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On the Reduction of CCD Observations of "Close" Visual Binaries

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ABSTRACT: We discuss the accuracy of CCD astrometry, and we present an improvement on the method used for the photometric reduction of visual double stars CCD data, whenever the angular separation of the components is only a few arcseconds.

1. ON THE ASTROMETRIC ACCURACY

The instrumental astrometric accuracy of CCD measurements depends on many factors but mainly on the quality of the star images on the CCD frames, on the intrinsic accuracy of the software used for fitting the star profiles and on the quality of the flat–field and BIAS determinations.

In our first attempt (Sinachopoulos *et al.* 1988) we used the STARLINK software for reducing our data. Photocenters were determined with an accuracy of 0.07 pixels which corresponds for the CCD–chip used to $2.1\,\mu$.

Later, we used the MIDAS software (Sinachopoulos 1988). For our new data, we determined the separations of the photocenters with an accuracy of $\sigma_\rho = 0.23$ pixels corresponding to $3.5\,\mu$ per exposure.

We used DAOPHOT (Stetson 1987) afterwards (Sinachopoulos & Seggewiss 1990) for the data which have been obtained using a lower quality CCD chip, and the component angular separation accuracy was $\sigma_\rho = 0.39$ pixels or $5.8\,\mu$.

Recently (Sinachopoulos & Prado 1992), we used ROMAFOT (Buonanno *et al.* 1983) for the reduction of our latest data. We found $\sigma_\rho = 0.05$ pixels or $1.0\,\mu$.

Since there were important quality differences between our data sets, it is unfair to make conclusions about the performances of the different software packages we have used. Nevertheless, we believe that the accuracy of the determination of the photocenter of a well exposed star on a good quality CCD frame is one micron or better.

2. ON THE PHOTOMETRIC ACCURACY

Determining the instrumental magnitude difference between the components of close binaries is not a simple task, since the two stellar profiles overlap each other.

Single field stars are sometimes present on the frames. It is then possible to use these stars to estimate the point spread function (PSF) of the stars on the frame accurately enough and thus to be able to use standard software for crowded fields such as DAOPHOT or ROMAFOT for the photometric reduction.

But usually, only the two components of the binary are present on the frame. In this case, we make a row and a column projection of the frame and a Franz profile (Franz 1967) is fitted on the data. The Franz's profile is a generalised

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Lorenz distribution. Rakos *et al.* (1982) have also discussed it, since they have used it for the photometric reduction of area scanner data.

According to Franz the profile of a single star is given by

$$f(x) = \frac{H}{\left(1 + \frac{|x-A|}{B}\right)^{P\cdot\left(1+\frac{|x-A|}{C}\right)}} + sky$$

where the parameter A denotes the star's position, H the star's height, B the star's half-width, and P and C are two profile determining parameters.

Therefore, the profile of a double star is given by:

$$f(x) = \frac{H_1}{\left(1 + \frac{|x-A_1|}{B}\right)^{P\cdot\left(1+\frac{|x-A_1|}{C}\right)}} + \frac{H_2}{\left(1 + \frac{|x-A_2|}{B}\right)^{P\cdot\left(1+\frac{|x-A_2|}{C}\right)}} + sky$$

This function is fitted to the data according to the standard least-squares method. It is easy to determine start values for the parameters A_1 and A_2 with an accuracy of one pixel which is sufficient. Accurate start value for sky is always estimated. But the situation is very different for the heights of the stars H_1 and H_2. Since the two profiles are overlapping, the H_1 and H_2 start values are usually overestimates, and it is not trivial at all to calculate for each H_i start value the contribution of the other component in order to correct it. Finally, the two profile determining parameters P and C are correlated, and this in fact produces an additional numerical instability to the standard least-squares fitting algorithm.

3. THE EXPERT SYSTEM ROUTINE

For this reason, it was necessary to improve the software used originally in Vienna. For this purpose, we developed a procedure corresponding to the *expert systems* method (Quinlan 1986) which is used in modern data processing. *Expert systems* are computer programmes, which offer problem solving methods based on facts and rules necessary for the formalization of knowledge on special topics. The idea behind this computer routine is that we (the "experts") know the possible limit values of the variables which must be determined by the least square fitting.

In the present case e.g., A_1 and A_2 are positive and less than the number of the pixels, H_1 and H_2 are positive and less than, say, three times the maximum value in the data array, B is positive and its maximum value can also be predetermined. P and C are positive and 5 seems to be near to its upper limit of P.

Therefore, it is easy to check after each iteration, whether the new values estimated by the least square fitting programme are inside the "allowed" limits or not and to modify some of them, if necessary, giving to them a more "reasonable" value, before starting the next iteration.

As the method can be applied to all data fitting algorithms, we give its simple mathematical formalism:

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Suppose, we have to fit to the data vector $\vec{r}$ the function

$$y = f(\vec{r}; x_1, x_2, \ldots, x_k),$$

where $x_i \in (a_i, b_i) \subset \mathbf{R}$ ($\mathbf{R}$ real numbers), using the least–squares method.

Let ${x_i}^m$ denotes the value of the variable x_i after the mth iteration and, in addition, $\forall i \in \{1, 2, \ldots, k\}$ appropriate $l_i > 1$ values have been defined before the beginning of the iterations for each x_i variable. Then, $\forall {x_i}^m \notin (a_i, b_i)$, we replace ${x_i}^m$ by ${x_{i_o}}^m \in (a_i, b_i)$:

$$\begin{array}{llll} {x_{i_o}}^m = {x_i}^{m-1} + \left(b_i - {x_i}^{m-1}\right)/l_i & \text{if} & {x_i}^m > b_i\,, & \text{or} \\ {x_{i_o}}^m = {x_i}^{m-1} - \left({x_i}^{m-1} - a_i\right)/l_i & \text{if} & {x_i}^m < a_i. & \end{array}$$

4. CONCLUSION

The above described routine gave to the software used the numerical stability needed, so that the data reduction is now performed with high efficiency.

5. ACKNOWLEDGMENTS

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