for the aperture. Secondly, an analytical calculation has been done to determine the accuracy of the algorithm as a function of aperture offset in the limit of large count rates.

I conclude that with readily achievable counting rates, the aperture offset can be determined to within 0.08". The bright earth can be used as a target for these observations. Some recommendations are made for strategies for use of the TAV and Banana APs.

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Simulation of Aperture Finding Using the HSP Onboard Target Acquisition Application Processor

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0. Summary

This report describes the results of studies to determine the adequacy of the HSP onboard target acquisition application processor (AP) for determining the offsets in deflection coordinates of HSP apertures from their nominal locations. This use has been proposed in conjunction with a new deflection control AP (VFBANANA) to allow onboard correction of the aperture motion in deflection coordinates which is introduced by thermal bending of the HSP (the "banana mode").

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1. Description of the HSP TAV Algorithm

In the mode which will be used for deflection offset measurements, the HSP TAV algorithm is as follows:

(1) Using the HSP Area Scan mode, collect a small image with 0.5" beam spacing covering the nominal position of a 0.4" aperture. The image has at most 20×20 pixels, but usually can be much smaller, since the maximum expected image motion is about 1" (2 pixels).

(2) Determine the location (i, j) of the brightest pixel in the image.

(3) Calculate the centroid (x, y) of the 3×3 neighborhood surrounding the brightest pixel:

$$x = \sum_{k=i-1}^{i+1} \sum_{m=j-1}^{j+1} k\, C_{km} \quad ,$$

where C_{km} is the number of counts in pixel (k, m) of the image. The equation for y is identical except that the sum is weighted by m instead of k.

(4) The offset for the given aperture is then

$$(x_{off}, y_{off}) = (x, y) - (x_r, y_r) \quad ,$$

where (x_r, y_r) is the position of the reference pixel in the image (supplied as a TAV AP parameter).

2. Description of the Monte Carlo Simulation

A Monte Carlo simulation was performed to determine the accuracy with which the above algorithm determines the center of a uniformly illuminated aperture. The following assumptions were made for the simulation:

(1) The aperture being observed is 0.4" in diameter and is uniformly illuminated.
(2) The read beam of the image dissector tube (IDT) is 1" in diameter.
(3) The TAV image is collected as described above, with 0.5" spacing between pixels.

The number of counts expected in one pixel when the IDT read beam is centered on the aperture is a parameter of the simulation. At low count levels, the accuracy of the offset is determined by the statistical fluctuations in the image. As the number of counts increases, the accuracy of the offset determination converges to a limiting value which is set by the algorithm (see §4).

At a given count rate $\langle N \rangle$, a single Monte Carlo trial consisted of the following steps (which are a faithful simulation of the steps described in section 1):

- Initialize the image to zero.
- Choose a (random) position (x_t, y_t) for the true location of the center of the aperture in the image.
- For each pixel in the image {
  - Choose the (random) number of counts, N, for this pixel using the Poisson distribution with mean $\langle N \rangle$.
  - For $i = 1$ to N {
    - Choose a (random) position (x_c, y_c) for this count, uniformly distributed about (x_t, y_t) in a 0.4" diameter circle.
    - If the distance from (x_c, y_c) to the pixel center (x_p, y_p) is less than the radius of the IDT read beam, 0.5", then increment the number of counts in this pixel.
  - }
- }
- Apply the TAV algorithm described above to measure the target offset (x_{off}, y_{off}) from the image center.
- Calculate the error R_{err} in the observational determination of the offset by calculating the distance from the true position (x_t, y_t) to the measured position (x_{off}, y_{off}).

For each count rate, at least 100 trials were run to determine the distribution of the error R_{err} in the position of the aperture.

3. Summary of Monte Carlo Results

The following table summarizes the results of the simulations. The mean error in the offset determination is given along with the dispersion about that mean. In addition, the fraction of observations leading to an error greater than 0.1" is given.

Table 1: Error as a Function of Counts/Pixel

Mean Counts/Pixel $\langle N \rangle$	*Mean Error* $\langle R_{err} \rangle$	*Std. Dev. of Error* $\sigma(R_{err})$	*Fraction with* $R_{err} > 0.1''$
16	0.068"	0.042"	0.20
25	0.058"	0.031"	0.12
50	0.053"	0.025"	0.04
100	0.047"	0.020"	0.01
200	0.046"	0.018"	< 0.001
500	0.043"	0.017"	< 0.01
1000	0.044"	0.015"	< 0.01

When the brightest pixel has 200 counts or more, the position of the aperture center is determined to an average accuracy of < 0.05". Only 2% of the trials have errors as large as 0.08".

For the case with $\langle N \rangle = 200$ counts, 1000 trials were run to determine the distribution of R_{err} more accurately. Here are the results:

Table 2: Distribution for AVGCT=200

R_{err} *Range*	*Fraction*
0.00 – 0.02	0.08
0.02 – 0.04	0.28
0.04 – 0.06	0.41
0.06 – 0.08	0.21
0.08 – 0.10	0.02
> 0.10	< 0.001

4. Analytical Results

It is possible to determine the behaviour of the TAV algorithm in the limit of a very high count rate (so that statistical fluctuations from pixel to pixel are unimportant). The relative number of counts as a function of the position of the IDT read beam is determined by the overlapping area of two circles of radii $r_1 = 0.5''$ (representing the IDT beam) and $r_2 = 0.2''$ (representing the focal plane aperture). If the centers of the circles are separated by a distance Δr, then the overlapping area

$$A(\Delta r) = \begin{cases} \pi r_2^2, & \text{if } \Delta r < r_1 - r_2; \\ 0, & \text{if } \Delta r > r_1 + r_2; \\ -\Delta r\sqrt{r_2^2 - c^2} + r_2^2 \,\mathrm{Cos}^{-1}[-c/r_2] & \\ \quad + r_1^2 \,\mathrm{Cos}^{-1}[(c + \Delta r)/r_1], & \text{otherwise,} \end{cases}$$

where

$$c = \frac{r_1^2 - r_2^2 - \Delta r^2}{2\Delta r} \quad .$$

The error in the measured location as a function of aperture position (x, y) can be determined by simulating the same TAV algorithm described in §1 above, using the overlapping area as the brightness in each pixel of the image.

Figure 1 shows the total error R_{err} as a function of aperture location for x and y ranging from -0.25" to 0.25" from the center of a pixel. (Note that since the pixels are separated by 0.5", the true aperture position is always with 0.25" of the center of some pixel.) Figure 2 shows the error in x only as a function of (x, y).

The largest error for any value of (x, y) is $R_{err} \simeq 0.07"$, which occurs for $|x| = |y| \simeq 0.12"$. These results agree very well with those from the Monte Carlo simulation discussed above.

An interesting point is that the error is quite small when the aperture is positioned near the center of a pixel. For example, if $(x^2 + y^2)^{1/2} < 0.1"$, then $R_{err} < 0.04"$. This implies that the centering algorithm performs best when the inital estimate of the aperture location is accurate (see §6 for how this might be exploited in operations.)

5. Targets for Aperture Offset Measurements

As long as the number of counts in the brightest pixel of the TAV image is greater than 200, the HSP TAV algorithm is sufficient to determine the aperture positions to a mean accuracy of better than 0.05" (2 deflection steps on the image dissector), with errors larger than 0.08" less than 2% of the time. This is less than 10% of the large aperture diameter, so it is sufficient to achieve the high precision photometry for which the HSP is designed.

The necessary counting rates are easily achieved on all detectors using the sunlit earth as a source. The following representative count rates are drawn from *Standard Astronomical Sources for HST: 6. Spatially Flat Fields* by Cox, Bohlin, Griffiths, Gunn, and Kelsall (STScI, 15 June 1987).

Table 3: Count Rates for Sunlit Ocean

Detector	*Filter*	*Count Rate (cts/sec)*
VIS	F160LP (clear)	1.1×10^7
	F450W	4.4×10^6
UV1	F140LP (clear)	3.2×10^4
	F240W	680
UV2	F140LP (clear)	3.2×10^4
	F160LP (clear)	3.3×10^4

For each detector, the first filter is the clear filter used for target acquisition (but which also has associated 0.4" diameter apertures). The second filter is in the middle of the IDT cathode and may possibly be more desirable for aperture-finding both because any distortions will be smallest there and because it is far enough from the large 10" diameter target acquisition aperture to be unaffected by the glare of light spilling through that aperture.

Since the deflection offset need be measured for only a single aperture on each IDT, aperture offsets can be measured using the bright earth as a target with sample times less than 0.5 second at each point of the image; total exposure times are less than 2 minutes for a 20 × 20 area scan.

For the VIS IDT, the moonlit earth is also an adequate target for measurement of the aperture deflection offsets.

Table 4: Count Rates for Moonlit Ocean

Detector	*Filter*	*Count Rate (cts/sec)*
VIS	F160LP (clear)	1.8×10^2
	F450W	45

6. Recommendations for Operations

The VFBANANA AP allows deflection corrections to be calculated using the offsets measured by the TAV AP, using a polynomial which is a function of 1 or 2 temperatures from HSP telemetry, or using a sum of both. Consequently, there are 3 ways of using the TAV AP in conjunction with the banana AP:

(1) Measure the offset from the nominal aperture location using the TAV AP. Then, using the banana AP, add this offset to deflections for observations made during the following orbit(s).
(2) Use the predicted offset vs. temperature model in the banana AP with no measurement at all from TAV AP.
(3) Measure the offset from the *predicted* aperture location using the TAV AP. Then, using the banana AP, add this offset *along with the predicted correction* to deflections for observations made during the following orbit(s).

During the early part of the ST mission, the first method will be used because the coefficients of the temperature polynomial will not be known well enough to be useful. However, as time passes and more data are accumulated on the values of the offsets as a function of temperature, the second method will be usable. The main advantage of the second method is it is very easy for the ground system to plan: it does not require an observation of the bright (or dark) earth to precede a scientific observation.

The advantage of the third method is that the offsets being measured by the TAV AP will be small if the prediction using the temperature polynomial is good. That means that, as described in §4, the errors in the TAV determination of the aperture location will be quite small. Consequently, if the temperature polynomial is known to give aperture positions to an accuracy of about 0.2" or better, the third method will give the best results for the final accuracy of the deflection location used for the aperture.

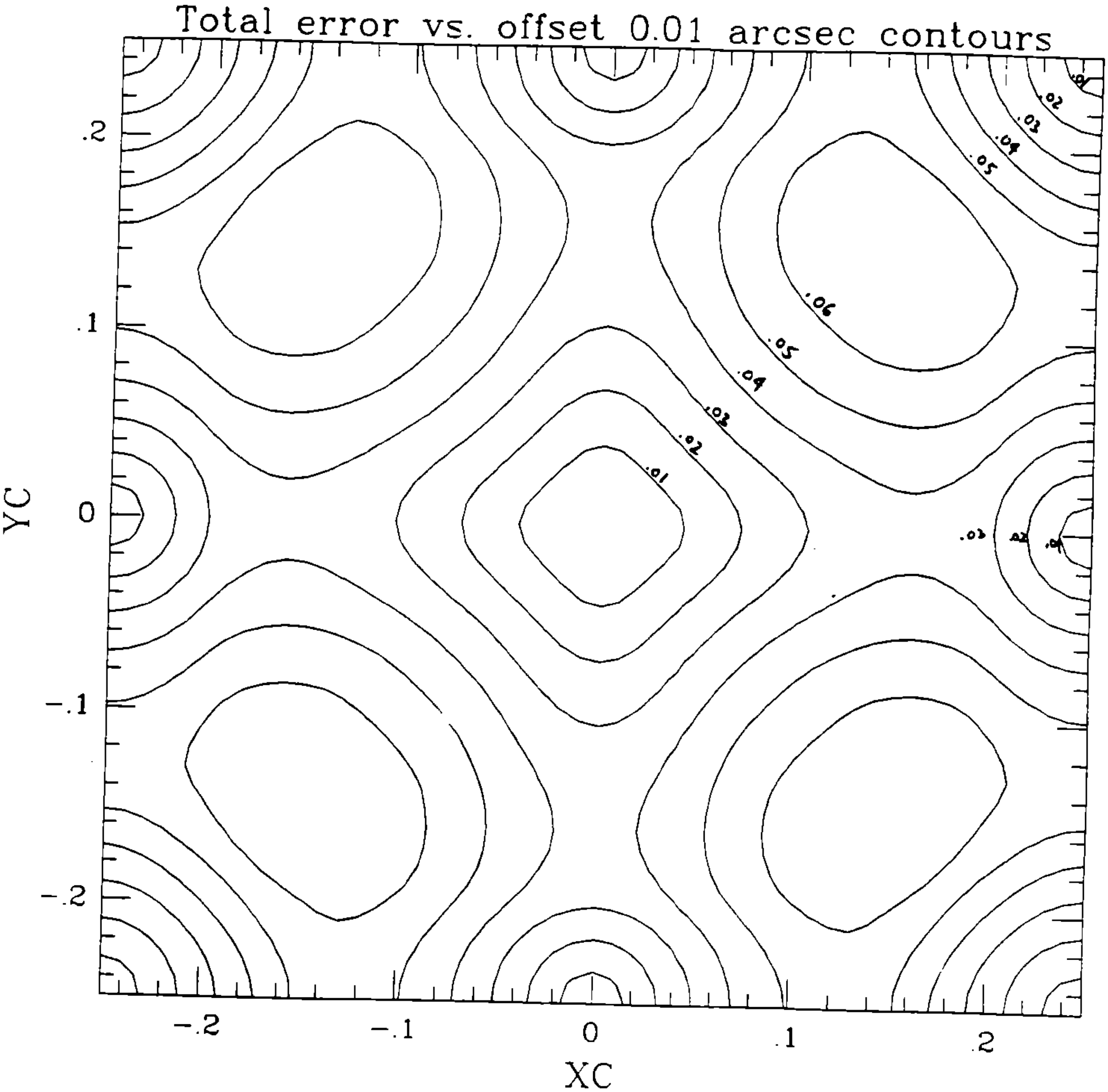

Figure 1: *Total error R_{err} as a function of aperture position.*

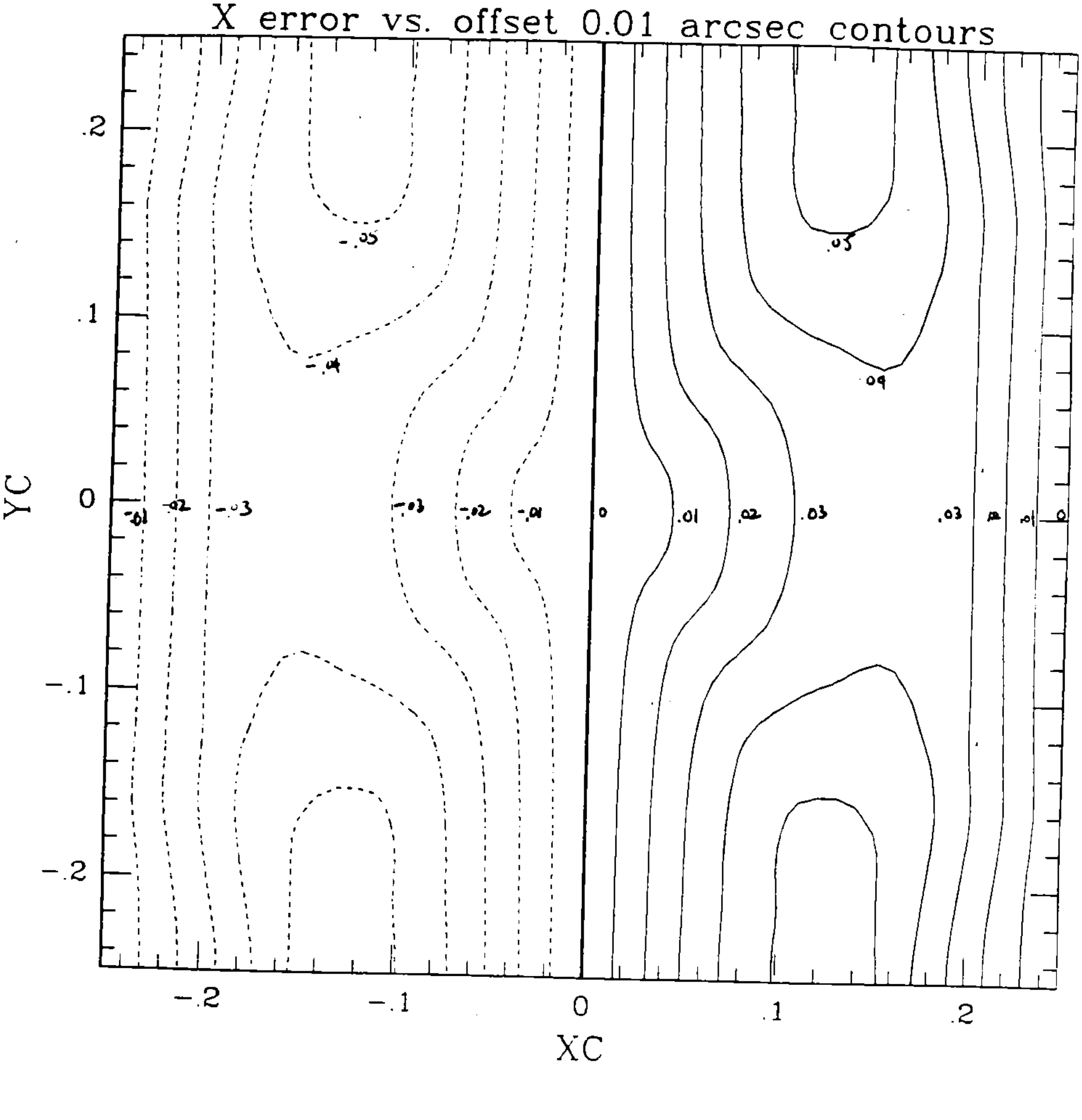

Figure 2: *Error in x only as a function of aperture position.*