THE COMPARED EFFICIENCY OF CENTERING ALGORITHMS

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SUMMARY. The purpose of this study is to compare the quality of three digital image centering algorithms; 1) the fit of marginal distributions by *Gaussian*, 2) the maximum of the *Autocorrelation* of a stellar image by its symmetrical, 3) the 2-dimensional fit of stellar images by a mean stellar *Profile*.

The two main conclusions are: 1) the 3 centering methods give the same accuracy if the star is isolated, bright and unsaturated. But as soon as one of these conditions fails, fast algorithms lack robustness and the only reliable method is the 2-d profile fit, 2) preliminary tests on Schmidt plates digitized with the MAMA (Machine Automatique à Mesurer pour l'Astronomie) show that under the above restrictions, the centering algorithms do not alter the final astrometric accuracy, neither do the digitizing machine.

1. Description of the algorithms

A description of the gaussian fit to marginal distributions can be found in L.-T. JG. Chiu (1976).

The second algorithm (Lepool, 1985) computes the point-symmetric autocorrelation matrix in a subimage; a paraboloid fitted near the maximum of the matrix gives the center of the star.

The 2-d stellar profile algorithm use a 2-d template built by adding together a selection of clean stellar images. The counts statistics assumed to be Poissonian is computed from the actual count distribution. A multiple star model built from a previously established catalog of objects is fitted to the content of a window centered on each object. The fit is done by minimizing the Chi-square. The position and intensity of each non-central component are let free during the first pass and then fixed to the best values obtained during the last iteration. The model-images are moved over the pixel grid using a paraboloid approximation to the count distribution in the inner part of the profile and bilinear interpolation outside. The size of the window is defined by the area where the contribution of the central object is in excess of a given fraction of the sky noise amplitude. If the number of sky pixels in the window is large enough, the sky and stars are fitted independently. The algorithm is similar to the DAOPHOT program (Stetson, 1986).

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2. CCD ASTROMETRY

We test the efficiency of the 3 methods on 116 CCD images. The CCD frames were obtained from 1985 April 17 to April 21 at the Cassegrain focus of the 1.54m Danish telescope at the European Southern Observatory in order to study the photometric variability of the faint counterpart (V=19.0) of the X-ray source 4U1556-605. The mean exposure time was 5 mn and the filter used was close to the Johnson V band. The CCD RCA chip has a pixel size corresponding to 0.47 x 0.47 arc-sec on the sky. The camera was left unchanged during the observing run so that no field rotation occurs.

Figure 1 shows on one of the CCD frames the positions of the 15 stars chosen to test the algorithms. All images were recoordinated to a common frame using the preliminary center of a given star as new origin.

The mean center of stars 2, 3 and 4 which have the best accuracy is x_c and y_c For each algorithm and for the x and y coordinates of the 15 stars we list in Table 1 the quantities $\sigma(x_i-x_c)$ and $\sigma(y_i-y_c)$. These quantities are equivalent to the variance of x_i and y_i as long as the error on x_c and y_c are negligeable. Table 1 gives the number of rejected measurements due to confusion by a neighbour star or due to the failure of the method to detect the center. The expected minimal variance of (y_i-y_c) computed using the Cramer-Rao limit (see for instance Kendall and Stuart, 1973) is also listed in Table 1 for comparison.

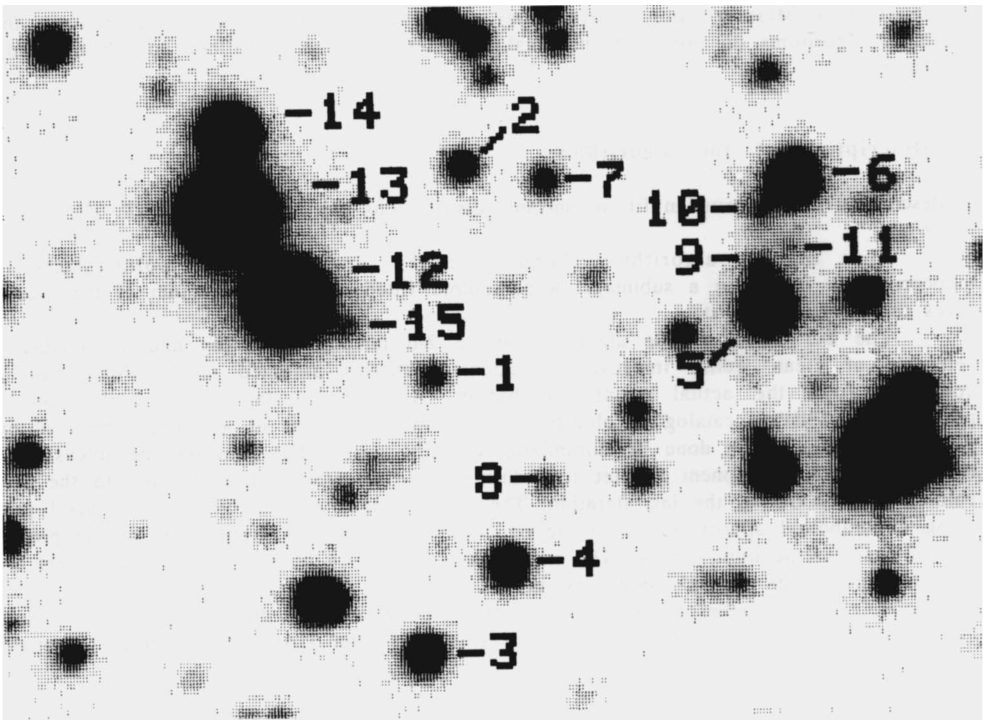

FIGURE 1 : One of the 116 CCD images. The 15 labelled stars are used to test the centering algorithms.

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The 3 algorithms applied to CCD frames have similar accuracy for isolated unsaturated stars suggesting that some optimum has been reached and that oversophisticated algorithms are The 2-d profile fit is the only one relevant in the case of overlapping stars. The two other methods are mostly unable to recognize or to separate a faint star in the wing of a brighter one.

The best accuracy reached is 0.015 pixels (Table 1). This corresponds to a differential astrometric error of .007 arcsec for a 5 minutes exposure on a V=18.3 magnitude star (star 2). We note that only for isolated stars is the comparison with the Cramer Rao limit meaningful. In this case, the algorithms are unable to reach the optimal accuracy estimated assuming a purely poissonian photon statistics. It is likely that the observed discrepancy is due to an oversimplification of the assumed statistics. In the case of the CCD images, the read-out noise (independent of count rate) and the flat-fielding noise (r.m.s. proportional to count-rate) probably account for some part of the excess error. The discrepancy between x and y shows that non modeled effects (probably charge transfer problem) are prominent.

3. SCHMIDT PLATE ASTROMETRY

Our test material is composed of two Schmidt plates taken at the Centre d'Etude et de Recherches en Geodynamique et Astronomie (CERGA) with the Schmidt telescope (main mirror 1.52m , focal length 3.16m). Exposures were 13mn long on hypersensitized IIa-0 through a GG385 filter. The field located near the globular cluster M5, at intermediate galactic latitude, is moderately crowded and most stellar images are well separated.

On each plate, 8 cm^2 have been digitized with a 10 x10 μm step using the MAMA at the Observatoire de Paris. About 500 stars are detected using a threshold method, for which we compare the 3 algorithms.

We seperate the stars in four groups of magnitudes. The comparison of positions between the two plates is made using a translation-rotation and scaling. The dispersion of residuals is 1.5 μm on bright stars. A more sophisticated plate transformation appears to be unable to minimize residuals.

Since the two plates were obtained during the same night, we expect to measure "null" proper motions. The measured "proper-motions" reflect the distribution of plate to plate deviations for each class of magnitude. We give in Table 2 the corresponding standard deviations together with the standard deviation of the differences of positions between the two algorithms applied on the same plate. Basically the centering accuracy is independent of algorithms, and may be as good as 1μm (i.e. 0.065 arc sec on Schmidt plates) for bright stars and is strongly magnitude dependent (about three times larger at m_V=17.5 than at m_v=15; the detection limit is m_V= 19.5).

In the reduction chain "Schmidt plate +MAMA + centering algorithms", the final differential astrometric accuracy is not altered by the scanning machine nor is it by the choice of the algorithms. The accuracy of centering degrades for faint stars. This may be a limitation in differential astrometry when using faint background stars as a fixed reference frame.

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TABLE 1 : Comparison of the centering accuracies of the 3 algorithms on CCD images. The standard deviation of (xi-xc) and (yi-yc) for star i are listed for each of the 3 methods. (xc and yc are the mean coordinates of stars 2, 3 and 4). The Cramer-Rao limit is the minimum achievable accuracy deduced from the photon statistics of images. The columns 'N failure' give the number of times each algorithm failed to detect a star.

n°	magnitude	sigma x			sigma y			N failure			Cramer Rao limit
		Gauss	Correl	Profile	Gauss	Correl	Profile	Gauss	Correl	Profile	
1	-9.04	.035	.044	.036	.025	.038	.035	1	0	0	.013
2	-9.74	.026	.027	.029	.014	.015	.016	0	0	0	.009
3	-10.58	.021	.021	.022	.011	.014	.015	11	0	0	.005
4	-10.64	.017	.018	.015	.014	.012	.012	17	0	0	.005
5	-11.97	.076	.078	.066	.025	.030	.028	6	0	0	.004
6	-11.69	.075	.073	.067	.028	.032	.029	5	0	0	.004
7	-9.26	.043	.075	.055	.055	.059	.047	0	0	0	.011
8	-8.43	.067	.062	.045	.044	.046	.041	2	0	0	.021
9	-8.80	**	.096	.102	**	.040	.104	112	41	0	.015
10	-8.57	.089	**	.230	.135	**	.110	94	112	0	.018
11	-7.91	.096	**	.142	.045	**	.163	53	116	0	.031
12	-13.86	.023	.025	.028	.105	.218	.056	25	0	0	.003
13	-14.44	.400	.043	.030	.097	.312	.062	18	0	0	.003
14	-12.34	.018	.029	.018	.031	.100	.049	2	1	0	.004
15	-8.55	.298	.255	.346	.124	.089	.418	68	41	0	.019

TABLE 2 : For each class of magnitude, we give in μm :

1) in columns 2 and 3, the standard deviations of the difference of positions between the two plates,

2) in columns 4 and 5, the standard deviations of the difference of positions given by the two algorithms on the same plate.

Star sample	sig x μm	sig y μm	sig x μm	sig y μm
mv 18 to 17 93 stars	4.3	3.6	2.1	2.4
mv 18 to 16.5 137 stars	2.9	2.7	1.9	1.5
mv 17 to 16 109 stars	2.7	2.5	1.4	1.13
mv 16 to 13 98 stars	1.4	1.9	0.53	0.48

REFERENCES

Chiu, L.-T. G., 1976, Astron. J. 82, 842

Kendall, M., Stuart, A., 1973, The advanced theory of statistics, Vol 2, p9, Griffin (London) Editor

Lepool, R., 1985, Private communication

Stetson, P.B., 1986, D.A.O. preprint, December 1986